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Short communication

Correction method of the manned spacecraft low altitude ranging based on γ ray

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ABSTRACT

γ photons altimeter, which is a low altitude measurement of the spacecraft based on Compton effect at the moment when it lands on earth, is an important equipment for spacecraft landing control. Manned spacecraft landing control needs γ-ray altitude control system to revise ignition signal for retrograde landing rocket at different landing speed. To make the spacecraft speed zero at the moment landing on the surface, a method that makes ignition altitude correction of the spacecraft at different landing speeds is figured out, which is based on the number of γ-ray particles reflected field gradient. According to the established theoretical model, the method feasibility is proved by a mathematical derivation and verified by an experiment, and the adaptability of the method under different parameters is also described. The results indicate that the error of the altitude signal error is less than 0.05 m at the height of 0.5 m to 1.5 m when the landing speed of spacecraft is in the range of 6 m/s to 10 m/s. The method provided has great significance for the manned spacecraft engineering need.

1. Introduction

Manned spaceflight and deep-space exploration are two major scientific exploration researches carried out worldwide in the field of aerospace, and what they all have in common is the presence of EDL (Entry, Descent and Landing) processes [1–5], namely the need to return to Earth or the spacecraft landing on the moon. In order to achieve this goal, the spacecraft uses the parachutes or the engine to decelerate during EDL process, and retrograde landing rocket is used in the final step of EDL [1–11].

For manned spacecraft, in order to protect the personal safety of the astronauts and enhance the reliability of the spacecraft, two sets of parachute systems are designed: the major parachute and the spare one. Due to the different weight of the capsule and the different area of the parachute canopy between the two sets of systems, the theoretical landing speed differs when different systems are used. Additionally, due to the uncertainty of the altitude, the atmospheric environment and the landing site, the landing speed will be impacted. Thus the precise landing speed of the aircraft is unpredictable [10]. The spacecraft's retrograde landing rocket which can use FGMs (functionally graded materials) [6–8, 12–14,22–25] to decrease spacecraft's weight and increase heat-protection properties has a working time and specific impulse, the spacecraft requires the retrograde landing rocket to start work in a specific altitude to ensure that it just ends work at the moment when the spacecraft landing on the ground at a certain speed. When the falling speed of the spacecraft changes, the ignition altitude of the retrograde landing rocket should correspondingly change to ensure that the expectation speed of spacecraft landing on the surface of the planet can be zero at other landing speeds [9–15].

At present, landing sensor such as Doppler radar altimeter, radar altimeter and laser altimeter can all measure the altitude during the period of landing. γ photons altimeter "KAKTUS", which is developed by the Russia has been successfully applied in the Union TM spacecraft [17–21] to make the landing controllable when the spacecraft flies at low altitude. In the sixties and seventies of the last century, America has started the research of the type of the bar touching sensor, for the landing technologies of Apollo spacecrafts. A spacecraft gave out a signal to ignite the thrust reversed rocket once the touching bar touches the ground. The altitude measured is the altitude between the spacecraft and a point on the ground [21–29]. For the recent two years, the American NASA's project "Autonomous landing hazard avoidance

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technology, ALHAT" is researching the technologies about the radar sensor and the laser altimeter, to make the altitude of the moon landing spacecraft between 100 m∼20 km measurable [17–20, 30–34], Barometric altimeter has been broadly applied to the altitude measurement of the unmanned aerial vehicles on the earth. It's also applied to the independent landing controls. A barometer altimeter is utilized as the pressure sensor, and a digital signal processor (DSP) is employed as the on-board micro processor. The media average filter is designed to process the raw data from the barometer to obtain high accurate measurement of the altitude. Barometer can achieve an accuracy of 0.23 m for the altitude measurement [35].

Due to the different landing surface of different celestial body is not completely flat, what the laser altimeter or mechanical touch altimeter measures are all the altitude value for a particular point, which cannot reflect the real landing point within a certain region. γ photons altimeter emits gamma photons diffused through certain area and the receiver receives the value of the reflected photon in the area to reflect accurately the altitude of the place [9–20]. γ photons altimeter can measure the average altitudes between the spacecraft and the landing ground as possible. The other advantage of applying the γ photons altimeter lies in the γ rays' strong penetrabilities. During the landing process, the interference brought by the dusts which are raised by the engine is slight [9, 10,21].

The principles of the radar altimeter and the laser altimeter on measuring the speed are that by measuring the time of the spacecraft flying by two altitudes and making a division calculation [16–20]. Due to the super high speed of the electromagnetic wave and light, it can be considered that the altitude of the spacecraft is measured in an instant. But, the principles of the γ photons altimeter on measuring the speed are different from that of the radar altimeter and the laser altimeter. γ photons altimeter launches γ photons to the ground with a launcher. γ photons are then reflected to the receiver. Because of the different densities of the γ photons on different altitudes, the receiver can calculate the altitude by measuring the quantities of the γ photons with a counter and dividing the total quantities with the time of measurement, the density of the γ photons is obtained.

Because the spacecraft is in a moving state during the EDL process, γ photon altimeter will bring in large errors by calculating the speed by measuring the altitudes on different time. Because the landing controls of the spacecraft need only the ignition altitudes of the engine corresponding to different falling speed rather than the specific values of the speed, a method for rectifying the altitudes of the engine's ignitions is proposed in this article. Removing the calculations of the specific values of the speed of the spacecraft. It calculates the thrust reversed rocket's ignition altitudes rectified with different falling speeds.

The bottom of the spacecraft is equipped with retrograde landing rocket, when the spacecraft fell to the ground from the altitude H_0 and the rate of decline in the return capsule is v_0, the γ photon altimeter below the spacecraft issues a directive and the retrograde landing rocket starts ignition work and reduces the rate of decline in the return capsule to v_1 within the altitude range of brake stroke H_a. Before landing the retrograde landing rocket should first be turned off to avoid the "explosion" phenomenon caused by blocking the vents. To simplify the calculation, assuming that the thrust F_r of the retrograde landing rocket keeps constant within the altitude of the entire brake stroke H_a, and during this period the resistance of the parachute system is not considered, then the ignition altitude H_0 of the retrograde landing rocket is determined by the following three formulas [10]:

$$H_S = \frac{1}{2g}\left(v_2^2 - v_1^2\right), \tag{1}$$

$$F_r H_a = \frac{1}{2}m\left(v_0^2 - v_1^2\right) + mgH_a, \tag{2}$$

$$H_0 = H_a + H_S. \tag{3}$$

In the above formula, m is the quality of the return capsule. H_S stands for the remaining altitude of braking return capsule and v_2 for the return capsule landing speed. In particular, due to the impact of landing field environment, altitude and the atmosphere during the returns process [9,10], the spacecraft's landing speed is not a changeless value, but changes within a range [1]. In order to adapt to the above style, the spacecraft ignition altitude correction is required, i.e., at high landing speeds, the ignition altitude is higher while at lower landing speeds, the ignition altitude is lower. Automatic compensation of the ignition signal altitude, altitude is determined by the following formula:

$$H = H_0 + K(V - V_H), \tag{4}$$

In the above formula, H is the altitude of the ignition. H_0 is the desired altitude. V_H is the desired speed. K is correction coefficient. V is the actual rate of decline. The value of K is related to the total impact and working time of the thrust reversed rocket engine and the landing speeds corresponding to different parachutes taken by the spacecraft when falling. The specific calculating method is referred to the document 13 [13], Generally, K is between 0.15∼0.27 [1,9,10].

2. The spacecraft low altitude ranging method based on Compton effect

2.1. The physical model

Gamma photon altimeter is consist of the transmitter, the receiver and the controller. The transmitter contains a radioactive source, and transmits a dose of gamma rays to the ground. The receiver will receive the gamma photons diffused through the surface of the planet, and convert the gamma photons into electrical signals. While the controller will send out a height signal after analyzing the electrical signal of the receiver output. As shown in Fig. 1, the transmitter transmits a dose of gamma rays to the ground. Diffuse through the surface of the planet, the gamma photons into light pulses through the NaI crystal, the photo multiplier tube converts the optical signal into a weak current pulse signals [9]. Furthermore, the amplified converted current signals into pulse signals.

Fig. 2 shows the γ photons altimeter altitude measurement mathematical model. At the H_0 altitude transmitter continuous emission to the ground gamma rays by 2ψ angle [9]. At the altitude $H = H_0 + B$, receiving terrestrial gamma photons back scattered by the receiving processor. d is the horizontal distance between the crystals and the transmitter.

Then the density of gamma photons captured by the *NaI* crystal and scattered back from the ground can be expressed as:

$$\phi_P = \frac{I_0 \cdot K_0 \cdot \lambda}{4\pi} \times \int_{\theta=0}^{\Psi}\int_{\beta=0}^{2\pi} \frac{\varepsilon_\gamma(E_0, \rho, Z, \theta_0, \theta_1, \beta)\cdot \sin\theta}{[d^2 + H^2\cdot \mathrm{tg}^2\theta + H^2 - 2d\cdot H_0 \cdot \mathrm{tg}\,\theta \cdot \cos\beta]} d\theta \cdot d\beta. \tag{5}$$

In the above formula: I_0 for activity radioactive sources, K_0 is the decay constant 3.7×10^{10} times/s, λ is the decay coefficient, $\varepsilon_\gamma(E_0, \rho, Z, \theta_0, \theta_1, \beta)$ as inverse scattering probability, E_0 is photon radiation energy sources, ρ is the density of the surface material, and Z is the role of the effective atomic number of the material, β is azimuth angle; θ is in the range of 0∼ψ. θ_0 and