

Control System in Missiles for Whole-Trajectory-Controlled Trajectory Correction Projectile Based on DSP

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(Received 29 March 2013; revised 23 December 2013; accepted 6 February 2014)

Abstract: A control system for correction mechanisms through the whole trajectory is proposed based on the principle of one-dimensional trajectory correction projectile. Digital signal processing (DSP) is utilized as the core controller and global positioning system (GPS) is used to measure trajectory parameters to meet the requirements of calculating ballistics and system functions. Firstly, the hardware, mainly including communication module, ballistic calculation module, boosting & detonating module and data storage module, is designed. Secondly, the supporting software is developed based on the communication protocols of GPS and the workflow of control system. Finally, the feasibility and the reliability of the control system are verified through dynamic tests in a car and live firing experiments. The system lays a foundation for the research on trajectory correction projectile for the whole trajectory.

Key words: trajectory correction projectile; digital signal processing (DSP); GPS; entire course controlling; data storage

CLC number: TJ765

Document code: A

Article ID:1005-1120(2014)03-0325-06

1 Introduction

The one-dimensional trajectory correction projectile (ODTCP) is of smart munitions which aim at improving the accuracy of impact point. With the correction mechanism assembled in the original munitions, the projectile-borne detecting system measures the trajectory in real time. Meanwhile, the trajectory calculation module calculates the trajectory. Corrections are given based on the deviation compared with the ideal trajectory. Domestic and foreign researches mainly include the detection technology of trajectory parameters, the design of correction mechanism, the trajectory correction algorithm, the modularization of correction system and the improvement of correction capability, etc^[1-5]. While these efforts focus on the trajectory end correction, correction capability for the whole trajectory is limited. Generally, the correction mechanism is integrated with fuze, which increases the complexity of the correction system and makes it hard to de-

sign. Therefore, we present a novel approach for the whole trajectory correction of ODTCP to analyze the projectile control system.

According to different trajectory detection means, ODTCP can be divided into two parts: active detection and semi-active detection projectiles. The trajectory calculation of semi-active detection is conducted by fire control system which also gives control instructions of actuator movements except driving; while the trajectory calculation of active detection is exerted by missile-borne computer which is mainly in charge of trajectory calculation. In our approach, the whole course controllable one-dimension trajectory correction system is an independent module, using global positioning system (GPS) to detect trajectory, and the trajectory calculation is conducted by projectile control system. Thanks to its independent actuator, the control system generates control instructions, and drives the executing agency to complete the correction function reli-

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bly. Meanwhile, flight data storage module of the system is also designed to strengthen the analysis of the test result.

2 Correction Project and Control System Principle

2.1 Correction project design

To achieve the whole-trajectory correction, the best solution is to improve the damping coefficient of correction mechanism. Based on the comprehensive study of one-dimensional trajectory correction, an independent correction system is developed consisted of correction and control components. The components can be assembled in the projectile on any location without changing the original aerodynamic shape by taking full use of the available space. Fig. 1 shows the correction system structure. In Fig. 1(b), correction components include actuator, drive mechanism and opening-damper mechanism. The control components include a DSP controller, GPS and boosting & detonating module, etc, which covers the measurement and the storage of trajectory parameters, trajectory calculation, the generation of control instructions and driving signal.

2.2 Working principle of control system

Fig. 2 is a flowchart of the control system. First, the system powers on before firing, and GPS module automatically updates the receiver ephemeris after positioning, meanwhile, DSP controller is configured with target information and environment information. DSP controller completes transformation of coordinates to con-

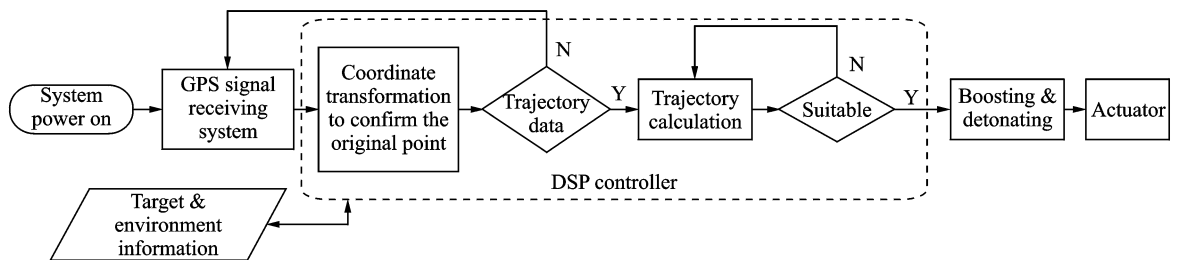
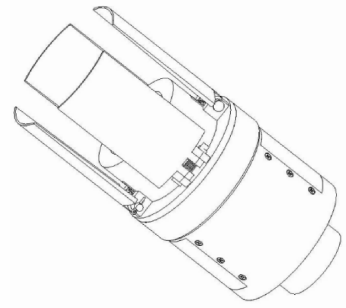


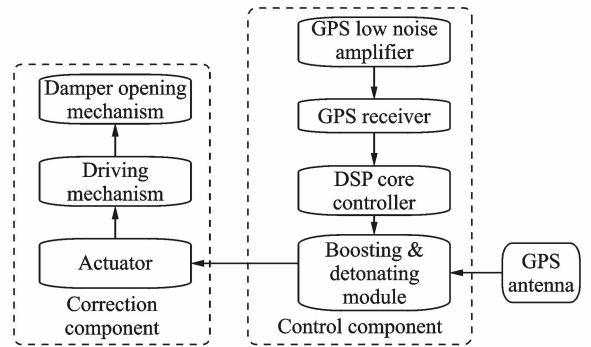
Fig. 2 Working flow of control system

3 Hardware Design of Control System

The control system for self-trajectory correc-



(a) Outline of correction mechanism



(b) Block diagram of control system

Fig. 1 Correction program

firm the original point of trajectory by GPS data. Then, flight information, measured by projectile-borne GPS receiver in real time, is transformed into trajectory data such as flight distance, height, velocity and trajectory angle. DSP controller determines whether trajectory data meet the requirements of calculation parameters of trajectory calculation module. If it is suitable, driving signal will be sent to the actuator by controlling the boosting and detonating module. The actuator drives the damper to complete trajectory correction.

tion projectile should be extremely reliable and fast enough for real-time calculation, as well as highly integrated and miniaturized. All these re-

quire higher performance of projectile-borne process unit. The frequency of GPS signal is 10 Hz, which means the control system should complete trajectory-data shifting, trajectory calculating and control signal sending only within 100 ms. On this condition, the trajectory calculation time must be less than half of GPS data refresh time, i. e. 50 ms. High reliability requires hardware system to adapt to harsh environment like serve temperature, overload, impact, and complicated electromagnetic environment. Considering limited projectile space, strict restrictions for the volume and the weight of hardware system is proposed, and high integration and miniaturization should be set as the design principles at the beginning. Therefore, TMS320F28335ZJZA manufactured by TI Company is chosen as the core controller owing to its fast frequency, high precision and strong mathematical ability. It supports IEEE-754 single-precision floating-point processing, and enhanced control peripherals and strong signal process ability have been integrated in it^[6]. Fig. 3 shows the hardware structure of control system.

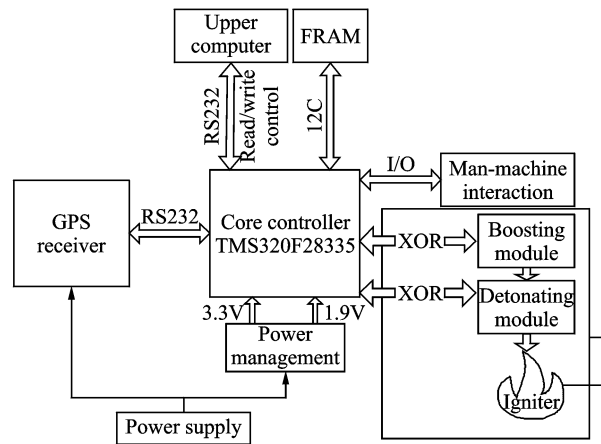


Fig. 3 Hardware structure of control system

3.1 Communication module

DSP core controller needs to communicate with GPS receiver by RS232 interface. To simplify designing, TTL voltage is chosen as the interface voltage, for the distance between GPS receiver and hardware system is less than 10 mm. To conveniently read trajectory data, FRAM can

be read or erased by I/O pin with making the most of multi-RSS232 interface which can also be used for target information configuration.

3.2 Boosting and detonating module

An independent trajectory correction module can drive damping mechanism whose control target is an igniter, which means abundant energy is required for detonating. Therefore, boosting & detonating module is developed. Considering system safety, controllable boosting chip MAX8570 is selected as the core component, and corresponding peripheral circuit is designed, as shown in Fig. 4. $\overline{\text{SHDN}}$ pin, the net named Ctrl_28V in Fig. 4, is the control interface. A logic low at $\overline{\text{SHDN}}$ will place the chip in low-power shutdown mode while pulling $\overline{\text{SHDN}}$ high for normal operation, therefore, system configures the voltage on this pin for boost controlling. Unknown high level may appear during system initialization, which is extremely dangerous and may cause correction module malfunction. Test results show that the GPIO pins of DSP has the characteristics of high homogeneity, as a result, an exclusive-OR gate input by two same GPIO pins is chosen to control the $\overline{\text{SHDN}}$ for higher reliability.

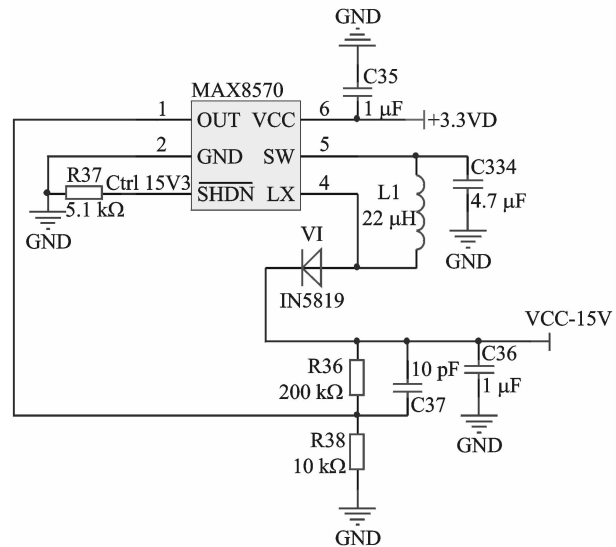


Fig. 4 Schematic of boosting module

The energy output by boosting module, stored in a large-capacity capacitor, detonates the igniter under the control of thyristor. Fig. 5

shows the control principle. To ensure the high reliability of detonating module, an exclusive-OR gate is used just like $\overline{\text{SHDN}}$, mentioned above, since the console port of the thyristor, the net named Ctrl_out in Fig. 5, also works in the high level.

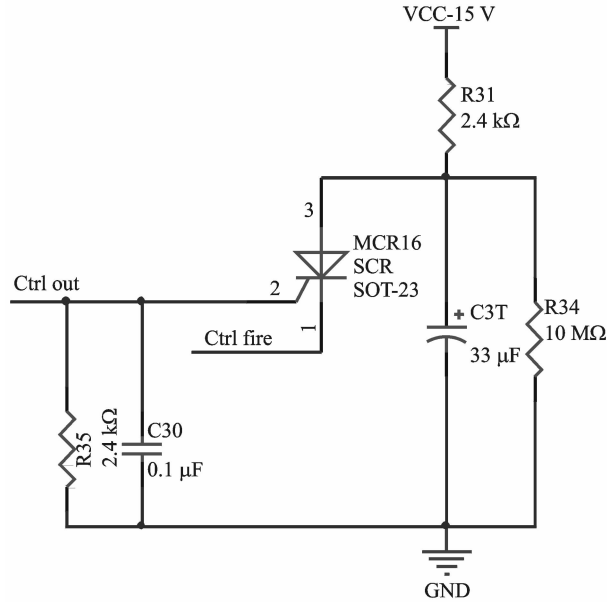


Fig. 5 Schematic of detonating module

3.3 Data storage module

Flight data storage is a critical work for trajectory correction projectiles. EEPROM, Flash, SRAM are the common projectile-borne memory, and each has its own merits. EEPROM is a mature and reliable technology, yet it is not fast enough and costs much valuable CPU-time; Flash bad blocks, whether they ship with the device or appear over time, may lead system to infinite loops or crash, and the process of handling these blocks occupies much system time; SRAM has the advantage of lower power consumption and higher speed while it is bulky and low integrated. Besides all the advantages mentioned above, Ferroelectric random access memory or FRAM is nonvolatile and reads and writes like a RAM. It provides reliable data retention for 10 years while eliminating the complexities and system level reliability problems. FRAM performs writing operations at bus speed using a familiar two-wire (I²C) protocol and no write delays are incurred. Also, FRAM exhibits much lower power during writing. These capabilities make FRAM ideal for

nonvolatile memory applications requiring frequent or rapid writing. FM24CL64 is chosen as the memory for this system, and Fig. 6 shows the circuit schematics.

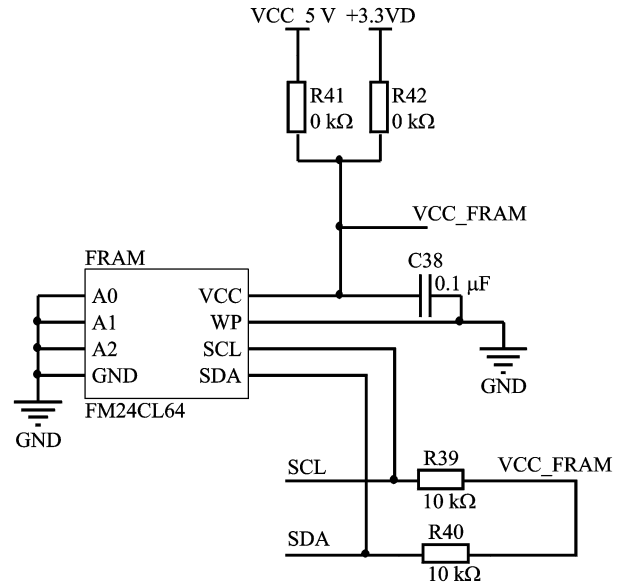


Fig. 6 Schematic of data storage module

4 Software Design of Control System

According to GPS receiver communication protocol and the function of control system, corresponding software is developed. Fig. 7 shows the flow diagram. System software contains mainly the following function module: data read and erase module, GPS data receiving module, coordinate transformation module, trajectory calculation module and control signal generation module, etc.

After the system powers on, GPS system starts to search the satellite and locates as well as stores GPS satellite ephemeris, meanwhile DSP controller sends commands to clear old ephemeris after each module has been initialized. GPS receiver sends location data to the controller per 100 ms which will be then verified by the data verification module. The controller will not continue until the location data meets the rules. It is worth mentioning that the original data from GPS receiver is needed to be transformed from the WGS84 coordinate to the ballistic coordinate. Ten groups of static location data are enough for DSP controller to confirm the origin point. Two con-

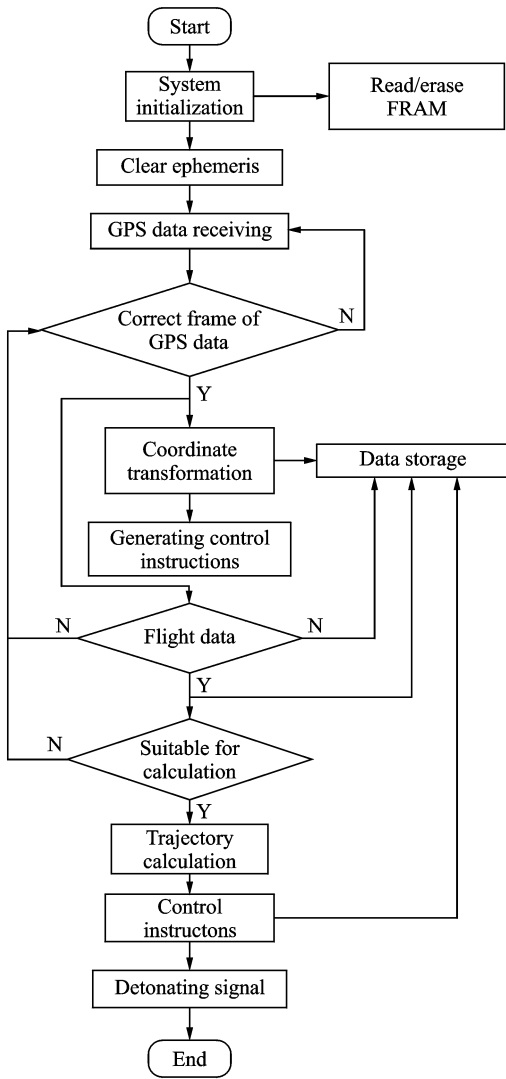


Fig. 7 Software working flow of control system

control signals are generated afterwards. One starts the boosting module and the other starts the buzzer. The shooter decides whether or not to fire the projectile by the sound of buzzer.

On the condition that the GPS data are trajectory data during the flight, the software continues to check whether the GPS data meet the requirements of ballistic calculation or not. If they do, trajectory calculation module will then generate the detonating command with the detonate signal followed. All flows mentioned above will be repeated if any error occurs in GPS data.

Ten groups of static GPS data, trajectory data, trajectory calculation data, lock-lose data, control command are stored in FRAM. These data can be read or erased by controlling the GPIO pins after landing.

5 Experiments

5.1 Dynamic tests

The whole correction system has been tested dynamically in the car outside. GPS receiver's sending port is connected to computer in which serial debugging assistant (SDA) receives GPS data in real time by RS232 interface. Fig. 8 shows the dynamic data received by the computer, where red line represents the speed showing the acceleration and deceleration processes of the car, blue line shows the X -coordinate and the corresponding Y -coordinate of the matching real terrain. Fig. 9 shows the data read from FRAM. The speed faster than 15 m/s is considered to be the flight trajectory data which are already set in the software. The speed curve and terrain curve correspond with the curves in Fig. 8, which indicates that no effective data have been omitted. Igniter is detonated after the car speed is slightly faster than 15 m/s. These indicate that the trajectory calculation module and the control instructions work properly with expectations.

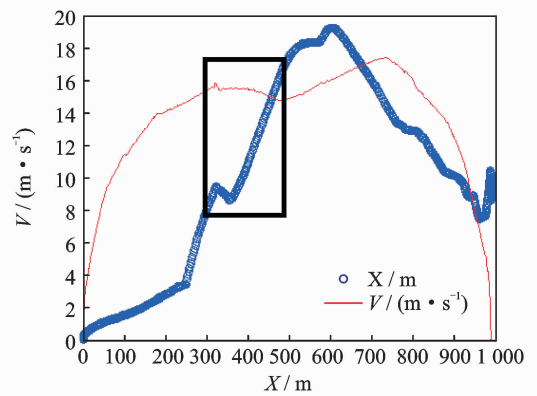


Fig. 8 GPS data from SDA

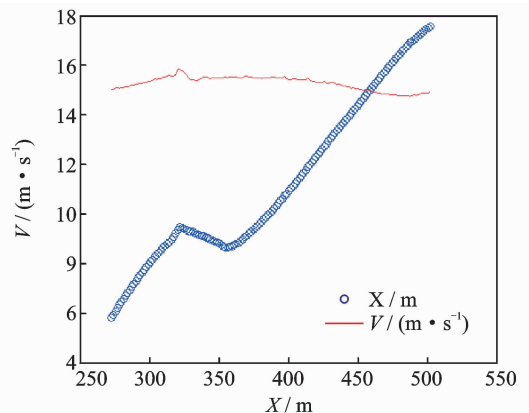


Fig. 9 GPS data from FRAM

5.2 Flight experiments

Principle flight experiments are conducted with the trajectory correction system assembled into a certain projectile. The distance is set as 700 m, and emission angle 25° as shown in Figs. 10–11. Fig. 10 shows the trajectory curve where 1# stands for the un-corrected trajectory with the range of 891 m and 3# stands for the corrected trajectory with the range of 690 m. 1# curve in Fig. 11 is the velocity of whole ballistic trajectory. As shown in Fig. 10, the velocity of 1# decreases step by step, while 3# suddenly drops around 450 m which is supposed to be the moment when the damping mechanism is working. From the experimental results, each module of the control system works properly and reliably with expectations.

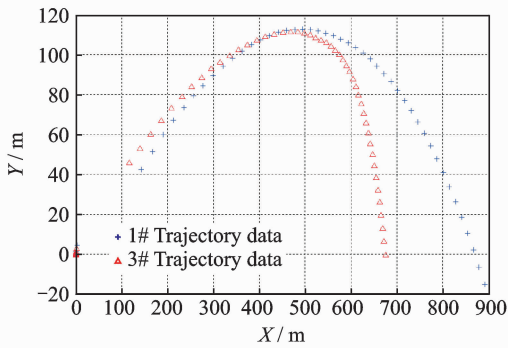


Fig. 10 Trajectory curve

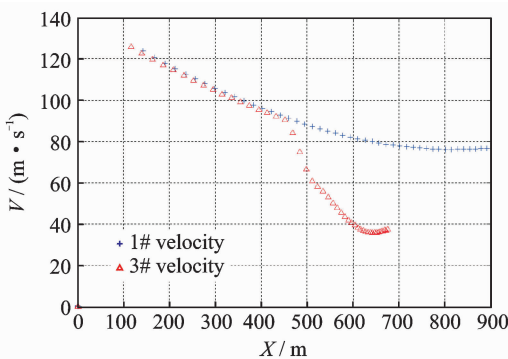


Fig. 11 Velocity curve

6 Conclusions

(1) An available correction method is put forward for whole ballistic trajectory, and its feasibility is proved by the experiment.

(2) Software and hardware design of the correction system is introduced; furthermore, the feasibility and advancement of the control system scheme are validated through testing, indicating that the whole system meets the requirements of the system.

(3) The results of the experiments shows incontestably that the correction system is feasible and reliable, which provides a new idea for ODTCP.

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(Executive editor: Zhang Bei)