2015 IEEE International Conference on Control System, Computing and Engineering, 27 - 29 November 2015, Penang, Malaysia

Development of Pole-like Tree Climbing Robot

M.I. Nor Faizal, W.A.F.W. Othman, S.S.N.A. Syed Hassan

School of Electrical and Electronic Engineering, Universiti Sains Malaysia
Seri Ampangan, 14300 Nibong Tebal, Penang, Malaysia

iqbalnorfaizal@gmail.com

Abstract— **A climbing robot is designed to climb a tree with diameter of 10 cm. The robot utilizes modular mechanism as locomotion of the robot that consists of 6 steps which enable the climbing module to carry its weight by using two servo motors. The robot utilizes encompassing grip in gripping module which wrapped the tree to increase the surface area of frictional force. In the initial condition, the climbing module extends and both upper and lower gripper in grip. The climbing motion starts when the lower gripper releases, the climbing module contract upward and the lower gripper return to grip again. Then, the upper gripper releases, the climbing module extends again and the upper gripper returns to grip. This sequence will continue until the robot reaches the desired location. The Arduino Uno microcontroller is used to send the PWM signal to the servo motors to control the robot movement. To ensure the efficiency and performance of the robot, various simulations and test have been done. The weight in simulation data is 0.9 kg whereas the actual weight is 0.88 kg. After the tests have been done, the simulation average climbing speed is 0.1568 m/s while the actual average climbing speed is 0.00183 m/s.**

***Keywords*— Pole like tree climbing robot, modular mechanism, encompassing gripper, torque, pulse-width modulation**

I. Introduction

In this modern age, robot has become part of human necessity. It has been used for a variety of work either for simple task such as cleaning [1] or for heavy task like manufacture a car [2]. The demand for robot has been increasing lately because of its function which helps human to make their task faster and less complicated. There are types of robot in the industry where each one of them has specific function and unique to each other.

Tree climbing robot [3] is one of the robots which specializes in climbing up or down or both on tree surfaces. Although this type of robot has already been defined by its name, each robot has their own unique way to climb the surfaces. A suitable climbing mechanism is needed to be able to climb on one surface or the robot will not able to complete the task given. For example, claw type of gripper [4] could not be used for glass surface because glass surface is slippery and easily breakable. It is similar to tree climbing. The robot needs suitable climbing technique to climb the tree.

There are several techniques that have been developed by past researchers to be implemented into the robot. For example, Ripin *et. al* [5] has proposed the concept of modular mechanism for pole climbing robot. The mechanism consists of separating module for gripping module and climbing module. There are 2 grippers and each of it is placed at top and bottom of robot. The robot can move vertical upward and downward. Furthermore, the robot is able to avoid obstacles when climbing the pole.

The robot designed by Faroux and Morillon [6] is capable to climb poles with a cylindrical or conical shape. The robot used rolling self-locking concept: rolling allows continuous ascension whereas self-locking guarantees null energy consumption while staying still on the pole. However, the robot could only climb up a pole with high coefficient of friction or else it will slip.

G. Clark Haynes *et al* [7] proposed dynamic leg mechanism for dynamical, high speed climbing of a uniformly convex cylindrical structure. The robot is design with its specialized ability to quickly gain elevation and park at a vertical station silently with minimal energy consumption.

Je-Sung Koh and Kyu-Jin Cho [8] has created biometric robot by implementing memory alloy coil actuator mechanism in its design. It is built with smart composite microstructures (SCM). Memory alloy coil actuator is activated by using pulse-width modulation (PWM) to control it shape and position of robot. The robot is so small which can be used as search and rescue mission or gathering useful information in small area. However, SCM is quite expensive to be created and only can be made by manufacturer specializing in microstructure.

After reviewing past research about climbing robot and considering many factors such as cost, material and time constraints, modular mechanism with compact design has been proposed to be implemented into the robot design.

II. Methodology

In this work, methodology is separated into three different sections, which are mechanical design, embedded system and testing.

A. Mechanical design

In mechanical design include the conceptual design of the robot, fabrication and assembly process.

1) Robot structure

Fig. 1 shows the conceptual design of complete robot created by using SolidWorks. This design is using modular mechanism to perform its locomotion. The robot consists of 2 main module, which are gripping modules and climbing module. The climbing module uses the modular mechanism to perform its locomotion, which are ascending and descending motion.

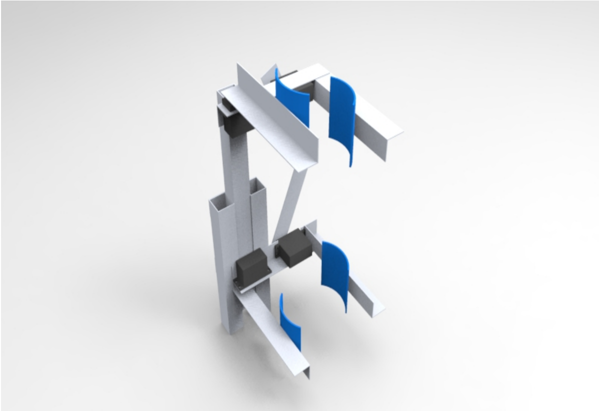

Fig. 1 Conceptual design of complete robot

2) Climbing module

Fig. 2 shows the climbing module part. There are two servo motors which are located on both upper and lower gripper. Both servos are connected to the linkage to perform rotation motion. As the connecting rod rotate, the slider move in linear motion. The torque of servo motors is used to overcome the weight of the lifting part and the friction between slider and end bar. However, oil is used to lubricate the slider and end bar to reduce the friction. A gripper is connected at slider and one more gripper is attached at the end bar.

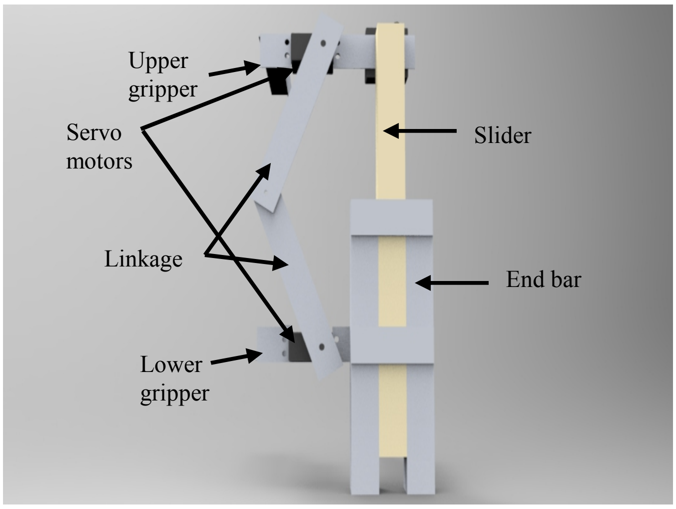

Fig. 2 Climbing module

3) Gripping module

Fig. 3 shows the gripping module part. There are two gripper modules, which are the upper gripper and the lower gripper. Each gripper consists of one servo motor which attached to aluminium frame. The PVC pipe that has been cut into desired dimension is attached to the aluminium bar which is connected to servo horn of the servo motor. To increase the friction of the gripper, sand paper is attached to the PVC.

The servo motor rotation direction indicates the operation of the gripper. When the motor rotates in anti-clockwise direction, the gripper will grasp the tree tightly. Otherwise, the gripper will release the tree as shown in Fig. 4.

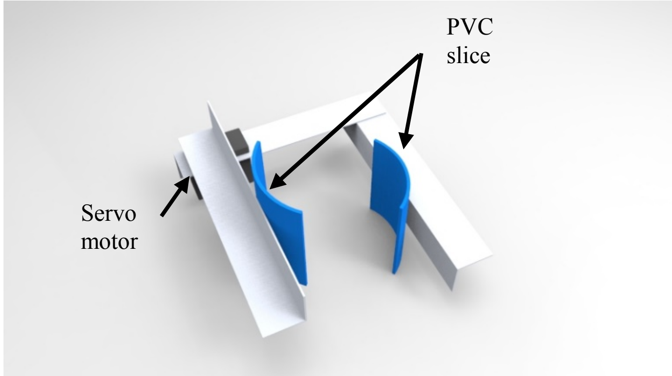

Fig. 3 Gripping module

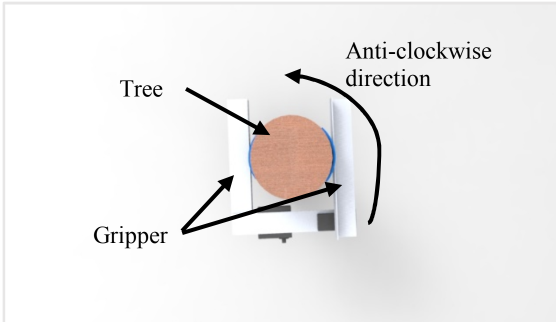

Fig. 4 Operation of gripping module

4) Motor selection.

In this work, RC servo motor with metal gears has been chosen as the motor for climbing module and gripping module because of high torque and easy to control. Table I shows the specification of motor that was used to control the movement of the robot.

TABLE I
SPECIFICATION OF MOTOR

Motor	Specification
RC servo motor with metal gear	• Speed (sec/60deg): 0.22/4.8V, 0.20/6.0V • Torque (Kg-cm): 9.0/4.8V, 11.0/6.0V • Size (mm): 40.8x20.18x36.5 • Weight (g): 55 • Rotation angle: 180 degree • Pulse width range: 0.582ms to 2.5ms (estimation) • Designed for "closed feedback"

B. *Embedded system*

1) System Architecture

Fig. 5 depicts the system architecture of the robot. The Arduino Uno is used as the processing unit to control 4 servo motors. The electronic components used include the 7.4V Lithium-Ion Rechargeable Battery, push button and voltage regulator +6V. The system has been designed in order to make the climbing robot run autonomously.

The 7.4V DC voltage supply is directly connected to Arduino Uno. The voltage supply also connected to voltage regulator +6V via push button as the master control. If emergency case happens, the user can use this push button to cut off the power supply and the robot will stop its operation. Pulse-width modulation (PWM) signal generated from Arduino Uno is sent to servo motors to control its operation.

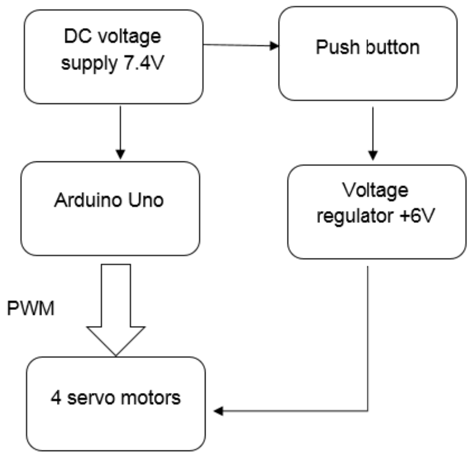

Fig. 5 System architecture

Servo motor required 6V to operate at desired torque and speed. However, the battery supplies more voltage than 6V. If the servo motor uses more voltage than it required, it could damage the motor. Therefore, voltage regulator is needed to regulate the voltage to be 6V and used it to operate the servo motors.

2) Software Design

Programming code is created using Arduino IDE and uploaded into microcontroller Arduino Uno in order for the robot to perform sequences of operation in correct manner. The programming code is only focusing on generating the PWM signal to the servo motors autonomously. Fig. 6 shows the flowchart of the overall program.

Programming code allow the robot to perform climbing action in upward direction only. The Arduino gives the PWM signal to the servo motor to initialise the position of grippers and climbing module. When the robot starts to move, the lower gripper opens. Next, the climbing module contract upward and then, the lower gripper close again. The upper gripper open and follow by climbing module extends upward. The upper gripper closes again. This sequence is repeated to make the robot moves autonomously.

C. Testing

In order to evaluate the performance of the robot, simulation test and physical test are carried out.

1) Simulation testing

In simulation, mathematical model is derived from kinematic of climbing module and used for calculation to find average climbing velocity. Fig. 7 shows the kinematic of climbing module.

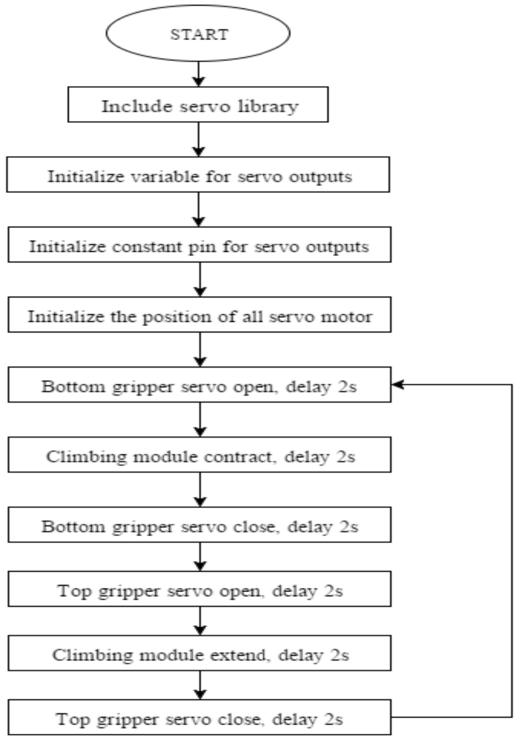

Fig. 6 Flowchart of overall program

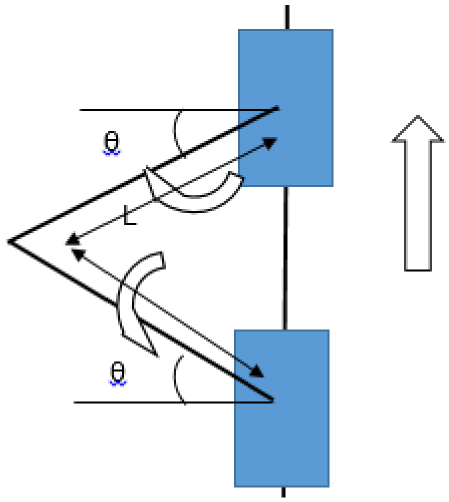

Fig. 7 Kinematic of climbing module

The climbing module is capable to move vertically upward and vertically downward. There are total of two motor in climbing module which one of it inside the upper module and other inside lower module. Both modules are connected by linkage and slider. The motors will rotate to desired angle, θ while upper and lower module move along guide bar to desired position. The displacement of climbing module, L_T is expressed as

$$L_T = 2L\sin\theta \tag{1}$$

where L is length of linkage (crank). By using Matlab software, the maximum displacement of climbing module can be calculated using Eq. (1) and graph is generated.

Since the speed of motor is 0.20s/deg as shows in Table I, the total time taken for one climbing cycle can be calculated. One climbing cycle means one complete sequence of climbing operation which has shown in Fig 6. The total time taken for the robot to complete one climbing cycle, T is based on the Eq. (2) below.

$$T = 4t_G + 2t_C \tag{2}$$

where t_G is time taken for gripping module to rotate and t_C is time taken for climbing module to move.

The minimum torque required for each module need to be calculate in order to see the performance of robot. Mathematical equation of the gripping module is derived based on kinematic diagram as shows in Fig. 8.

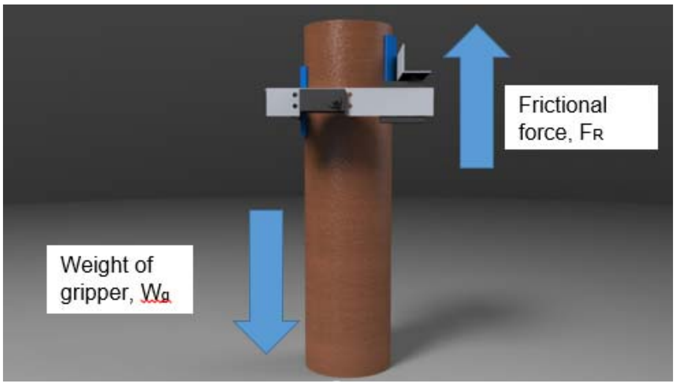

Fig. 8 Kinematic of gripping module

In order to stay on the tree, the friction force, F_R produces by the gripper must be larger than the weight of gripping module, W_G. Thus, Eq. (3) and (4) is derived based on the statement above.

$$F_R > W_G \tag{3}$$
$$F_R = \mu_s N \tag{4}$$

where μ_s is static coefficient of friction between gripper and tree surface and N is normal force of gripper module on the pole.

The torque required for servo motor, T is calculated based on Eq. (5).

$$T = Fr \tag{5}$$

where F is total force acting on the tree and r is length of gripper.

Assuming total force acting on the tree, F is equal to normal force of gripper module, N hence, the formula of minimum torque required for servo motor, T is derived into Eq. (6).

$$T > W_G r/\mu_s \tag{6}$$

For climbing module, torque of two servo motors need to be higher than weight of climbing module, W_C and the friction force between end bar and slider, F_{RB}.

$$2T > W_C L + F_{RB} \tag{7}$$

where L is the length of linkage. The frictional force between end bar and slider can be assumed as negligible since the lubricant is applied between end bar and slider. Therefore, the minimum torque for climbing module can be calculated using Eq. (8).

$$T > W_C L/2 \tag{8}$$

After assembly, the total weight of robot, W_T is the sum of weight of climbing module, W_C and gripping module, W_G.

$$W_T = W_C + 2W_G \tag{9}$$

Therefore, Eq. (6) and (8) need to be changed in terms of total weight of the robot, W_T to become Eq. (10) and (11). These two equations are used to analyse the performance of complete robot.

$$T > W_T r/\mu_s \tag{10}$$
$$T > W_T L/2 \tag{11}$$

2) Physical testing

In physical testing, the robot is tested on selected tree as shows in Fig. 9. In this test, the robot will be given a task to climb up 1m, the tree with 10 cm diameter. The time to complete the task is recorded and compares with simulation test results.

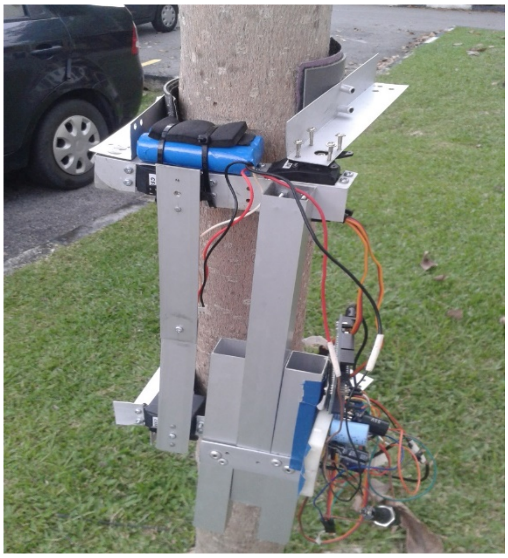

Fig. 9 Practical testing

III. Result and Discussion

The robot is analysed using Matlab to calculate the mathematical equation derived before. By setting the angle of rotation, θ in range of 0 to 180, Eq. (1) is calculated and graph is created as shown in Fig. 10.

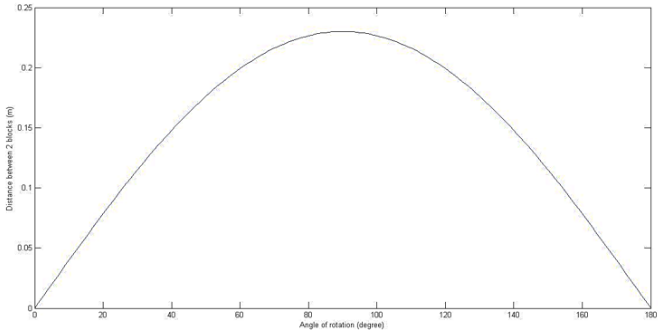

Fig. 10 Graph of climbing module displacement, L_T

The maximum displacement between two blocks is 0.230 m at 90 degree while the minimum distance between two blocks is 0 cm at 0 or 180 degree. Since the motor has 1.2 rotations per second (rps), the climbing module need 0.3 second to reach maximum displacement assuming there is no delay cause by weight and signal processing.

It is same goes to gripper module which rotates from 0 to 65 degree to close and open. The time taken for gripper to open or close, t_G is 0.2167 second. Therefore, total time taken to complete one climbing cycle is calculated by using Eq. (2).

After the calculation, the robot needs 6.378 second to reach 1 meter of tree which equivalent to average velocity of 0.1568 m/s.

TABLE II
ACTUAL CLIMBING RESULTS

Number of run	1	2	3
Time taken (s)	543	551	546
Average time taken (s)	546.66		

The average time taken for the robot to climb up 1 meter on tree surface is 546.66 s which mean the average velocity of the robot is 0.00183 m/s. By comparing the simulation data and the practical result, the average velocity of practical result is far from the simulation data. This is because the simulation data not consider the weight of the robot to calculate the climbing speed and assume the ideal event.

In order for gripping module working properly, the minimum torque required for servo need to be calculated by using Eq. (6). The performance of gripper module can be determined by comparing the simulation data and actual data, as shown in Table III.

The torque of motor is 11kg.cm. From the calculation, the torque of motor is higher than minimum torque required for both simulation and actual data. Therefore, the gripping module should not have problem to grip on the tree based on the calculation. When the testing done, it capable to grip on tree without slipping.

For climbing module, the minimum torque required for servo need to be calculated by using Eq. (8). The performance of climbing module can be determined by comparing the simulation data and actual data as shown in Table IV.

TABLE III
SIMULATION DATA AND ACTUAL DATA FOR GRIPPER TESTING

Type of data	Simulation data	Actual data
Gripper weight, W_G (kg)	0.3	0.28
Length of gripper, r (cm)	8	8
Coefficient of static, μ_s	0.6	0.6
Minimum torque required, T (kg.cm)	4	3.73

TABLE IV
SIMULATION DATA AND ACTUAL DATA FOR CLIMBING TESTING

Type of data	Simulation data	Actual data
Climbing module weight, W_C (kg)	0.3	0.32
Length of linkage, L (cm)	11.5	11.5
Minimum torque required, T (kg.cm)	1.725	1.84

The torque for each motor used in climbing module is 11kg.cm. Since the torque of motor is higher than the minimum torque required for both simulation and actual data, the climbing robot should able to carry its own weight.

The assembled robot needs to be evaluated in order to see the performance of the robot. Since the weight of robot have increase during assembly, therefore the total weight for simulation and actual data is calculated by using Eq. 9 and result is shown in Table V.

TABLE V
TOTAL WEIGHT FOR SIMULATION DATA AND ACTUAL DATA

Type of data	Simulation data	Actual data
Climbing module weight, W_C (kg)	0.3	0.32
Gripper weight, W_G (kg)	0.3	0.28
Total weight, W_T (kg)	0.9	0.88

The minimum torque required for the climbing module of assembled robot is calculated using Eq. (11) and result is shown in Table VI.

TABLE VI
CALCULATION FOR CLIMBING MODULE IN ASSEMBLY TESTING

Type of data	Simulation data	Actual data
Total weight, W_T (kg)	0.9	0.88
Length of linkage, L (cm)	11.5	11.5
Minimum torque required, T (kg.cm)	5.175	5.06

The torque of motor is 11kg.cm. The torque of motor is higher than the minimum torque required for both simulation and actual data. The result shows the climbing module is able to carry its total weight.

For gripping module, the minimum torque required for the motor of gripping module is calculated using Eq. (10) and result is shown in Table VII.

TABLE VII
CALCULATION FOR CLIMBING MODULE IN ASSEMBLY TESTING

Type of data	Simulation data	Actual data
Total weight, W_T (kg)	0.9	0.88
Length of gripper, r (cm)	8	8
Coefficient of static, μ_s	0.6	0.6
Minimum torque required, T (kg.cm)	12	11.73

The torque of motor is 11 kg.cm. Since the torque of motor is less than the minimum torque required, the gripper could not perform its function well. This should explain the reason of the robot is not able to fulfil the minimum torque required for the robot to stay on the tree without falling. As a result of testing, the robot is unable to grip properly on the tree and keep falling down to the ground.

IV. CONCLUSIONS

A new compact design and low cost pole like tree climbing robot has been developed by using modular mechanism. It simple design using only 4 servo motor which 2 servo motor for climbing module and other two for gripping module. The robot is capable to climb tree with average velocity of 0.00183 m/s. The robot is unable to avoid any obstacles because there is no obstacle avoidance function has been installed although obstacle avoidance has been mention in Ripin's mechanism before.

For future recommendations on this project, the gripping module needs to be change with higher torque. It could be done by changing the design of gripping module or changed the servo motor with a motor that have higher torque. The gripping module must have strong structure or framework which builds by using strong material, but light in weight because the gripping module tends to bend and reduces the surface contact between gripper and tree, hence lose its friction force. Actual simulation which, taking the weight of the robot and not the ideal case is required to compare the practical consequences and appropriate simulation data. Installation of obstacle avoidance should be considered in future works.

V. ACKNOWLEDGEMENT

The authors would like to thank Universiti Sains Malaysia (USM) for the support of the research under grants no 304-PELECT-60313019.

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