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Design of Radio Beacon for Spacecraft-memory Localization

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Abstract

With the development of space technology and more and more space experiments, it has brought forward higher requests for memory of hard-recovered solid-state recorders. Therefore, Recovery of the memory becomes more important. Aiming at the disadvantages of present ways of recycling, we introduce a real-time GPS positioning wireless beacon which can be applied in memory recovery. This paper introduces the principle of the system, circuit, and the function that can realized. Experimental results show that the beacon in a static environment and dynamic environment had a good performance in GPS positioning, and a high positioning accuracy. During Signal transmission, the receivers can receive the raw GPS signal without error and can depict the running track of memory.

Keyword: *GPS, DDFS, beacon, protection, UAV*

1. Introduction

With the development of the new spacecraft, we need a large number of experiments under testing system of all-sided design and manufacturing technics. The purpose of experiments is to obtain various parameters of the spacecraft launch. These parameters are stored in the large capacity memory of recovered solid-state recorders in paper [1], by analyzing experimental parameters to estimate whether the test is successful, so it related to the result of experiments whether the memory is recovered successfully.

At present, there are two main ways to search for the wreckage of spacecraft memory: one way is that ground personnel looked for wreckage after debris landing; the other is INS Navigation System or GPS Navigation System in several papers [2, 3]. By mean of datafusion with inertial navigation systems (INS) has low accuracy, high expense and high power consumption under high dynamic movement [4]. As for GPS Navigation System, in the past, the precision of the system is limited in outdoor environment. The position accuracy can be achieved with GPS is 10m in civilian applications. However, with NASA cancellation C/A codes and the domestic navigation algorithm development recently, civilian accuracy could reach to 5 m, and it is adequate for our applications. In another way, the accuracy around 10m that achieved can meet our requirement. Therefore, we introduce the wireless beacon based on GPS Navigation System. In current wireless beacon design, most of them would work after the spacecraft memory landing. With this way, the GPS receiver, signal generator, MCU, and power supply were integrated into a whole, and there was a trigger outside of the beacon. When the memory was about to land, the altitude sensor would trigger the switch and the beacon started to work. Searcher on the ground searched the radio signal by onboard reception device or helicopter search receiving equipment to confirm the location of the memory wreckage. But in most condition, the areas of the debris landing are mountains or desert, thus beacon was often buried by dirt or stone result in poor signal and low probability of success [5].

This paper presents a novel beacon that can work in the air with the memory. For the problem of Doppler Effect, they have developed greatly [6]. GPS receiver can rectify error codes itself in the navigation information processing and transmission, because of the amount of GPS information data is small and high repetition rate, we use FPGA as information MCU, the direct

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digital frequency synthesis technology is application where PM modulation is 406 MHz carrier-frequency [7].

2. Design of the Entire System

Currently, there is ready-made GPS receiver module, but because of manufacturer secrecy, we cannot grip the core circuit. Through the above theory analysis, we know that we can design a circuit diagram of the beacon system as a signal-source; the system block diagram is shown in Figure 1.

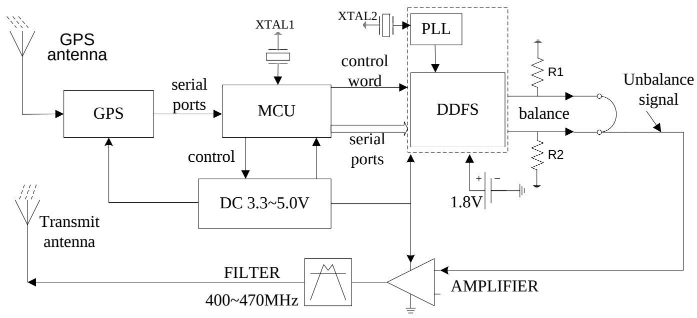

Figure 1. Structure of Entire System

The speed of Memory in free falls from several kilometers per second to hundreds of meters per second, in this process, the beacon sends GPS position signal incessantly. So that the receiving apparatus in the ground can receive navigation data at different points in time, and is able to describe the trajectory of the memory eventually. Because of the beacon high-speed movement, we need to set the GPS module with high data update rate. In our system GPS data update rate is 20Hz, and each packet of data is about 71 bytes [8], so the amount of data transferred per second would be 113600bps. We can see that from the above equation the update rate is less than 115200bps. If the memory speed is 500m/s, the positioning data is 25m flight transmission time. Although this is only a rough estimate, we can increase the amount of data to increase positioning accuracy. With the system structure, the GPS chip and microstrip antenna make up GPS receiver, and the data are sent via RS232 serial interface to the microprocessor. The signal is modulated by direct digital frequency synthesis (DDFS) technology to the high frequency instantly. In order to filter circuit clutter and amplify the useful signal, we increase the power amplification and signal filtering module in circuits.

3. Design of Beacon Protection

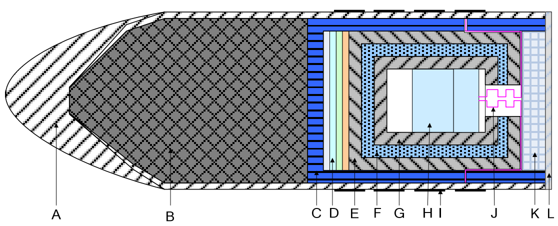

Figure 2. Schematic Design Beacon Protection System

A: the protective structures Shell
B: ammunition
C: PTFE stress wave isolated reflective layer

D: layers of different density metal foam cushioning material
E: super-hard aluminum shell
F: polyurethane suspension buffer layer
G: super-hard aluminum
H: Beacon
I: microstrip antenna array
J: Beacon and microstrip antenna bow cable
K: titanium rigid connection
L: backshell

The beacon was placed in the outer surface, when the memory is separated from the rocket body; there is a relatively high velocity and rotational speed. At the same time as the load memory and beacon debris friction with the atmosphere produces high temperature in the falling process, the beacon-working environment is a great challenge. Therefore, the protection has become a key factor for system. The key protective structure is to absorb a kinetic energy storage module and stress wave attenuation collision, the energy storage module itself is the buffer material absorption, and reduces the stress peak value, increase the pulse duration. As shown above, beacon circuit board is super duralumin shell; the outside aluminum shell is the buffer substance, the outside buffer substance is still super-hard aluminum shell. We put the beacon and the three layer of the shell together as Beacon module. The middle layer is a multi-layer composite metal foam cushioning materials of different densities. Cushioning material is mainly used for collision energy absorption, when the buffer module is subjected to axial impact force reaching a certain value, the buffer module will happen some ductile fracture, and the other part will occur plastic deformation. We assume that beacon quality is v_0 , the overall speed becomes zero after landing, but beacon module is still at the speed of v_0 impact on the buffer device. Buffer device in the ductile fracture stage absorbed energy is:

$$E_h + E_c = \frac{1}{2}mv_0^2 - \frac{1}{2}mv_1^2 \tag{1}$$

Which E_h is the shear fracture stage of the deformation energy; E_c is a buffer module in the fracture process of plastic deformation and thermal energy. The v_1 is the residual velocity of beacon at fracture stage. Beacon compress buffer module by speed v_1, a permanent change approximately shaping contact with the beacon module, away from the contact zone where there is elastic deformation.

$$\frac{1}{2}mv_1^2 = E_1 + E_2 \tag{2}$$

Among them E_1 is plastically deformed, E_2 is elastic deformation energy.

$$\frac{1}{2}mv_0^2 = E_h + E_c + E_1 + E_2 \tag{3}$$

So buffer material energy consumption coefficient is larger, we can make the beacon module kinetic energy absorption effective by buffer material during the collision process. Layered composite buffer structure, nonlinear viscoelastic material typical energy consumption performance, increases the amplitude of the wave propagation attenuation and waveform dispersion, reduce the stress wave pulse peak stress, and make the pulse longer wavelength, which to prevent the destruction of the beacon module.

Location of the B there is a small amount of ammunition. Because of the less content, ammunition explosion has no destruction of protective structure and beaconing. When the memory drops to a certain height from the ground the beacon was ejected from the debris, to some extent reduce the beacon machine buried in sand probability. Because the ammunition is less, the explosion will not cause damage to the beacon and microstrip antenna. Connection line with arcuate line in the beacon and microstrip antennas, can avoid the beacon falls the ground lead to fracture for collision with the ground.

Microstrip antenna consists of receiving antenna and RF microstrip antenna, the signal frequency of the GPS signal received by the system is L1 (1575.42MHz); signal transmitting frequency is 406MHz; they mutually will not interfere too much.

4. Analysis of Beacon Trajectory

The Figure 3 is the aircraft fight path diagram, the aircraft exploded in the air at point A after about 140s after taking off. The aircraft-arrow continues fly, loaded with memory and beacon debris shedding and under the effect of the initial momentum flight. In flight process debris under the earth gravity and the air resistance, so the wreckage of flight state can be divided into 4 stages. The explosion point A to the highest point B, at this stage the wreckage away from the Earth decelerates operation; the speed of the vertical direction is zero at the point B. From B to C, debris begin to do accelerated motion in the vertical direction, horizontal direction still decelerated motion, and trajectory of debris becomes steeper. After reaching point C parachute opened, debris begins to slow down. When debris have been moving to D the air resistance and gravity equal, and debris remains to the uniform motion. Due to the time of debris landing is very short, we need start beacon to eliminate the GPS receiver cold-start time before reaching point D. We assume that the memory and rocket separated when the height is 40000m, initial velocity in vertical and horizontal directions are both 1500m/s. Speed of debris in the uniform motion phase is about 400~500m/s, the GPS positioning will not be a large error or mistake at this speed.

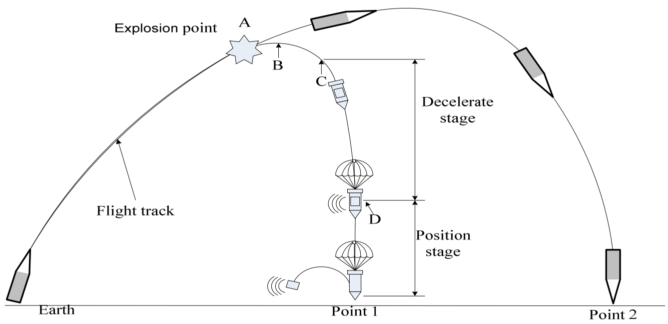

Figure 3. Schematic Diagram of the Rocket and Memory Flight Path

5. Analysis of Beacon Signal Spectrum and Power

In order to test the signal frequency and power, we use Agilent N9010A spectrum analyzer to measure the signal. Due to spectral analyzer for input signal power must be less than 1W, the signal power display in spectrum analyzer is 30dBm (1000 times) attenuation. We can see that the peak point of frequency is 406MHz; the bandwidth of 25KHz. Signal spectrum is relatively pure. The peak power is 2.83dBm and original signal is about 1.9W. If the distance of signal transmission is in 20~30km, the ideal of free space attenuation is about 80dBm, the actual space add 40~50dBm attenuation, then the total attenuation is about 120~130dBm. Because the sensitivity of the receiver can be less than -110dBm, so the beacon signal strength can meet the strength requirement of wireless signal transmission.

From the frequency-spectrum analysis of the signal above, we can see that signal frequency and power can meet the transmission requirements. However, we need to ensure the information has no error codes. The Figure 4 is a packet of fixed format string (400bit) sent to the micro controller of the system.Through the amplifying and filtering circuit, 50-connection line is displayed on N5061B signal analyzer of the Agilent.

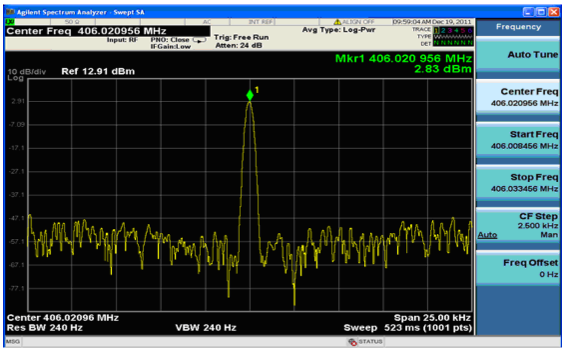

Figure 4. Signal Spectrum

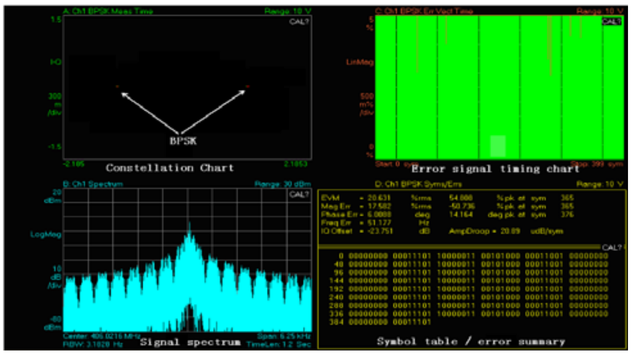

Figure 5. Signal Demodulation Diagram

The upper left side of the window shows the constellation of the signal; the lower left side is the frequency spectrum of the signal with bandwidth of 6.25 KHz. The system uses binary phase modulation technique. From the lower left side can be seen that there is spurious signal spectrum in narrow band, which is generally produced by the design of the circuit itself, and therefore we need to design a small bandwidth filter to ensure filtering out the noise generated by the circuit board. We set a fixed format data information, the lower right corner of window display the character information demodulation. The total codes are 400bit, and the data displayed in lower right side is according with the string we set. It shows that there are no error codes in the signal frequency points.

6. Experiments and Results Discussion

In order to verify the performance of the system, we conducted some outdoor experiments. In this experiment, the beacon was placed on the small flight (UAV) which speed was 50m/s.

Figure 6. Small-unmanned Aerial Vehicles for Test and Beacon Equipment

In the experiment, the beacon was installed on the belly of small UAV, whitting a transmitting antenna together. In order to test the transmission distance, the gain of the whip antenna we used was only 1dB. GPS receiving antenna (25dB) was a microstrip antenna designed at the top of the UAV. UAV flight parameters were listed in the following table.

Table 1. Small UAV Flight Parameters

altitude（m）	3000
Maximum speed（m/s）	50
flight radius（km）	25
flight time（h）	1.8
The maximum flight distance（km）	50

Figure 7. The Ground Receiving Equipment

The ground receiving equipment required the omnidirectional antenna that had strong ability of reception. We put the receiving equipment on the high, open ground in order to receive signal efficiently. The receiving equipment can judge the signal strength by RSSI and direction. The information can be displayed and stored on computer in real-time.

TIME	LATITUDE	N	LONGITUDE	E	ALTITUDE
30 32 33 32 31 32 2E 30 30	33 38 30 30 2E 34 32 30 35 33	4E	31 31 32 32 37 2E 30 34 35 38 32	45	32 38 35 38 2E 35 30
30 32 33 32 31 32 2E 30 30	33 38 30 30 2E 34 31 39 39 36	4E	31 31 32 32 37 2E 30 34 35 38 36	45	32 38 36 30 2E 30 30
30 32 33 32 31 32 2E 30 30	33 38 30 30 2E 34 31 39 36 37	4E	31 31 32 32 37 2E 30 34 35 38 31	45	32 38 35 35 2E 30 30
30 32 33 32 31 32 2E 30 30	33 38 30 30 2E 34 31 39 34 37	4E	31 31 32 32 37 2E 30 34 35 36 33	45	32 38 35 38 2E 30 30
30 32 33 32 31 32 2E 30 30	33 38 30 30 2E 34 31 38 38 39	4E	31 31 32 32 37 2E 30 34 35 32 39	45	32 38 35 39 2E 30 30
30 32 33 32 31 33 2E 30 30	33 38 30 30 2E 34 31 38 35 39	4E	31 31 32 32 37 2E 30 34 35 36 33	45	32 38 35 38 2E 35 30
30 32 33 32 31 33 2E 30 30	33 38 30 30 2E 34 31 38 34 33	4E	31 31 32 32 37 2E 30 34 36 30 36	45	32 38 35 35 2E 30 30
30 32 33 32 31 33 2E 30 30	33 38 30 30 2E 34 31 38 36 39	4E	31 31 32 32 37 2E 30 34 36 36 33	45	32 38 35 30 2E 30 30
30 32 33 32 31 33 2E 30 30	33 38 30 30 2E 34 31 38 33 33	4E	31 31 32 32 37 2E 30 34 36 37 39	45	32 38 35 31 2E 30 30
30 32 33 32 31 33 2E 30 30	33 38 30 30 2E 34 31 38 30 34	4E	31 31 32 32 37 2E 30 34 36 38 39	45	32 38 35 31 2E 35 30
...	ASCII 3 8 0 0 . 4 1 8 0 4		ASCII 1 1 2 2 7 . 0 4 6 8 9		ASCII 2 8 5 1 . 5 0

Figure 8. Received ASCII Codes Image in 0.5s

We analyzed the raw data for transmission firstly. The picture above showed the received information within 0.5s after the UAV took off a certain time. As can be seen from the figure above, latitude, longitude and altitude data in the last three raw were converted into ASCII format, the latitude and longitude of the change within the accuracy of 0.001, changes in altitude within a few meters. Because take-off speed of the aircraft was low, the error of data in any row was much small in the takeoff speed. The positioning data can better meet the requirements.

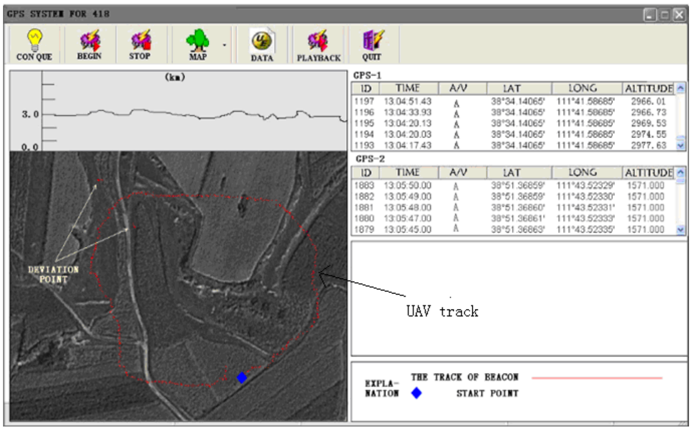

Figure 9. Small UAV Flight Track Image

The left side of the figure above showed the UAV flight trajectory in the projection image of ground, the right side data received by receiver in a certain time, where GPS-1 was a small transmitted UAV signal beacon, and GPS-2 was ground receiving the location information of the device itself. Blue marker was the take-off point in the left figure; the red curve was the projection of the aircraft. Red curve of the figure normally describe the trajectory of the UAV flight, there was no large deviation, but still in some remote point deviations from the navigation, data at some point cannot locate the right location. However, we can describe the trajectory of the flight on whole data analysis and trajectory diagram shows the system as a whole can complete the positioning under the given conditions, which aviation aircraft positioning laid a good foundation. For subsequent development provides a good reference.

7. Conclusion

Aiming at the navigation for high dynamic aircraft and signal transmission, this paper introduces a beacon that can provide an order of better real-time position magnitude accuracy. The system is applied in the search field, it can greatly increase the success rate for the recovery of aviation aircraft and save time to ensure experimental success rate. However, this system still has some problems, such as loss of data during transmission, the trajectory deviation from the normal figure at some point, which we need to do further improved design.

References

[1] Yong-feng Ren, Xiao-hua Liu, Wen-qiang Xu, Wen-dong Zhang. *Multi-Channel Data Compression,* IEEE A&E Systems Magazine. 2008; 9: 14-21.

[2] Haidong Guo. Neural Neural Network Aided Kalman Filtering For Integrated GPS/INS Navigation System. *TELKOMNIKA Indonesian Journal of Electrical Engineering.* 2013; 11(3): 1221 ~ 1226.

[3] Yanran Wang, Hai Zhang, Qifan Zhou Adaptive Integrated Navigation Filtering Based on Accelerometer Calibration. *TELKOMNIKA Indonesian Journal of Electrical Engineering*. 2012; 10(7): 1869~1878.

[4] Alessandro Benini, Adriano Mancini. An IMU/UWB/Vision-based Extended Kalman Filter foe Mini-UAV Localization in Indoor Environment using 802.15.4a Wireless Sensor Network. *J Intell Robot Syst.* 2013; 70: 461-476.

[5] Jan Stepanek MD, David W Claypool MD. GPS signal reception under snow cover: A pilot study establishing the potential usefulness of GPS in avalanche search and rescue operations. *Wilderness and Environmental Medicine*. 1997; 8: 101-104.

[6] Ken Harima, Hirobumi Saiti, Takuji Ebinuma. Navigation message demodulation for GPS receiver on-board spinning rockets, GPS Solut. 2012; 16: 495-505.

[7] Timo Rahkonen, Harri Eksyma, Anttimantyniemi, Heikki Repo. A DDS Synthesizer with Digital Time Domain Interpolator. *Analog Integrated Circuits and Signal Processing*. 2001; 27: 109–116.

[8] Biagio Forte. Optimum detrending of raw GPS data for scintillation measurements at auroral latitudes. *Journal of Atmospheric and Solar-Terrestrial Physics*. 2005; 67: 1100-1109.