A-9. Study on Mars Positioning System for Flying Robot of Mars Explorer

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Abstract

Mars is closer than other planets from the earth, and Martian environment is similar to the earth's environment. Moreover, Mars manned project is the center of attention in the near future. In this research, flying robot for Mars explorer is proposed to investigate Mars landform and ice layer without running on the ground across the undulate landform. Furthermore, Mars positioning system by using sun tracking mechanism is proposed to construct the autonomous navigation and control system. In order to verify the validity of Mars positioning system, the simulated experiment on the earth is executed at Maebashi city in Gunma prefecture, Japan.

Key Words: Mars explorer, Flying robot, Mars positioning system, Sun tracking, Detecting landform

火星探査用フライングロボットにおける火星測位システムの検討

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概 要

火星は地球との距離が他惑星と比較して近くその環境も地球と類似しており，また近年，有人化計画の観点からも注目されている．本研究では，火星の地形や大気，氷層調査などの広域に科学調査を遂行することのできる火星探査機の検討を実施するため，回転翼機構を有する火星探査用フライングロボットを提案する．また，火星における自律誘導航法系を構築するため，太陽光捕捉機構を使用した火星測位システムを提案し，地上模擬実験を実施してその有効性について確認を行う．

1. Introduction

Recently, a considerable number of studies on planet researches is conducted actively. Especially, the distance between Mars and Earth is nearer than other planets, and the environment in Mars is similar to one in earth[1].This paper examines that the Mars explorer robot[2] in order to investigate the landform and the ice layer, secure living spaces to conduct manned plan, and procure the resources. On the Mars investigation, since there are a lot of areas which is difficult to move on such as many crater areas and soft sand areas in Mars, it is not convenient to adopt Mars explorer robot for running grand. Therefore, this paper is proposed the flying robot for Mars explorer[3][4] adopted rotor mechanisms. Then, as it is important to obtain the information of its own position in case of the robot investigates on Mars, the authors propose Mars positioning system[5][6][7] which is able to obtain the information of its own position by observing the movement of the sun. Moreover, the authors consider the way to obtain the data of landform while flying by constant altitude in the case of the robot conducts navigation flight. Furthermore, the authors propose the way of detecting landform[8] to fly by constant altitude, and simple experiment for detecting landform is tested. Finally, multiple robot system is proposed to obtain wider data of the landform by one robot cooperates with other robots.

2. Flying robot for Mars explorer

Several studies for Mars have reported that there are a lot of crater, valley, and volcano in Mars. On these landform, to adopt Mars explorer robot for running grand makes the range of investigation narrow. On the other hand, as the atmosphere exists in Mars, fixed wing plane and flying robot is able to fly there. Therefore, the authors propose the flying robot which has four rotor mechanisms in order to explore Mars. Fig.1 illustrates the aspect of the robot. It controls own attitude, moving velocity, and azimuth by controlling the lifting power of four rotors independently. Then, the robot controls its own lifting power by changing of the angular velocities of rotors. The counter torque of it occurred by rotating rotors disappear by making the adjacent rotors reversely, and the body turning for azimuth angle can be prevented. In case of it moves horizontally, it obtains horizontal thrust by leaning the body.

Fig.1 The aspect of the flying Mars explorer robot

3. The Mars positioning system

3.1. Solar orbit plane from observer

The flying robot of Mars explorer is needed ability for flight to various places. For mars explorer, if the robot is controlled remotely by the operation from the earth, the time delay is caused by communication increases. And the robot is not controlled quickly to response any situation. So, the constructing of autonomous technique is essential. In order to move the robot automatically, at first the robot has to find its own position in Mars. GPS is used for the method of finding the position on the earth. On Mars, however, the positioning system such as GPS does not exist. Therefore, the authors propose Mars positioning system that can obtain its own position by analyzing the orbit of the sun.

This positioning system by tracking the sun observes the sun from the observing point, and calculates its own position by regarding the orbit of the sun as a plane. Fig.2 illustrates the relation between the observer and the solar orbit plane. About the potential information, the latitude is calculated by the angle between the solar orbit plane and the vertical plane to the ground, and the longitude is calculated by dividing the difference of the southern time between the standard point and the observing point by the time the Mars turns on its axis only one degree. Moreover, the azimuth is obtained by the direction of the solar orbit plane.

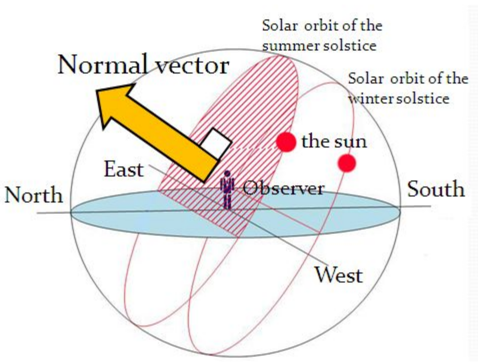
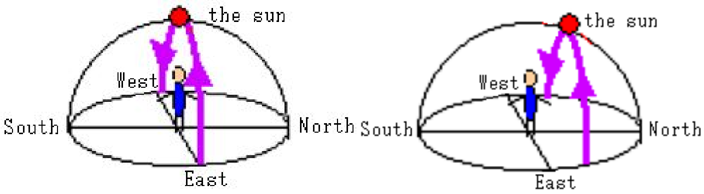


Fig.2 Observer and solar orbit plane

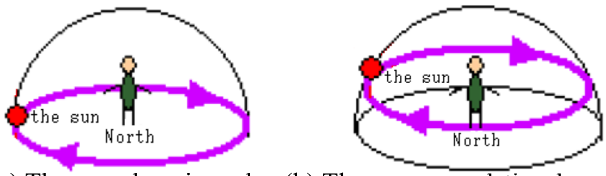
3.2. The relation between the Solar orbit plane and the latitude

In this section, the authors explain about the relation between the solar orbit plane and the latitude more specifically. Fig.3 and Fig.4 illustrates the differences of the solar orbit in the cases of the vernal equinox day and the summer solstice day at an equatorial point and the North Pole. Fig.3 and Fig.4 show that the inclination of the solar orbit plane does not change on the seasons. On the other hand, the angle between the solar orbit plane at an equatorial point and the vertical plane to the ground is zero degree, and it accords with an equatorial latitude. Moreover, the angle between the solar orbit plane at the North Pole and the vertical plane to the ground is ninety degrees, and it accords with the latitude at the North Pole. Therefore, this method is able to calculate the latitude by the inclination of the solar latitude at the North Pole. Therefore, this method is able to calculate the latitude by the inclination of the solar orbit plane. Consequently, the latitude is calculated by the angle between the solar orbit plane and the vertical plane to the ground.



(a) The vernal equinox day (b) The summer solstice day

Fig.3 The solar orbit at an equatorial point[9]



(a) The vernal equinox day (b) The summer solstice day

Fig.4 The solar orbit at the North Pole[9]

3.3. The calculating method of the longitude and the direction

In this section, the authors explain the specific calculating method of the longitude and the direction. Fig.5 illustrates the three-dimensional coordinate which indicate the view of the method. The process of calculating them as follows:

(a) Acquire some data of the solar azimuth φ from the standard direction decided optionally, the angle α between the sun and z-axis, and the time t.

(b) Using the azimuth φ, the angle α between the sun and z-axis, and equation (1), transform the coordinate f(φ, α) into f(x, y, z).

$$\begin{cases} x = sin\alpha cos\varphi \\ y = sin\alpha sin\varphi \\ z = cos\alpha \end{cases} \tag{1}$$

(c) Considering the inclination of the body on x-y plane in each times, transform the coordinate into three-dimensional coordinate f(x', y', z') around x-axis and y-axis by using equation (2) and shown in Fig.5. Consequently, the solar orbit plane is made by connecting these coordinates in line.

$$\begin{bmatrix} x' \\ y' \\ z' \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & cos\theta_x & sin\theta_x \\ 0 & sin\theta_x & cos\theta_x \end{bmatrix} \begin{bmatrix} cos\theta_y & 0 & sin\theta_y \\ 0 & 1 & 0 \\ -sin\theta_y & 0 & cos\theta_y \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix} \tag{2}$$

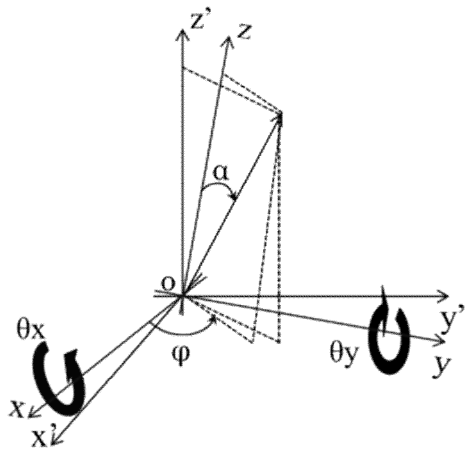


Fig.5 The three-dimensional coordinate

The latitude is the same as the angle between the solar orbit plane and the vertical plane to the ground, as stated above. So, the coordinate f(x', y', z') into f(x'', y'', z'') around y'-axis and z'-axis are transformed by using equation (3).

$$\begin{bmatrix} x'' \\ y'' \\ z'' \end{bmatrix} = \begin{bmatrix} \cos\varphi' & -\sin\varphi' & 0 \\ \sin\varphi' & \cos\varphi' & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos\alpha' & 0 & \sin\alpha' \\ 0 & 1 & 0 \\ -\sin\alpha' & 0 & \cos\alpha' \end{bmatrix} \begin{bmatrix} x' \\ y' \\ z' \end{bmatrix}$$

$$= \begin{bmatrix} \cos\varphi'\cos\alpha' x' - \sin\varphi' y' + \cos\varphi'\sin\alpha' z' \\ \sin\varphi'\cos\alpha' x' + \cos\varphi' y' + \sin\varphi'\sin\alpha' z' \\ \sin\alpha' x' + \cos\alpha' z' \end{bmatrix} \quad (3)$$

Then, calculating the angle α' the solar orbit plane accords with y''-z'' plane and the deviation on season H, the latitude is obtained. In this case, α'indicates the latitude and φ' indicates the angle from south into the observing standard direction. Fig.6 illustrates the solar orbit plane in the three-dimensional coordinate.

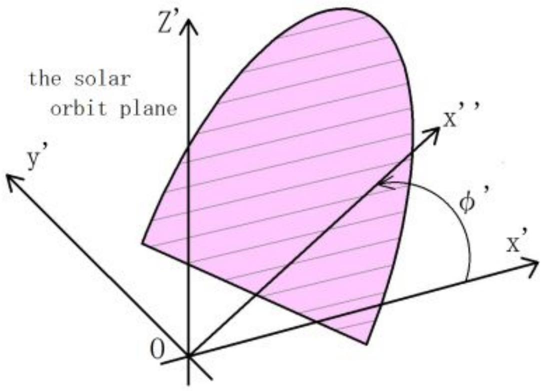


Fig.6 The solar orbit plane in the three-dimensional coordinate system

The specific calculating process as follows:

(a)Using unknown quantity α', φ' and equation (3), transform the coordinate f(x', y' z') into f(x'', y'', z'') around y'-axis and z'-axis.

(b) Using least-squares method, calculate α', φ'and H that satisfies equation (4) in order to makes all x-element zero on each times. Fig.7 illustrates the latitude α' and the deviation on season H.

$$\cos\varphi'\cos\alpha' x' - \sin\varphi' y' + \cos\varphi'\sin\alpha' z' - H = 0 \quad (4)$$

Accordingly, the latitude and the quarters can be calculated from the observing standard direction.

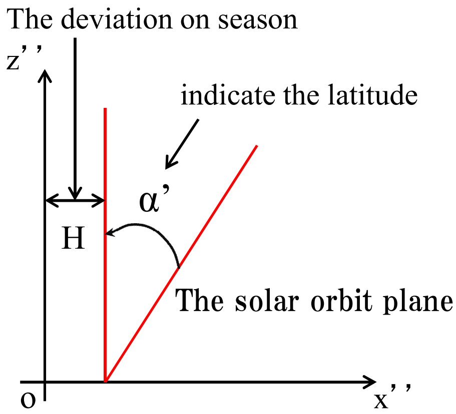


Fig.7 The latitude α' and the deviation on season H

3.4.The calculating method of the longitude

In this section, the authors explain the specific calculating method of the longitude. The process of calculating them as follows:

(a) Determining the prime meridian on Mars, decide the standard point in the line. Then, make the clock which is converted the rotation period of Mars into twenty four hours, and provide that the time that the sun is highest in every hour at the standard point is southern time (12:00).

(b) Calculate the time the elevation is the highest value by using the data of the solar elevation at the observing point. The time is the southern time at the observing point.

(c) Calculating the difference of the southern time between two points, determine the difference of the longitude by dividing the time Mars turns on its axis only one degree (about 4.10995 minutes) into the value.

(d) Calculate the longitude at the observing point by adding the difference of the longitude to the longitude at the standard point. In this case, for the standard point is decided as the prime meridian, the difference of the longitude that is calculated in (c) indicates the longitude at the observing point itself.

For the processes mentioned above, we can acquire the information of position concerning the longitude at the observing point.

3.5.The algorithm of the calculation of Mars positioning system

Fig.8 illustrates the block diagram of Mars positioning system. The necessary input in order to obtain thepotential information is five: the azimuth of the sun φ[deg], elevati--on α[deg], the time of measurement T[hour], the latitude angle θ_x[deg], θ_y[deg]

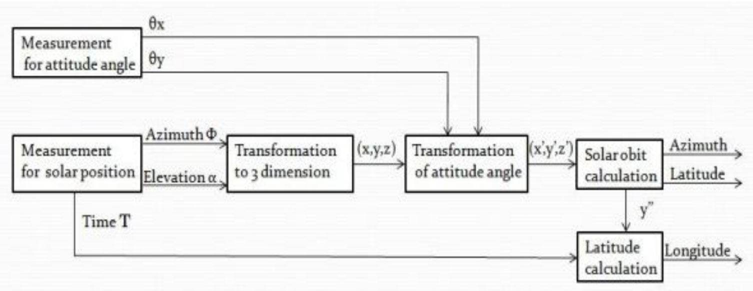


Fig.8 The block diagram of Mars positioning system

The flow of determining its own position as follows:

(a) Convert the solar position into the three-dementional data f(x, y, z) by using the azimuth φ and the elevation α.

(b) Transform the coordinate into f(x', y', z') by considering the body's latitude angle $\theta_x$and θ_y.

(c) Calculating the solar orbit plane based on the data mentioned above, determine the azimuth and the latitude.

(d) Calculate the longitude by using the time T and y'' which is obtained from the solar orbit plane.

4. Positioning experiment on earth

4.1. The alternative experiment of Solar tracking on the earth

In order to confirm the validity of the theory mentioned above, we conduct the simple and alternative experiment on the earth. At first, we explain the relation between the experiment on the earth and the practicability on Mars. About the latitude and the azimuth, for the principle that calculates the solar orbit plane do not change, we can regard the experiment on the earth as on Mars. About the longitude, we can experiment by choosing 135° E longitude as the standard point, and using the time in Japan as the standard time. Therefore, it is quite likely that the authors can con--firm the validity of Mars positioning system by the alternative experiment on the earth.

4.2. A Solar tracking experiment used a camera

Fig.9 illustrates the solar tracking device which is used for solar tracking.

Two servo motors is connected to cross by the joint ball, and the camera which is put in the shade plane is fixed on the top of the serve motor which turns vertical direction. Then, this device equips a program of binarization which indicates the sun that the camera recognizes as white and another light as black. That is to say, the device recognizes the sun as a white circle with accuracy, and moves these servo motors in order to accord the center of this mask image (an image which is binarized) with the center of the circle. Moreover, the authors obtain the data of the elevation and the azimuth of the sun by reading the current angles of two servo motors on optional times. Table 1 presents the condition of the experiment. The measure time is two hours from 11:00 to 13:00, and the measure interval is five minutes.

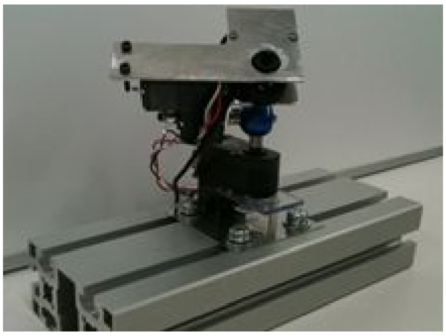


Fig.9 The solar tracking device

Table 1 The condition of the experiment

Observation place	Maebashi city in Gunma Pre.	
	36° 22'N	139° 01'E
Observation day	2011/11/16, 11:00∼13:00	
	(Japan standard time)	
Measurement interval	5 [minutes]	
Angle of inclination	θx: -0.1[deg]	
	θy: 1.0[deg]	

4.3.The result of the experiment

Fig.10 illustrates the data of the elevation and azimuth of the sun, and table 2 presents the analysis results of the information of position by using these data. Table 2 shows that the information of position has been obtained compared with the nominal data. Therefore, the authors

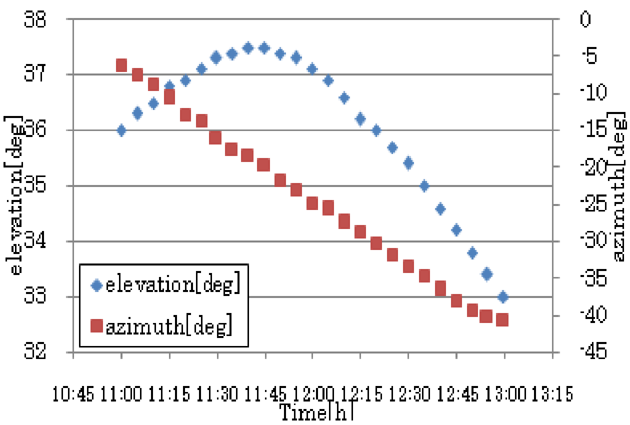


Fig.10 The data of elevation and azimuth

could confirm the validity of Mars positioning system by this experiment.

Table 2 The analysis results

	Nominal	Analysis results
Latitude	36° 22'N	34° 31'N
Longitude	139° 01'E	138° 45'E
Direction	-	19° 24'(from South to West)

5. An execution of detecting landform

5.1.Flying of constant altitude

The flying robot needs to avoid a collision and measure the data of landform accurately. Therefore, we propose the way which the robot flies with constant altitude. Fig.11 illustrates the situation. The following is the means of flying with constant altitude:

(a) Grasp the forward landform by using a sensor of measuring the distance.

(b) Design the robot's flying orbit in order to fly with constant altitude by using the data of (a).

(c) Control the angular velocities of four lifting power system in order to fly along designed orbit

The robot flies by repeating the process mentioned above. Moreover, the authors are able to obtain the three dimensional data of the landform which the robot passes by the landform data obtained by conducting (a).

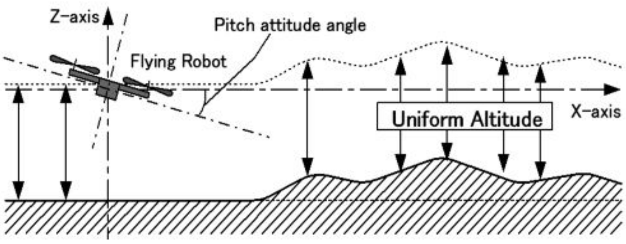


Fig.11 Constant altitude flying

5.2.An execution of detecting landform

The authors explain an execution of detecting landform in case of the robot flies with constant altitude. Fig.12 illustrates the situation in case of it obtains the data of landform. The sensor which measures the distance is placed in the body of the flying robot on the condition that it is inclined the constant angle in order to grasp the landform of the line. In case of detecting the landform, we obtain the landform data of the line by changing the distance and the latitude angle which measured by using the sensor of measuring distance into coordinate data by using the following equations:

$$X_l = x_b + r_{15} \cdot \cos(\theta + 15°) \quad (5)$$

$$z_l = z_b - r_{15} \cdot \sin(\theta + 15°) \quad (6)$$

x_l: x axis coordinate data of landform [m]

z_l: z axis coordinate data of landform [m]

x_b: x axis coordinate data of the robot [m]

z_b: z axis coordinate data of the robot [m]

r_{15}: a distance data of a sensor of distance [m]

θ: an attitude angle of the robot [deg]

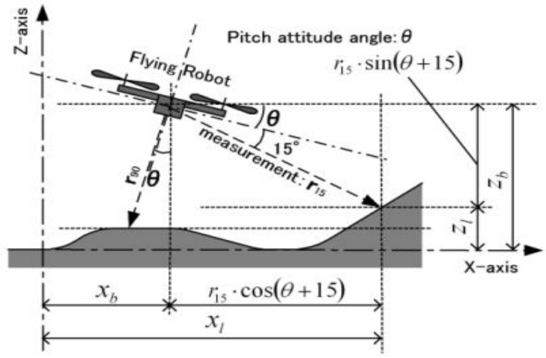


Fig.12 Landform detection

5.3. An Experiment of Detecting Landform

The authors conduct an experiment of detecting landform in order to confirm the validity of an execution of detecting landform. Fig.13 illustrates the aspect of the experiment device. The authors place an infrared sensor slanted 30 degree below an axis active device which moves only the direction of pitch angle, and place an imaginary landform at the bottom of the device. Next, the way of the experiment is explained. At first, the active device in the direction of pitch is revolved, and the data of rotation angle and the distance data of sensor r are captured to the PC. Furthermore, the data of x, y coordinates of the landform are obtained by using equation (5) and (6).

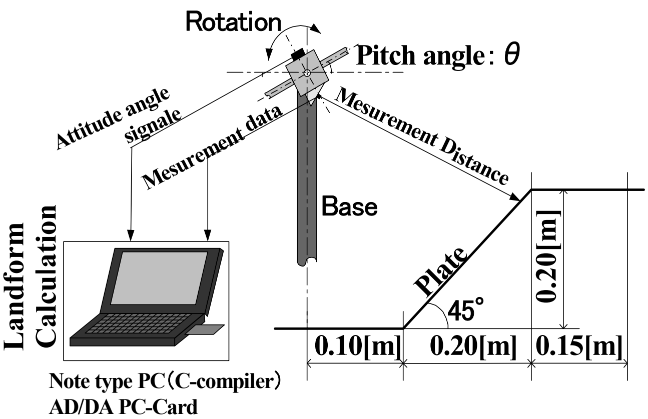


Fig.13 The experiment device of landform detection

Fig.14 illustrates the result of the experiment. The result indicates the landform data copies the nominal landform successfully. And the validity of an execution of detecting landform could be confirmed by this experiment.

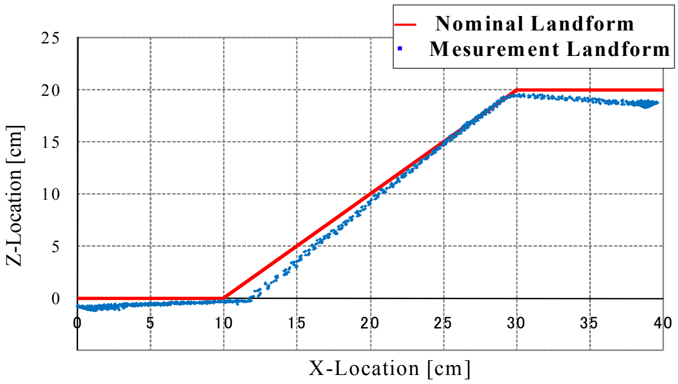


Fig.14 The result of landform detection

6. A Concept of mars explore by using multiple robots

On Mars investigation, compared with the simple robot, plural robots can obtain wider data of the landform by building a multiple robot system that one robot cooperates with other robots. Fig.15 illustrates the aspect of the multiple robot system. The authors consider the system under the following topics: leading robot and following robot.

At first, concerning the leading robot, the authors arrange the robot that acquires the sunlight from a fixed point land at an optional place, and define a meridian at the position as the prime meridian on Mars. The robot not only sends the data of its own position to the following robots but charges a battery by using sunlight, and supplies it to the following robots. On the other hand, the following robot investigates in a group. A following robot that is closest to the leading robot is regarded as a sub-leading robot, then the sub-leading robot receives the data of the following robots' position and sends them to the leading robot. Moreover, sub-leading robot periodically receives the data of the leading robot's position, and corrects the error of the data of its and the others' own position.

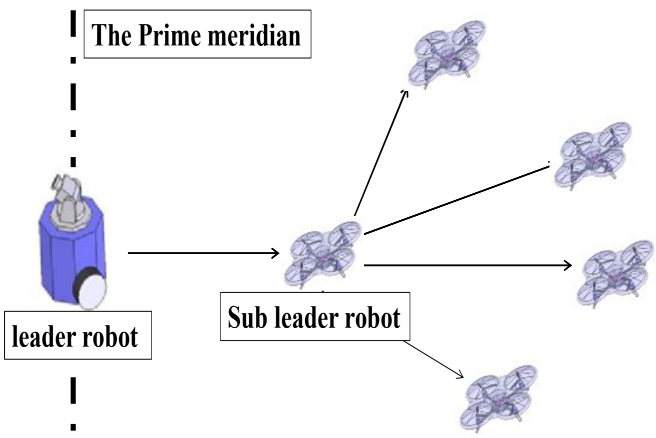


Fig.15 the aspect of the multiple robot system

7. Conclusion

The authors proposed the flying robot with quad rotor in order to explore Mars. Then, the authors proposed Mars positioning system which be able to find the robot's own position by tracking sunray, and conducted the alternative experiment by using the solar tracking device in order to confirm the validity of the system on the earth (at Maebashi city in Gunma Pre.). Consequently, this data showed the validity of the system. Moreover, we proposed the execution of detecting landform in the constant level navigation, and confirmed the validity by the simple experiment. A further direction of this study will more accurately measure the solar position by improving the detecting performance of the solar tracking device, become to be able to analyze the information of position in the middle of investigation, and materialize the idea of Mars explore by using multiple robots more deeply.

References

[1] Mars Fact sheet, http://nssdc.gsfc.nasa.gov/planetary/factsheet/marsfact.html

[2] H.Tajima, S.Sunada, H.Tokutake : Flight Stability ofan Airplane on Mars,53rd Space Sciences and Technology Conference,pp.405-408,2009

[3] Y.Kurosawa, N.Hirakoso, Y.Yuguchi : Study of Flying Robot for Mars Explorer with Rotors Mechanism, 20th on Astrodynamics and Flight Mechanics, pp.249-254, 2010

[4] N.Tsuzuki, S.Sato, T.Abe : Feasibility Study for a Small Mars Exploration Rotorcraft,14th Workshop on Astrodynamics and Flight Mechanics, A Collection of Technical Papers,pp.127-133,2004

[5] A.Tsuchiya, Y.Kuroda, T.Kubota, T.Yoshimitsu : A Method to Estimate Position and Orientation for Lunar Rover, The Japan Society of Mechanical Engineers, 2000

[6]Y.Kurosawa, N.Hirakoso : Study of Mars Positioning System by Using Sun Tracking for Autonomous Mars Explorer Flying Robot, 54th Space Science and Technology Conference, 2010

[7] N.Hirakoso, S.Matunaga, Y.Ohkami : Antenna Pointing Control for Satellite Tracking Systems with Perturbations,JSME,67-654C(2001-2), pp.377-384

[8] N.Hirakoso, K.Tomioka, T.Ishizaka : Study of Landform Scanning and Navigation Method for Constant using Autonomous Flying Robot, 27thNavigation and Control Symposium, 2010

[9] The Sun among Many parts of the Country http://www.max.hi-ho.ne.jp/lylle/taiyo4.html