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Analysis of Influencing Factors of Fixed Distance System Based on MEMS Acceleration Sensor

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Abstract: Precise strike capability and high efficiency damage ability of ammunition are the core of modern war. Precision strike is achieved through the fixed distance system at present, but the accuracy of displacement measurement system is affected by many factors. If the error influencing factors are not controlled and intervened, the displacement measurement will be greatly affected. Even some factors may cause the projectile to deviate completely from the intended course. Firstly, a displacement measuring system based on MEMS acceleration sensor is introduced in this paper. Then analyze and elaborate the difference of influencing factors that may cause errors in each link. It has certain reference value for the research work to improve the accuracy of the system.

1. Introduction

Accurate control of explosion points is a prerequisite for precision strikes using precision strike weapons in modern high-tech local wars. It has been a research hotspot in recent years. The core of realizing precision strikes is to improve the accuracy of the fixed range system. At present, the commonly used fuze explosion point control technology includes revolution counting explosion point control technology, timing explosion point control technology, and time counting revolution composite explosion point control technology [1]. The study of precision bombing technology is of great significance: facing the ever-changing battlefield, it can effectively improve individual combat capability, point-to-point precision strikes can improve the killing effect of weapon systems, and effective local damage in urban anti-terrorism can increase the damage to hidden places. Strike capability and improving the utilization rate of ammunition can produce obvious economic benefits. At present, the commonly used counted burst point control technology, the application of the timing burst point control technology is relatively mature, the errors and influencing factors in the timing counted burst point precision control technology are relatively clear, and the researchers are based on the influence of the error Factors have been improved and compensated to improve their strike accuracy [2]-[5]. In order to achieve precise range bombing of ammunition, improve the precision strike capability of ammunition, and further meet the needs of modern battlefields, the fixed range technology can still be further developed and researched. The fixed range technology based on MEMS acceleration sensor is a new kind of new proposed in recent years. The explosive point control method, which gives full play to the advantages of MEMS acceleration sensor: high accuracy, small size, can be embedded in a microprocessor and loaded into projectiles. The realization principle of this technology has taken shape [6]-[7], but its distance accuracy needs to be improved and further research is needed. If the influencing factors are not controlled and compensated, a certain error will be caused to reduce the distance accuracy, but there are few studies. The personnel conduct in-depth research on this. In order to speed up the development process of domestic MEMS acceleration fixed-range bombs and improve the accuracy of the bombs, it is necessary to conduct a comprehensive analysis, induction and classification of the factors affecting its explosive point control.

2. MEMS acceleration sensor fixed distance system

Measuring the acceleration of the projectile based on the MEMS acceleration sensor to achieve fixed distance is a new distance method. The key of this method is to establish the angle of attack and axis through the simulation measurement of the angle of attack of the projectile and the simulation analysis of axial acceleration and tangential acceleration. The relationship between the tangential acceleration and the tangential acceleration, the projectile acceleration measurement method [6]-[7]. Use MEMS sensors to collect real-time acceleration digital signals, and then use the DSP chip to calculate the arc length of the projectile according to the principle of quadratic integration of acceleration and displacement to obtain the projectile arc length, combined with the set inclination data, and according to the projectile's horizontal flight distance and trajectory arc length The relationship between is further calculated to obtain the horizontal flight distance of the projectile. When the calculated result reaches a given value, the processor sends a firing signal to the firing circuit. The firing circuit generates an instantaneous negative jump voltage to detonate the projectile, and the blast point is realized through the fixed distance system control.

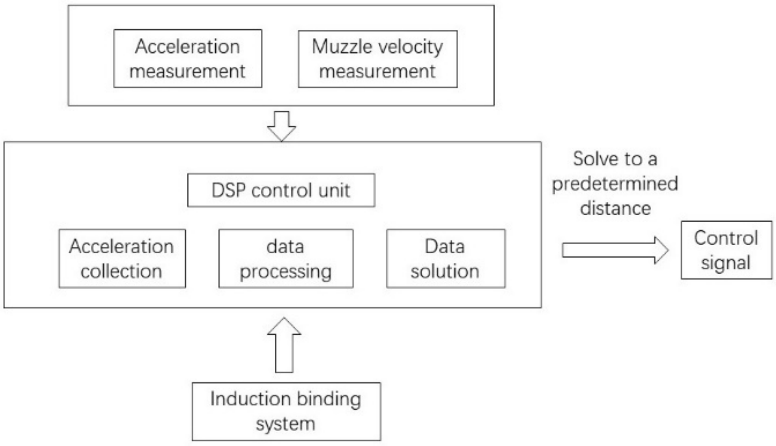

Figure. 1 Schematic diagram of the MEMS acceleration sensor fixed distance system structure

3. Analysis of error factors

3.1 Acceleration quadratic integral to find the error caused by the displacement process

The core of fixed-distance aerial bombing is to use the acceleration sensor to measure the axial acceleration value of the projectile in real time, and obtain the displacement through quadratic integration [8]-[9]. Due to the limited internal space of the fuze, the harsh working environment and the high-speed flight of the projectile, the sensor must be small in size, high in measurement accuracy, strong in overload resistance, high in resolution, and simple in peripheral circuit design.

Therefore, a thermal convection type MEMS acceleration sensor with small size and high overload resistance is selected to sense the acceleration value in real time. The basic idea of acceleration quadratic integration for displacement can be expressed by the following formula:

$$v(t) = \int_{t_0}^{t} a(t)dt + v_0(t_0) \tag{1}$$

$$s(t) = \int_{t_0}^{t} v(t)dt + s(t_0) \tag{2}$$

Since the thermal convection acceleration sensor is a digital acceleration sensor, it does not require an analog-to-digital conversion circuit and directly outputs digital signals. It samples at a fixed frequency. The ideal acceleration curve is continuous, but MEMS acceleration is sampled at a fixed frequency the signal obtained by the sensor is a digital signal, so it is not continuous in time.

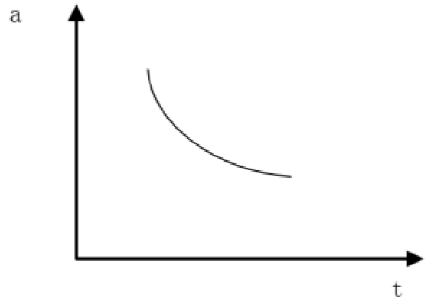

Figure. 2 Schematic diagram of ideal acceleration curve

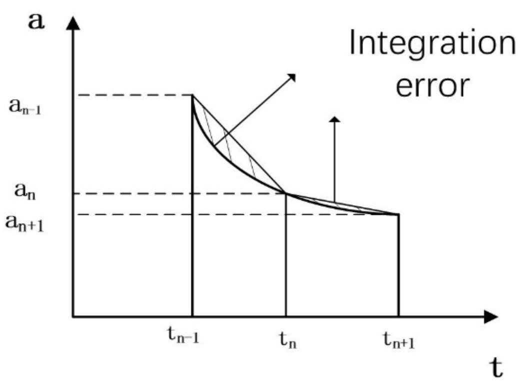

Figure. 3 Schematic diagram of the processing method of acceleration signal integration and its integration error

The curve in Figure 2 is a schematic diagram of the ideal acceleration curve, and Figure 3 is a schematic diagram of the MEMS acceleration sensor sampling at the same frequency. The usual processing method is to use the sum of the trapezoidal areas formed in the figure to approximate the ideal acceleration when performing an acceleration integration. Curve integral, the formula is as follows:

$$V_1 = \frac{a_{n-1} + a_n}{2} \Delta t \tag{3}$$

$$V_2 = \frac{a_n + a_{n+1}}{2}\Delta t \tag{4}$$

$$\Delta t = t_n - t_{n-1} = t_{n+1} - t_n \tag{5}$$

However, there is always an interval between discrete data. As the number of integration increases, the integration error (the error is shaded in Figure 2) will continue to accumulate and will be transferred to the second displacement integration. Therefore, the error caused by this approximate algorithm must be considered. Based on the continuity of the ideal acceleration curve, the method of constructing a smooth spline curve and reintegrating through discrete data can be considered to reduce the integration error. At the same time, when the MEMS acceleration sensor meets the performance requirements Next, try to choose a sensor with a high sampling frequency to effectively reduce errors.

3.2 Trend term error

The raw data collected from the MEMS acceleration sensor itself has a certain range of oscillations. In addition to this, some low-frequency components may affect calculations or observations. This interference signal will produce a DC error term in the acceleration acquisition process ε, so the actually measured acceleration is:

$$a(t) = a(t)' + \varepsilon \tag{6}$$

Where $a(t)$ and $a(t)'$ are the velocity signals of the measured acceleration and the actual acceleration at this time:

$$\begin{aligned} v(t) &= \int_{t_0}^{t} (a(t)' + \varepsilon)dt + v(t_0) \\ &= \int_{t_0}^{t} (a(t)')dt + \varepsilon t + \eta + v(t_0) \end{aligned} \tag{7}$$

The displacement signal of the second integral is:

$$\begin{aligned} & s(t) = \int_{t_0}^{t} v(t)dt + s(t_0) = \\ & \int_{t_0}^{t} (\int_{t_0}^{t} (a(t)')dt + \varepsilon t + \eta + v(t_0))dt + s(t_0) = \\ & \int_{t_0}^{t} (\int_{t_0}^{t} (a(t)'dt)dt + \frac{1}{2}\varepsilon t^2 + \eta t + v(t_0)t + \delta + s(t_0) \end{aligned} \tag{8}$$

Through the above error analysis, it is found that in the integration process, because the tiny DC component ε is accumulated in the time domain integration [10]-[11], the speed signal after one integration contains a trend term:

$$\varepsilon t + \eta + v(t_0) \tag{9}$$

Similarly, after quadratic integration, the displacement signal contains a quadratic trend term

$$\frac{1}{2}\varepsilon t^2 + \eta t + \delta + v_0(t)t + s(t_0) \tag{10}$$

Then every integration will cause the error to increase power, so often a small DC offset will cause a large deviation after a long time integration, or even completely change the trend of the integration curve, its existence seriously restricts the accuracy of the distance. The whole process of increasing and deviating from the baseline over time is called the trend item of the signal.

At present, the method of fitting polynomial extremum is often used to eliminate the trend term generated in the integration process, so as to obtain more accurate velocity and displacement signals. The trend item directly affects the correctness of the integral, it should be removed to make the fixed distance system more accurate.

3.3 Random interference signal

In the fixed-range system, the MEMS acceleration sensor is placed inside the fuze. During the launch process, it is affected by internal shocks, external battlefield noise, and the environment. Each data collected by the acceleration sensor may contain random noise and interference signals. Analyzing the collected acceleration signal, it can be seen that some of the signals are obviously isolated, and their amplitudes are high or low. This error is basically uncontrollable. Reducing random errors can effectively improve the distance accuracy of the system. Filtering is a common method to get the best measured value. Kalman filtering is usually used for signal processing for noise and random signals. It uses a recursive estimation algorithm to calculate the estimated value of the current state on the basis of the estimated value of the previous state and the measured value of the current state. It can be applied to both stationary random processes and non-stationary random processes. The difference from most filters is that the Kalman filter is a pure time-domain filter, which uses a time-domain design method. When used like a frequency domain filter, it is designed in the frequency domain and then converted to the time domain, which can process data in the time domain. Based on the above advantages of Kalman filtering, Kalman filtering can usually get better results for the signals measured by MEMS acceleration sensors [11]-[12].

3.4 Sensor zero drift error

Under ideal conditions, the output of the sensitive axis of the acceleration sensor should be 0 when the object is not moving. However, in actual applications, there are random deviations and fixed errors in acceleration. The original data must be preprocessed to obtain more accurate acceleration data before speed and the solution of distance. The zero offset error refers to the amplitude of the input signal being 0 but the measured value is not zero [14]-[16]. The zero offset error makes the integral initial value not 0, causing a large cumulative error. A relatively simple method is to use the arithmetic mean under the same state to subtract the ideal value to get the zero bias error:

$$a_{error} = a_s - a_t \tag{11}$$

Among them, an error represents the zero bias $_{error}$, as represents the average value of multiple measured accelerations under the same state, and $_{at}$ represents the ideal acceleration value under the same state. Specific method: Under static conditions, at this time $_{at}$=0, the sensor is allowed to stand for a period of time and then the acceleration data is read out, and the average value as is obtained by multiple static test experiments. In actual applications, the acceleration data can be obtained by subtracting the zero offset error from the acceleration measurement value.

3.5 Analysis of other error sources

There are certain errors in the components themselves. In the fixed distance system, the errors caused by the physical device structure principle and the limited manufacturing technology level cannot be eliminated by humans, so it is difficult to control and occupy a certain proportion in the entire error system. When selecting physical devices, try to choose components with high accuracy and reliability, and perform error comparison experiments when necessary. At the same time, the method of averaging multiple measurements can also reduce errors to a certain extent.

The system uses the DSP chip to perform real-time integration calculation of acceleration. It is necessary to optimize the innovative calculation algorithm, increase the running rate of the program to perform real-time and efficient calculation, and reduce the error caused by the slow running rate caused by the lengthy programming.

The measurement deviation of the initial velocity of the muzzle will also bring a certain error to the system. In the experiment of a fixed distance of 1000 meters, the flight time of the projectile is about 6 seconds. If the initial velocity error is only 1m/s, then the system will cumulatively cause a distance error of about 6m. Optimizing the hardware detection circuit in the missile-borne velocity measurement experiment program and accurately controlling the distance between the impulse response points can improve the accuracy and effectiveness of the initial velocity measurement [17]-[18].

In the process of wireless setting, set the length of the transmitting coil reasonably (usually 1~2 times the length of the muzzle), increase the signal-to-noise ratio, that is, increase the driving power of the transmitting coil, and improve the coupling characteristics between the transmitting and receiving coils. ; Secondly, the method of reducing noise by opening a vent on the muzzle device can effectively avoid the problem of signal distortion in the wireless setting process [19]-[20]. In addition, errors caused by natural factors such as the launch environment and climate are all issues to be considered.

4. Error classification

Through the above analysis, the errors can be divided into two categories: 1. System errors, including errors caused by the manufacturing accuracy of physical components such as MEMS sensors and control chips DSP used in the system, acceleration data algorithm processing, initial velocity measurement and wireless setting, etc. Error. 2. Random errors. Even under the same conditions, the same measured may have irregular changes. These changes are mainly random signals generated by external complex environments such as noise, heat, and magnetic fields. Unpredictable characteristics will lead to certain randomness. Error.

Through the above error analysis and summary, combined with the process of realizing the distance system, the general flow chart of the error processing of each link is shown as follows:

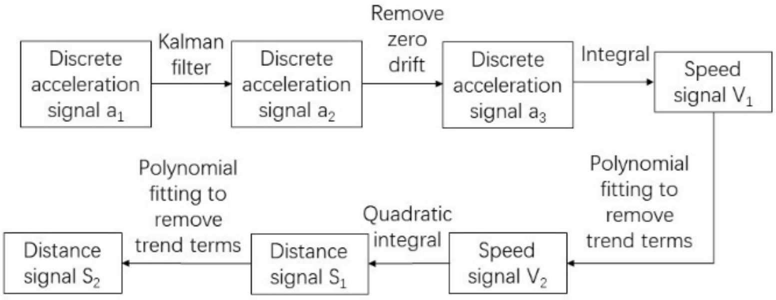

Figure. 4 Signal processing process

5. Summary

Achieving precision strikes is the eternal theme pursued by artillery systems. This article introduces the MEMS accelerometer distance system based on precise explosion point control technology, and analyzes and summarizes the factors affecting its distance accuracy in detail, and combines the current The research work gives some solutions to improve the accuracy of the system.

To improve the precision strike capability of fixed-range missiles, it is necessary to explore the causes of errors from theoretical analysis combined with specific experimental procedures, and on this basis, research improvements. In addition to the influencing factors mentioned in the article, there may be new influencing factors in different launch environments. Only by continuously improving the ability to analyze errors in practice and proposing effective improvement measures can we speed up the development process of fixed-range bombs in my country and improve their accuracy.

References

[1] Xu Lei, Fang Liqing, Huo Ruikun, Guo Deqing. Application research of MEMS acceleration sensor in fuze [J]. Flying Missile, 2018 (05): 91-95.

[2] Yao Zewu, Cui Houbao, direction east. Analysis of Influencing Factors of Explosion Point Control of Counting Rotational Bomb [J]. Journal of Sichuan Armory Engineering, 2008 (01): 22-25.

[3] Cao Chengmao, Ding Libo. Research on design of small-caliber artillery-air-blast fuze based on counting revolutions and fixed distance [J]. Journal of Ballistics, 2004 (04): 82-86.

[4] Wang Zhongyuan, Zhang Bisheng, Shi Jinguang, Yi Wenjun. Analysis of influencing factors of the fixed distance of the number of rounds of the shell [J]. Journal of Ballistics, 2006 (04): 8-11.

[5] De Spirito J, Heavey K R.CFD Computation of Magnus Moment and Roll Damoping Moment of A Spinning Projectile,ARL-RP_131 [R]. Rhode Island: AIAA, 2006.

[6] Niu Weimeng, Fang Liqing, Li Xu, Huo Ruikun, Qi Ziyuan, Guo Deqing. Measurement method of outer ballistic acceleration of fuze [J]. Journal of Artillery Launching and Control, 2020, 41 (01): 93-98.

[7] Niu Weimeng, Fang Liqing, Qi Ziyuan, Guo Deqing. Displacement measurement system based on MEMS acceleration sensor [J]. Instrument Technology and Sensors, 2020 (03): 62-66+72.

[8] Zhou Yingjie. Acceleration test integral displacement algorithm and its application research [D]. Chongqing University, 2013.

[9] Rong Taiping, Shen Chenghu, Yuan Zhongping, Xu Songmei. The principle and error analysis of displacement measurement with acceleration sensor [J]. Journal of Huazhong University of Science and Technology, 2000 (05): 58-60.

[10] Chen Weizhen, Wang Bingwen, Hu Xiaoya. Acceleration signal processing based on time domain integration [J]. Journal of Huazhong University of Science and Technology (Natural Science Edition), 2010, 38 (01): 1-4.

[11] Chen Jun, Li Jie. Several methods of extracting trend items of vibration signal and their comparison [J]. Journal of Fuzhou University (Natural Science Edition), 2005 (S1): 42-45.

[12] Xu Han, Zeng Chao, Huang Qinghua. Research on Error Compensation of MEMS Gyroscope Based on Kalman Filter Algorithm (English) [J]. Journal of Sensor Technology, 2016, 29 (07): 962-965.

[13] Yang Huijuan, Huang Zheng, Huo Pengfei, Wang Chao. Dynamic error compensation method of axial acceleration based on Kalman filte r[J]. Journal of Ballistics, 2014, 26 (01): 103-106.

[14] Wang Yan, Lu Jianping, Ma Tiehua. Processing method of zero drift of penetration acceleration signal [J]. Journal of Sensor Technology, 2015, 28 (04): 510-514.

[15] Bar-Shalom Y, Binniwal K. Variable Dimension Filter For Maneuvering Target TRACking [J]. IEEE Transaction on Aerospace and Electronic Systems, 1982, 18 (5): 621-629.

[16] Gao Qingyi, Chang Lulu, Wang Binxing, Wen Zhongyuan. Analysis of Zero Drift of MEMS Acceleration Sensor in Explosion Impact Environment [J]. Journal of Testing Technology, 2020, 34 (04): 349-354.

[17] Yang Zhao. Research on missile-borne velocity measurement technology [D]. North University of China, 2007.

[18] Yang Zhao, Wang Li, Ji Xia. Research on the method of missile-borne self-test speed [J]. Journal of Projectiles, Rockets, and Guidance, 2006 (04): 179-180.

[19] Wang Weiqiang. Programmable fuze setting data link design and accuracy analysis [D]. Nanjing University of Science and Technology, 2018.

[20] Huang Xuegong. Muzzle induction setting fuze technology and experimental research [D]. Nanjing University of Science and Technology, 2005.