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Aye-aye's middle finger kinematic modeling during tap-scanning

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ABSTRACT

The aye-aye (Daubentonia madagascariensis) is a nocturnal lemur native to the island of Madagascar with a special thin middle finger. The aye-aye's third digit (the slenderest one) has a remarkably specific adaptation, allowing it to perform tap-scanning (Finger tapping) to locate small cavities beneath tree bark and extract wood-boring larvae from it. This finger, as an exceptional active acoustic actuator, makes an aye-aye's biological system an attractive model for Nondestructive Evaluation (NDE) methods and robotic systems. Despite the important aspects of the topic in engineering sensory and NDE, little is known about the mechanism and movement of this unique finger. In this paper a simplified kinematic model was proposed to simulate the aye-aye's middle finger motion.

Keywords: Aye-aye, Kinematics, the Lagrangian method

1. INTRODUCTION

The aye-aye is a long-fingered lemur, a strepsirrhine primate native to Madagascar with a special thin middle finger.[1] It is the world's largest nocturnal primate.[2] It is characterized by its unusual method of finding food: it taps on trees to find pests, then bites holes in the wood using its forward-slanting incisors to create a small hole in which it inserts its narrow middle finger to pull the grubs out. This foraging method is called 'percussive foraging' or 'tap-scanning', and takes up 5–41% of foraging time.[3] The features of an aye-aye's foraging method are similar to non-destructive testing technologies used by engineers to inspect aging infrastructure including pipelines, composite materials used in the aviation industry, and bridges. The aye-ayes have a number of morphological characteristics that distinguish them from other primates and due to their bizarre feeding ecology and diet, they are considered as an exceptional example of adaptation among mammals.[4,5] They are currently considered one of the world's top 25 most endangered nocturnal lemurs that is the only extant representative of its family Daubentoniidae.[6] The only living member of the family Daubentoniidae has claws on each digit but the thumb,[3] a mean adult body mass of 2.5kg,[7] a head body length of 30-37 cm and a tail length of 74-90 cm[8] (see Figure 1). The aye-ayes also have the largest ears relative to head size.[9] They forage upon many food sources with a particular emphasis on larvae. They might extract insect larvae from decaying wood on dead or living trees, fallen deadwoods, and rarely living trees.[10,11] So, their feeding behavior has become synonymous with deadwood foraging. When a cavity is located, they used their continuously growing incisors to gnaw through the tree's exterior and extract the larvae within using the flexible middle finger[12,13]

The acoustic actuation part for the aye-aye is its hand and more specifically its middle finger. Differences in finger use correspond to differences in the third and the fourth finger morphology[13,14] . The exceptional middle digit serves as a probe-like instrument for scanning, locating and extracting xylophagous (wood-boring) larvae as well as other types of preys.In this paper, we will focus on the middle finger motion and a dynamic model will be presented in the next section.

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Figure 1. An aye-aye during tap-scanning (photo: David Haring, Duke Lemur Center)

2. KINEMATIC MODEL

A simplified mechanical model is proposed from the kinematics of a aye-aye middle finger to analyze its special mechanism. When an aye-aye strikes its finger against a wood, its finger joints rotate and it finger tip stands intersecting with the tree at a certain angle. A simplified model for the aye-aye's middle finger is proposed with the following assumptions: (i) the finger is straight and rotates about joints; (ii) while tapping, the palm is fixed; (iii) the finger is described as a two link Rotation-Rotation(RR) robot model. Figure 2 shows the geometric representation of the RR robot.

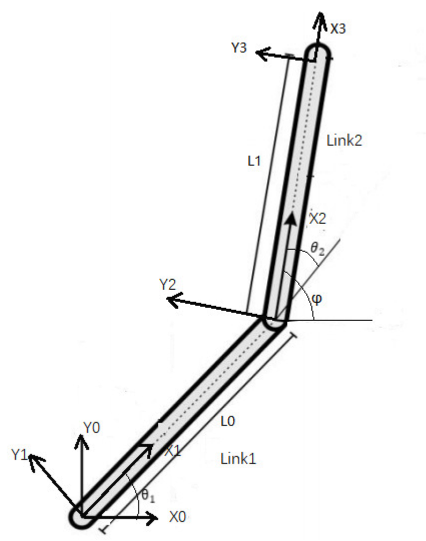

Figure 2. RR robot

Table 1 presents the geometric parameters of the robot according to the Denavit-Hartenberg convention.[15] In this table, i represents the number of the joint, a_{i-1} represents the distance along the axis X_i , α_{i-1} refers to the angle between the axes Z_{i-1} and Z_i, d_i represents the distance between the axes and finally θ_i represents angle to the axis X_{i-1} and X_i.

The position and orientation of the finger tip could be obtained through the forward kinematics.It is necessary to calculate the homogeneous transformation matrix T_i^{i-1} of each finger joint using the following transformation

Table 1. Geometric parameters of the finger

i	α_{i-1}	a_{i-1}	d_i	θ_i
1	0	0	0	θ_1
2	0	L_0	0	θ_2
3	0	L_1	0	0

matrix

$$T_i^{i-1} = \begin{bmatrix} cos\theta_i & -sin\theta_i & 0 & a_{i-1} \\ cos\alpha_{i-1} * sin\theta_i & cos\alpha_{i-1} * cos\theta_i & -sin\alpha_{i-1} & -d_i * sin\alpha_{i-1} \\ sin\alpha_{i-1} * sin\theta_i & cos\alpha_{i-1} * sin\theta_i & cos\alpha_{i-1} & -d_i * cos\alpha \\ 0 & 0 & 0 & 1 \end{bmatrix} (1)$$

Then the homogeneous transformation matrix T_3^0 from base frame to the the finger tip can be obtained by the chain rule:

$$T_3^0 = T_1^0 T_2^1 T_3^2 = \begin{bmatrix} C_{12} & -S_{12} & 0 & L_0 * C_1 + L1 * C_{12} \\ S_{12} & C_{12} & 0 & L_0 * S1 + L1 * S_{12} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} (2)$$

where $\mathrm{C}_{12} = cos(\theta_1 + \theta_2) = \cos\varphi$, $\mathrm{S}_{12} = sin(\theta_1 + \theta_2) = \sin\varphi$

Thus the position of the finger tip is:

$$X_E = L_0 * C_1 + L_1 * C_{12} \ (3)$$

$$Y_E = L_0 * S_1 + L_1 * S_{12} \ (4)$$

2.1 Inverse Kinematic Formulation

From Section 2.1, the inverse kinematics can determine the joint movements from a desired Cartesian position of the end effector.[15] The solution of inverse kinematics is the key to control the end effector trajectories. Using (3) and (4) and after several algebraic calculation, the inverse kinematics of the robot arm is:

$$C_2 = \frac{X_E^2 + Y_E^2 - L_0^2 - L_1^2}{2L_0L_1}$$

and then $\theta_2$would be

$$\theta_2 = Acos(\frac{X_E^2 + Y_E^2 - L_0^2 - L_1^2}{2L_0L_1})$$

To get θ_1 , we find expressions between angles γ and θ_1, θ_2

$$\theta_1 = \gamma - \beta$$

where

$$\gamma = Atan2(Y_E, X_E), \beta = Acos(\frac{X_E^2 + Y_E^2 + L_0^2 - L_1^2}{2L_0\sqrt{X_E^2 + Y_E^2}})$$

Here,we choose the "elbow-down" solution where the angle $\theta_2 > 0$.

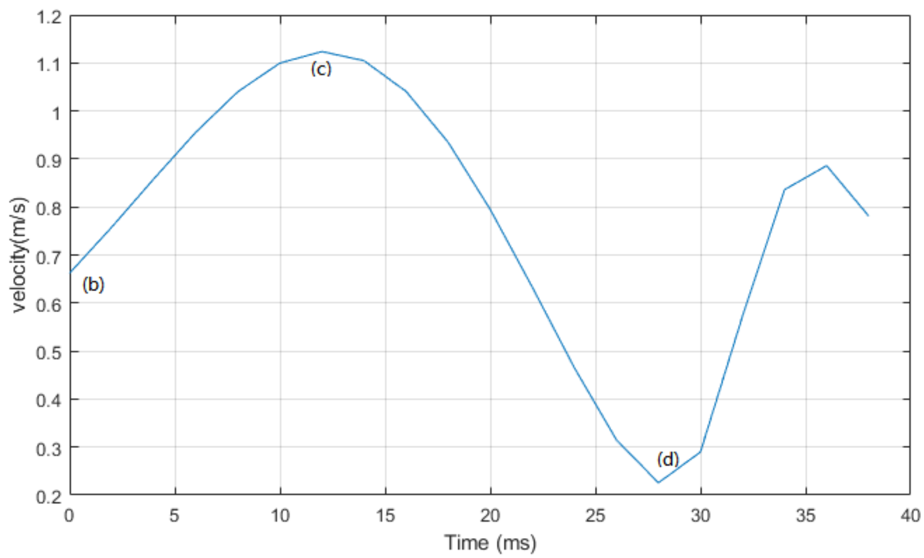

Figure 3. speed of simulation of aye-aye middle-finger tip

2.2 Simulation Result

We consider the simplified model of a two-link manipulator shown in Figure 2. In this experiment, we used the following parameters in our numerical simulation.

$$M_1 = 0.005kg, L_0 = 0.07m, M_2 = 0.005kg, L_1 = 0.04m,$$

We can set the initial position as $X_E = 0.03m, Y_E = 0.12m$,and final positions as $X_E = 0.1, Y_E = 0.1m$ .The The initial or final angle velocities and accelerations are set to be zero. Figure 3 shows the speed variation with respect to time. From Figure 3, it can be found that the finger tip velocity increases from (b) to (c), which means the finger get accelerated,and finally reaches to its maximum speed 1.1m/s at (c). Then the finger tip get its highest point at (d) with a minimum speed close to 0m/s.

3. CONCLUSION

In this paper, the aye-aye middle finger kinematics was modeled and its movement was numerically simulated. The kinematic model is presented to analyze the motion mechanism of aye-aye middle finger. In the future, the simulation results should be compared to the tracking results of actual middle finger during the tap scanning process. A more accurate model may need to be further studied because of complexity of the aye-aye middle finger kinematics.

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