A Study of Attitude Control Problem for Floating Robot
〜 An Initial Investigation of Hopping Robot
for Small Celestial Body Exploration 〜
浮遊状態のロボットの姿勢制御
〜 跳躍により移動する小天体探査ロボットに関する初期検討 〜

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Abstract

This paper present general outline about the system and control policy of new move method
robot for small celestial body exploration. Under low gravity environment, hopping motion is
supposed to have advantages over the other means of locomotion. This idea is also adapted for
"MINERVA", which is mounted on space probe Hayabusa. This robot is characterized by the
hopping motion and the attitude control method in air utilizing its legs. Since all of the necessary
performance are achieved by utilizing the same actuators, the system can be kept simple.

本稿では、新方式による小天体向けの探査ロボットについてその構成と制御手法の概要について述べ
ている。重力の小さい小天体上では、跳ねながらの移動が他の移動手段に比べて有利であると考えら
れ、その思想は探査機はやぶさに搭載された"ミネルヴァ"にも反映されている。本方式の特徴は天体
上を跳躍によって移動する点で、深空時に脚を用いた空中動作を行い、姿勢を制御する点にある。すべ
ての動作を同一のアクチュエータで行うことにより未知の環境において所望の位置へ移動するという
要求を満たしながらシステムをシンプルに保つことができる。

1 Introduction

Robot’s means of locomotion are selected to suit the objectives and environment. Up to the present
time lots of rovers which move by walk, wheels or pedrail have been developed for celestial body
research. However, if the robot is made aiming for "small" celestial body research, these meth-
ods are not necessary suitable. Under low gravity environment the friction force, which is pro-
portional to normal component of reaction, is so weak that friction dependent way like wheel is
not realistic. In addition, force of attitude resti-
tution is also weak, the way of locomotion with continuous contact including walk can not go on
smoothly. On the other hand, hopping motion generate momentarily-strong normal force which
result in generating big friction, hence hopping
robot can efficiently move in the low gravity envi-
ronment.

Therefore in this study, the author propose a
hopping robot with legs. This robot is characte-
rized by the attitude control method in air utilizing
its legs. Since all of the necessary performance are
achieved without other unnecessary actuators, the
system can be break-proof and compact.

2 System

The proposed robot consist of a main body and
three 2-link legs. In the column-shaped main
body, camera and all sorts of sensors are installed.
Each leg is attached to the main body in a radial
fashion. The joints connecting the body to the
legs have 2 degrees of rotational freedom, likewise
the knee joints have 1 degree of rotational free-
dom. The total mass is assumed to be about 4kg. The radius of the body is 150 mm. The length of legs is about 220 mm.

3 Control Method

Hopping motion is divided into 2 phases - "ground phase" and "aerial phase". Ground phase is divided further into "landing phase" and "takeoff phase". In addition to these phases, there exist recovery (from turnover) phase.

- Aerial phase
- Ground phase
  - Landing phase
  - Takeoff phase
- Recovery phase

As far as ground phase and aerial phase, following control method is employed.

Aerial phase As the situation demands, control method is adjusted. Under normal condition, active control is employed. Active control means that the attitude is controlled via aerial bodily motion. There no need to use any other attitude control devices. To be more precise, the principle of "cat-twist motion" is applied.

On the other hand, if the rate of rotation is too big to control by active control, passive control is employed. In the passive control rotational speed is controlled via controlling moment of inertia with expanding or contracting its legs.

Landing phase During the landing phase, it is important to soften dropping impact so as not to bounce back and to fall down. To achieve this objective compliance control is employed. To keep the control gain low means to make leg trajectory indistinct and it result in not only soften the impact, but get robust against irregular ground.

Takeoff phase Regardless of the ground irregularity, the robot have to hop not to begin to rotate. The trajectories of tip of legs is designed according to the initial posture, then the command joint angle is determined via inverse kinematics.

4 Conclusion

In this paper, some idea for new method robot for small celestial body exploration are proposed. In the aerial phase, by cleverly manipulating its legs, the attitude is controlled actively, or passively. The author will continuously investigate to demonstrate the feasibility of this system, and consider more suitable control method.

References

[1] A Study of Attitude Control of Nonholonomic Twist Motion, Koki Minamikawa. IAC-04-W.1.01.
