3D Posture Control by Using the Cat-turn Motion

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Abstract

In our previous paper, we made clear the principle of the cat-turning motion and realized the cat-turning by a robot. The robot can control three dimensional (3D) posture using cat-turning motion. It utilizes double cat-turning motion in order to conduct 3D posture change. This paper describes the principle of 3D posture control using double cat-turning motion and simulation result.

1. Introduction

Recently, many researches and developments of the space structure have been carrying out. Especially, its posture control is regarded as one of most important topics. However, in order to control the posture of space structure in the space, most of them need a lot of energy, such as the solid fuel, the nuclear fuel, the solar sell and so on. We consider that an innovative posture control with little energy will be required to create a new space generation in 21st century.
In this study, we conduct the development of a 3 dimensional (3D) cat-turning robot, which can control its posture by using its own internal power. When a cat falls upside down in the air, it turns its own body and makes a perfect landing. We apply such a cat-turning motion to the posture control of space structure without a lot of energy.
Firstly, we propose the 3D posture conversion method using the cat-turn motion in this paper. Secondly, the mechanism of the developed 3D cat-turning robot and the methodology of its posture control are described. Finally, by simulation and experimental results, it is shown that the proposed posture control method is very useful.

2. The Cat-Turn Motion

We made clear the principle of cat-turn motion. When a cat falls upside down in the air, as shown in Fig 1. When a cat starts to fall, its initial angular momentum is zero. (2) A cat bends over, (3) and twists both of upper and lower bodies around each central pivot. (4) It revolves on an axis, which links two centers of gravity of the upper and lower bodies. (5) Then, it makes a perfect landing from its paws.
This motion is explained by the following equation based on the law of conservation of angular momentum.

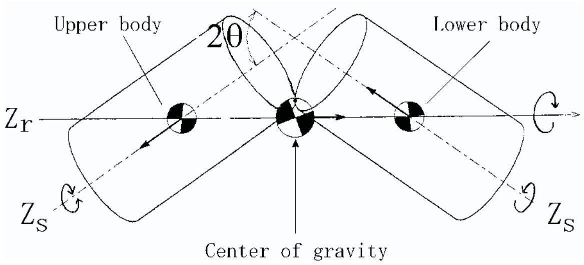

Figure 1: Conceptual image of Cat-Turning motion

$$I_r \cdot \omega_r + I_s \cdot \omega_s \cdot \sin\theta = 0 \qquad (1)$$

I_r, ω_r : Internal moment and angular verocity around the Z_r axis.
I_s, ω_s : Internal moment and angular verocity around the Z_s axis.
θ : The angle across the upper and lower body.

Where, the first term in the left side is an angler momentum around the Z_r axis, and the second term is one around the Z_s axis generated by twisting upper and lower bodies. The right side is constantly zero. This equation shows that the body rotates around the Z_r axis, because removing angler momentum around the Z_s axis generates an angler momentum around the Z_r axis.

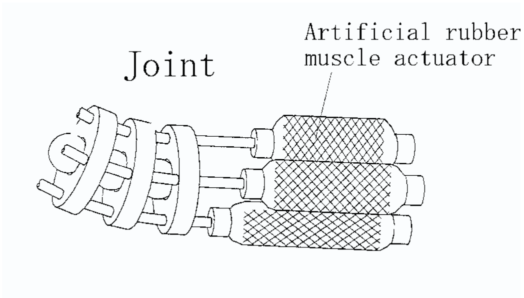

Figure 2: Mechanism of the Cat-Turning robot

3. Development of Cat-Turning Robot

3.1. 2 Dimensional Cat-Turning Robot

In 1991, we conducted the development of a 2 dimensional (2D) cat-turning robot based on cat-turning motion, which was the fastest development in the world.[1][2] This robot has two links, which emulate upper and lower body of a cat. A link consists of four pneumatic actuators, as artificial rubber muscles, which emulate two pairs of antagonist muscles as shown in Fig.2. And a backbone type joint connect two links.
We succeeded to control 2D posture of the developed robot without a lot of energy, based on the principle of cat-turning motion as shown in Eq.(1).

3.2. Development 3D Cat-Turin Robot

In order to realize 3D posture control of the robot, we develop a 3D cat-turning robot as shown in Fig.(3). This robot is achieved by four links, which are basically equipped every 90 degrees on a joint base in the identical 2D plane. Three gyro sensors mounted on a joint base detect three eulerian angles of each links to recognize 3D posture of the robot.
Each of links, which has same mechanism of a link of 2D cat-turning robot, can rotate around a joint base. Then the robot can take two patterns of 2D cat-turning robot as shown in Fig.(4). Therefore, it can revolve around two axes, which lay at right angle each other, and realize 3D rotation in the air. Moreover, the robot needs little energy by using this 3D posture control based on cat-turning motion, because of the law of conservation of angular momentum.

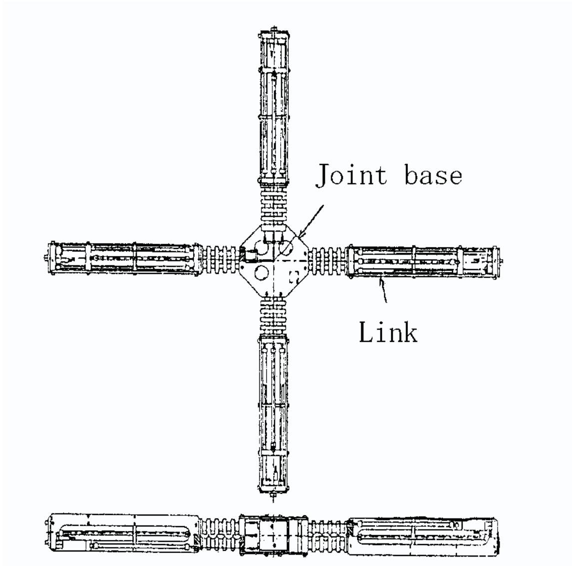

Figure 3: The development 3D Cat-Turning robot

4. Methodology of 3D Posture Control

To control the posture, we have to control the link's angle and the base's three eulerian angles. There are three gyro sensors in one leg, the total sum are twelve in this robot. So we can detect the link's angles in the air, and calculate the base's eulerian angles by measurement of gyro sensors. The joint between base and link, there are four wires connecting the artificial rubber muscle actuators. So the link's angle (θ_r) is controlled by the wire's length (Δl), as shown in Eq.(2).

$$\Delta l = 2r\theta_r \tag{2}$$

Δl : Variation of wire length
r : Wire length between bottom and center of wire
θ_r : Reference angle

And the Δl is controlled by the difference of respective internal pressure of artificial rubber muscle actuators (ΔP), there is the linear relation as shown in Eq.(3).

$$\Delta l = 2rK\Delta P \qquad K : Constant \tag{3}$$

The ΔP is detected by strain type pressure sensors at every sampling time. Therefore, we can control the θ_r by controlling the ΔP as shown in Eq.(4).

$$\theta_r = K\Delta P \tag{4}$$

And we use the 16 bit PC for the controller, and control program is written by C language.

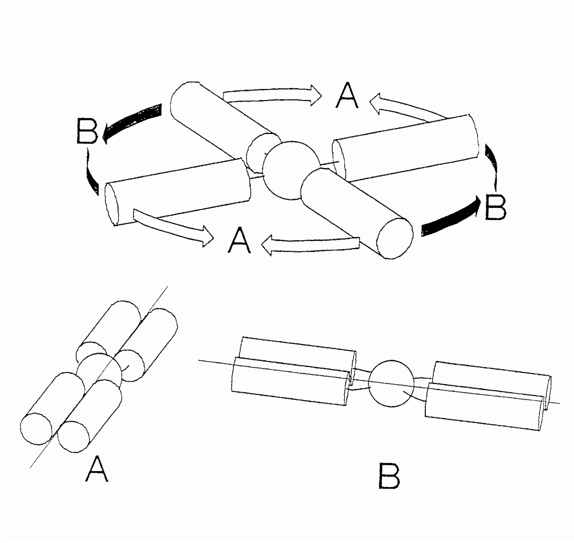

Figure 4: Conceptual image of 3D Cat-Turning robot

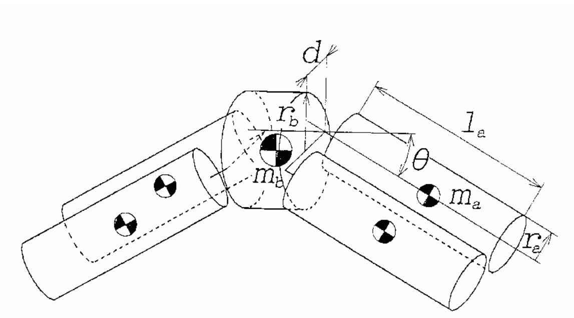

Figure 5: 3D Cat-turning model

5. Computer Simulation

To evaluate the characteristic motion, we make the simulation for that robot model, as shown in Fig.(5).

We enable to check the cat-turning motion and evaluate the effect of the system parameter for the simulation. To assess the cat-turning motion, we define the rate TR (Turning Rate) for the cat-turning motion shown in Eq.(5).

$$TR = 1 - \frac{2I_{ax}cos\theta + I_{bx} + 4m_a d^2}{4I_{ax}cos^2\theta + 4I_{ay}sin^2\theta + I_{bx} + \frac{4m_a m_b}{4m_a + m_b}L^2 + 4m_a d^2}$$
$$L = r_a(1 - cos\theta) + \frac{l_a}{2}sin\theta \quad (5)$$

I_{ax} : Internal moment around the center of link.
I_{ay} : Internal moment around the axis vertical of the center of link.
I_{bx} : Internal moment around the center of joint.
m_a : mass of a link. m_b : mass of a joint bace.
d : radius of joint bace.
r_a : radius of link. l_a : length of link.

For this simulation, we check the cat-turning motion. Fig.(6) is 3D stereo-pair of the motion. And we confirm the effect of parameters, TR is gradually much big in those conditions,

- Less small the radius of body m_b (shown in Fig.(5)).
- Less short between the gravitational point of body and the central pivot of the leg d.
- Much long the length of leg l_a.
- Much big the angle across the body and leg *theta*.

And the TR is about 0.23 in our developed robot.

6. Experimental Results

The experiment by a robot requires recreation of zero gravity condition in the robot. To substitute that condition, we need to provide the holonomic constrains force, which magnitude is equal but direction is opposite to the gravitation. Given that constrains force, the robot needs to fall down or be push up by the air. But for that experiment needs very big devices, and it is very difficult to gain the reproducibility. So we didn't experiment in that condition.
In our experiment, we hang up the robot by wire at the gravity center of body. Because we can check controllability of the motion in this position. In this experiment, we confirm that developed robot is enables to moving the legs along a two axes. Performing final time is about one second. In Fig.(7),(8), θ ϕ are body's eulerian angles measured by gyro sensors. Because of the constraints from the wire, it cannot change the body posture perfectly to cat-turning motion, we confirm to realize its motion.

7. Conclusion

We reach these conclusions for this report.

- The cat-turning motion is very effective to control the posture by using only internal power, in not only 2-dimensions but also 3-dimensions.
- It is possible in 3-dimensions to exchange one mechanism and axis using cat-turning motion, and it is very effective because the mechanism is much simple than having two axes.
- The joint modeled vertebrate's backbone is very effective by cat-turning motion. And it enables to exchange the axis for same mechanism, it is much simple than having two axes.

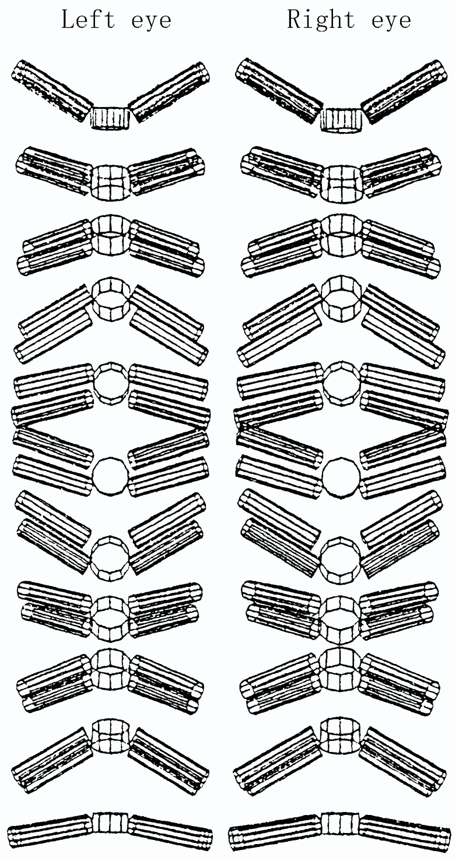

Figure 6: The results of simulation (3D stereo-pair)

- Using three gyro censers, easily we can detect the 3-dimension posture.

This study, we develop the 3 dimensional cat-turning robot which can control its posture by using its own internal power in the zero gravity. Next study, we evolve this motion, and interlace other motion and mechanism. And we hope to develop much effective mechanism which can control its posture in the any 3 dimensional situations.

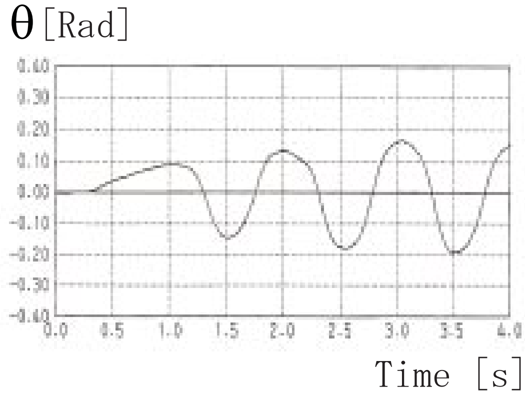

Figure 7: Experimental results of cat-turning motion θ

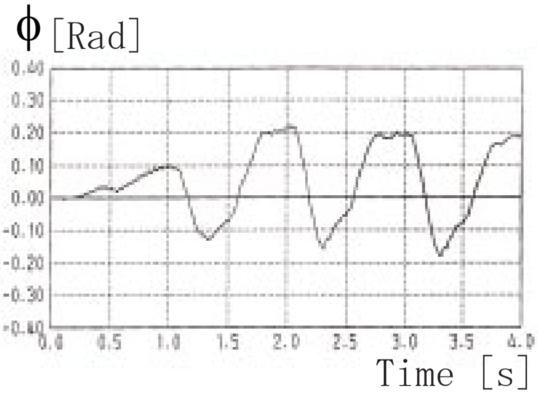

Figure 8: Experimental results of cat-turning motion ϕ

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