Development of GNC System for a Mars Airplane

Hiroshi Tokutake[1)] and Masayuki Kuribara[1)]

[1)] *Faculty of Mechanical Engineering, Kanazawa University, Kanazawa, Japan*

Abstract

Guidance, navigation and control system is essential for the mission successes of a Mars airplane. The airplane dynamics and flight trajectory should be controlled autonomously even in the storm with very light and small avionics system. In addition, the dynamics of the Mars airplane is faster than that of usual spacecraft, because it is affected by the dynamic pressure. This is a challenging problem. We propose the attitude sensing system and positioning system of the Mars airplane, which utilize the visual image and outputs of photodetectors. In this presentation, the attitude sensing system is focused on. In this system, sunlight and thermal radiation from the ground are detected separately using the differences in their wavelengths, and they are provided for the calculation of the airplane attitude. In the present research, basic experiments and the algorithm used to estimate the airplane attitude from the photodetector outputs are described.

火星探査航空機の GNC システム開発

火星探査航空機ではペイロードの制約から非常に軽量で小型の機器しか用いることができない．一方，非常に不確定な環境の中で精密な誘導制御を行う必要がある．また航空機は動圧を利用して飛行するため，通常の宇宙機と比べてダイナミクスの帯域は高い．このような困難な課題を解決するために，火星探査航空機ワーキンググループでは新しい小型軽量の火星探査航空機用姿勢検出システムと位置検出システムの開発を進めている．本発表では，火星探査航空機用 GNC システムの概要と姿勢検出アルゴリズム及び基礎実験結果について紹介する．

1. Introduction

The development of the guidance, navigation, and control systems of a Mars airplane designed for Japanese Mars exploration missions is presented. Autonomous flight under various flight conditions is required for the Mars airplane. Therefore, a robust stabilizing controller using a precise attitude sensor is necessary. We propose an attitude sensing system that detects sunlight and thermal radiation from the ground.

A commercial product for stabilizing model airplanes by detecting thermal radiation from the ground is available[1)]. In this research, the principal used in this commercial product is improved, allowing the attitude of the airplane to be more precisely estimated. A theoretical algorithm for estimating an airplane's attitude from the sensor output is also developed, and a basic experiment of the device is described.

2. Guidance, navigation and control of the Mars airplane[2)]

Because of the strict limitation of its payload, the flight- control system of the Mars airplane should be composed of small and lightweight hardware. However, the natural frequency of the Mars airplane's dynamics is faster than in other spacecraft as the Mars airplane is continuously affected by aerodynamic forces. This means that the precise and faster flight control should be attained through the use of small and lightweight devices. Therefore, in addition to an ADS (Air Data System) and rate gyros, which are used by conventional airplanes, an attitude estimation system using a photodetector is constructed and provided for the stabilizing controller. In the proposed system, several photodetectors are assigned on the airplane's surface (Fig. 1). The direction to the sun and ground from the airplane can be estimated from the sensor outputs. The pitch and roll angles of the airplane can be calculated from the direction to the ground. Also, when the position of the airplane is known, the yaw angle of the airplane can be calculated from the direction to the sun. These results depend on the fact that the direction to the sun and ground can be detected separately.

Table 1 shows the equipment used in the Mars airplane. It is supposed that the airplane position can be estimated from the visual image and landmark database. The positioning system is not discussed in this paper.

Table 1. Equipment used in the Mars airplane

Devices	Detected parameters	Applications
Camera	Position, altitude, and attitude	Guidance and navigation system, backup of the attitude sensor
Photodetector	Attitude	Control system, Inertial measurement unit
ADS (Air Data System)	Angle of attack, side slip angle, airspeed	Control system
Pressure sensor	Altitude	Control system
Rate gyro	Roll, pitch, and yaw rate	Control system, inertial measurement unit
Accelerometer	Acceleration	Inertial measurement unit

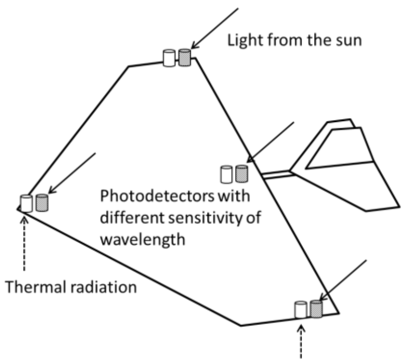

Fig. 1. Attitude sensing system

3. Basic experiment of the attitude sensing system

The ground direction can be detected using the thermopile sensor. The thermopile sensor HTIA-E of HEIMANN Sensor[3] was used. The cut on wave length is 5500 nm and it responses to the thermal radiation from the ground. The responses were measured. A sensor was set at an altitude of 1.2 m from the ground. Next, the direction of the sensor was changed in 10° increments and sensor outputs were recorded (Fig. 2). The experiments were carried out in the daytime and at night. During the daytime, both sun light and thermal radiation are present. The sun's altitude was approximately 10°, and its azimuth angle was approximately 270°. On the contrary, only thermal radiation is present at night. The results of the experiments are shown in Figs. 3 and 4. The output of the thermopile sensor is high when the sensor faces the ground. There is a large difference between the output of the thermopile sensor during the daytime and at night. The output of the thermopile sensor relates with the angle between the sensor and the ground when it faces sky.

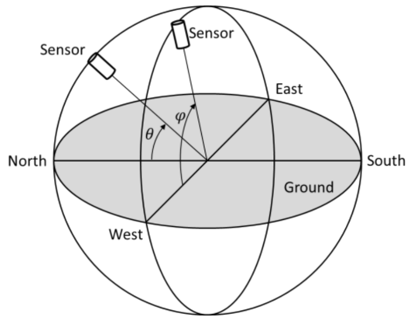

Fig. 2. Sensor direction

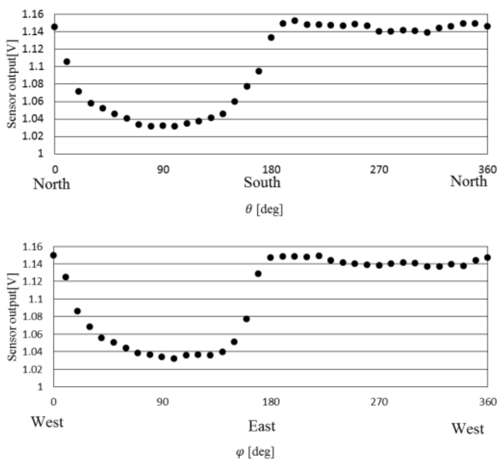

Fig. 3. Experimental results (thermopile sensor, daytime)

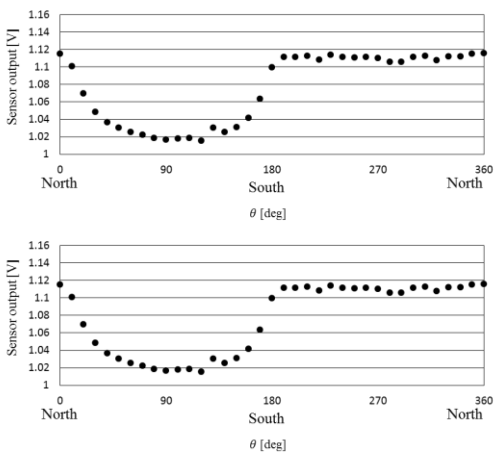

Fig. 4. Experimental results (thermopile sensor, night)

4. Conclusion

The concept of an attitude sensing system constructed from photodetectors was proposed. This system detects the direction to the sun and the ground. The equipped sensors should have different ranges of wavelength, and therefore the light from the sun and thermal radiation from the ground can be detected separately. The basic experiments using the thermopile sensor were performed and it was revealed that the sensor output is sensitive to the angle between the sensor and the ground.

References

1) FMA Direct: Co-Pilot CPD4, http://www.fmadirect.com/.
2) Hiroshi Tokutake and Yasuhiro Yuasa, "Development of the Attitude Sensor for the Mars Airplane," The 28th International Symposium on Space Technology and Science, June 5-12, 2011, Okinawa, Japan.
3) HEIMANN Sensor, http://www.heimannsensor.com.