The Jumping Tortoise: A Robot Design for Locomotion on Micro Gravity Surface

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Abstract

This paper propose a novel design for a possible micro robot for exploration of a small object such as an asteroid. Micro robots are discussed and developed for the MUSES-C asteroid mission in JPL as Nano Rover and ISAS as Minerva. Both designs are nice and interesting, however we propose an alternative smart design. The proposed design uses four sets of 1-DOF legs to hit and jump like an flea and a specially designed neck to turn over like a tortoise. The design is promising for limited weight and power budget and the motion performance is evaluated by computer simulations with a proper dynamic model.

1 Introduction

This paper propose a novel design for a possible micro robot for exploration of a small object such as an asteroid. Micro robots are discussed and developed for the MUSES-C asteroid mission in JPL as Nano Rover and ISAS as Minerva. Both designs are nice and interesting, however we propose an alternative smart design.

A schematic illustration of the NANO Rover is depicted in Figure 1 (a). Nano Rover uses wheel system mounted on a swingable leg. However a wheel may not work on the micro-gravity surface. The traction force of wheel T is given by $T = \mu N$ where μ is friction coefficient and N is the normal force, which is usually equal to mg on Earth but here g is almost zero.

A schematic illustration of Minerva is depicted in Figure 1 (b). Minerva uses reaction torque generated by a reaction wheel inside the body to trun over the surface. If the body is sphere it may not move. High friction with the surface is essential for it to move. And it may be difficult for miniaturization because the reaction torque is inertia dependent and if the length becomes one-tenth the inertia becomes one-thousandth.

Here, we propose an alternative smart design that will not meet the above problems, and be promising for limited weight and power budget, The motion performance is evaluated by computer simulations with a proper dynamic model.

2 Robot Design

As the design criteria, we assume the followings: the dimension is almost 0.1 meter cube or less, weight less than 0.5 [kg], the gravity $g = 0.01[m/s^2]$. Those criteria are the same as the NANO Rover and Minerva.

The propose design of our rover, the Jumping Tortoise, is depicted in Figure 2. The design uses four sets of 1-DOF legs to hit and jump like an flea and a specially designed neck to turn over like a tortoise. A comb on the neck works as an anntenna, and the neck motion provides a camera-pan function as well in upright position.

By controlling the phase and torque of four legs, the direction of the jump and the orientation of the rover may be controlled. A visual camera is considered a primary mission, but other sensors can be monted if they are small and light enough.

The specification and weight budget are listed in Table 1 and 2. Expected motion of the robot are depicted in Figures 3 and 4.

3 Leg Mechanics

The leg mechanics is depicted in Figure 5.

Let us denote mass by m, length of the leg L, and the gravity acceleration on the surface g. When torque τ is applied to turn the leg, the force to put the ground F is expressed by

$$F = \tau / L.$$

The normal force of the contact point N is summa-

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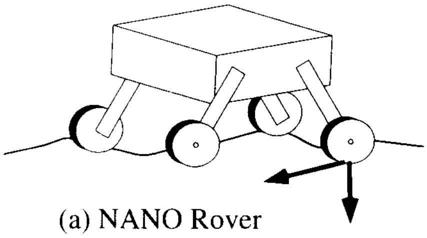
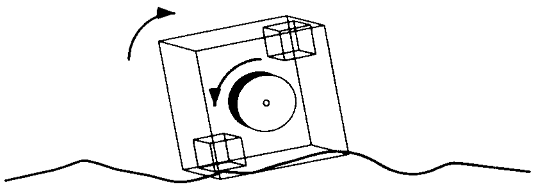


(a) NANO Rover



(b) Minerva

Figure 1: Different designs of rovers for MUSES-C asteroid mission

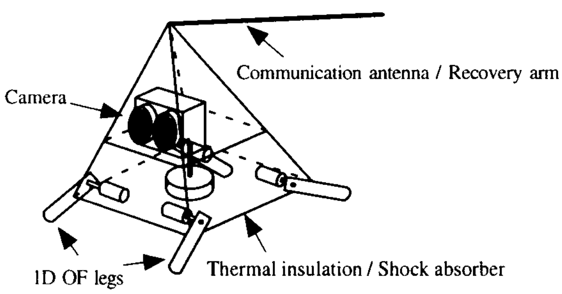


Figure 2: Proposing Robot Design

tion of mg and the vertical component of F.

$$N = mg + F\cos\theta$$

The thrust force in the horizontal direction T is generated by

$$T = F\sin\theta$$

when no slip, or

$$T = \mu(mg + F\cos\theta)$$

when the Coulomb's friction model is effective.

The above equation suggests that the trust force T is not zero even if the gravity is completely zero.

4 Friction Mechanics

Let us model the ground by a visco-elastic material with the stiffness K_w and the dumping D_w. The contact point is represented by (x, y, z), where z is normal to the surface and x and y are tangent of

Tabel 1:Rover Specification

dimension	120[mm]×120[mm]×90[mm]
mass	533[g]
power generation	solar cells (effective 324[cm^2])
power consumption	max. 2880[mW]

Table 2: Weight Budget

group	part	mass [g]
structure	panels and frames	158
	legs	4
	motors · gears	49
	encoders	25
	motor control circuits	50
control	computer and controllers	60
	Sun sensor	10
	wire harness	35
power	solar cells	20
	control unit	10
communication	transmitter/reciver	50
	anntena	1
mission	camera	30
	G sensor	30
total		533

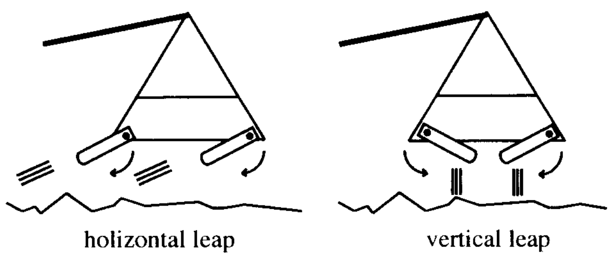


Figure 3: Jumping motion

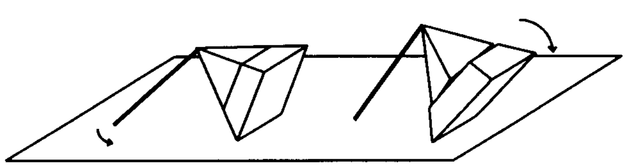


Figure 4: Turn-over motion

surface, perpendicular each others. The forces given from the ground are expressed as follows:

$$\begin{aligned} F_z &= \begin{cases} -K_w z - D_w \dot{z} & (\dot{z} < 0) \\ -K_w z & (\dot{z} \geq 0) \end{cases} \\ F_x &= -\mathrm{sign}(\dot{x})\mu F_z \\ F_y &= -\mathrm{sign}(\dot{y})\mu F_z \end{aligned}$$

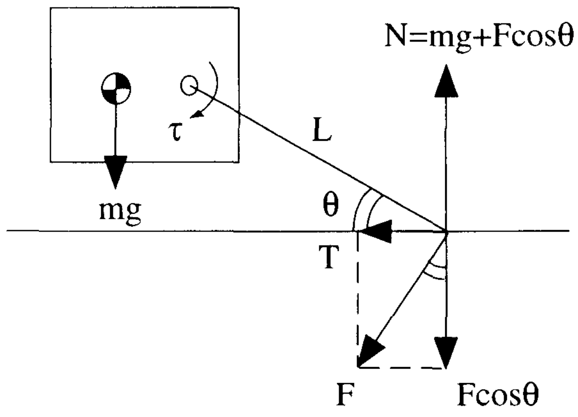


Figure 5: Leg Mechanics

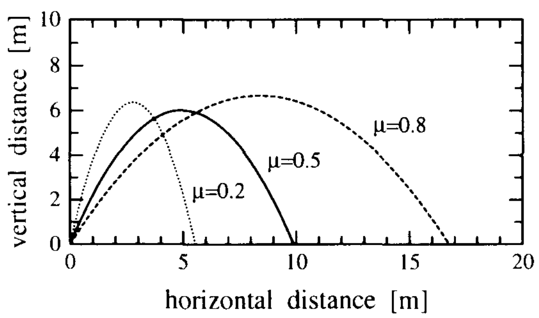


Figure 6: Jumping Trajectories

where the direction of the friction forces F_x, F_y faces to reduce the tangent velocity of the colliding part. A numerical computation algorithm is developed to avoid an energy gain due to improper modeling of friction.

5 Dynamic Simulation

Dynamic simulations are carried out with the above models of the leg mechanics and the friction mechanics. The motion trajectories of the jumping motion under $g = 0.01 m/s^2$, with different friction coefficients, are depicted in Figure 6.

6 Conclusions

In this paper, we propose a possibel design of a micro rover for an asteroid mission, particulary looking at the MUSES-C mission. The design is simple and promising. The weight and power budget are estimated. The motion performance is evaluated by computer simulations with a proper dynamic model.

We are looking for research collaborators and industrial sponsor who are attracted by the proposed design, and also an alternative launch oppotunities for asteroid or comet exploration, in which the proposed tortoise performs a giant leap.