Eco-friendly deliver, SCONE
[Six-legged robot Capable Of rotating motioN (Enhanced)]

Hyoung-Seok Kim

Korea Digital Media High School, Ansan, Republic of Korea

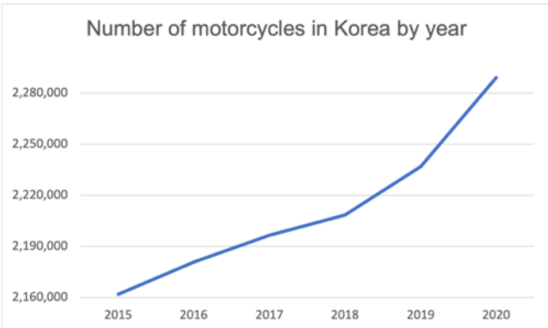
hayward_kim@dimigo.hs.kr

Abstract – This paper proposes the development of a six-legged robot capable of rotational motion, with the aim of exploring its efficiency in navigating steep terrain and stairs. Furthermore, this paper seeks to evaluate the driving speed and energy efficiency of existing truck-type delivery robots. The rise of delivery robots as a replacement of CO-emitting motorcycles has prompted major companies to explore new options for delivery agents. However, most of the delivery robots currently being used are four- or six-wheeled trucks that face limitations in crossing obstacles such as high-rise stairs or curb stones. This project aims to develop SCONE as a solution to such obstacles. To implement SCONE, ***Parallel Link Mechanism*** was utilized for efficient usage of actuators and enabling walking, and ***Arc-shaped Wheels*** with a center angle of $240°$ were attached to each end of the leg for driving. When powered by a battery, SCONE was unable to maintain an idle position or perform any movements. Although this was solved by powering SCONE with an external power source showing the walking speed of $0.5m/s$ and the driving speed of $0.7m/s$, motor overload occurred during rotational motion and climbing stars. Furthermore, slipping occurred while climbing steep terrain. This was caused by insufficient friction between the ***Arc-shaped Wheel*** and the test environment, on account of the low torque of the actuator caused motor overload. To address the issues at hand, it is recommended to eliminate the inefficient Parallel Link Mechanism and replace the tires with Airless Tires for improved traction on the ground.

Keywords: Arachnoid Bot, Computer Vision, Food Delivery, Parallel Link Mechanism, Six-Wheeled Drive

1. INTRODUCTION

The COVID-19 pandemic has caused a significant rise in the number of people practicing self-isolation, resulting in a decrease in outdoor activities. Consequently, food delivery has emerged as a preferred option for individuals who wish to enjoy their favorite meals without leaving their homes. However, the increasing usage of motorcycles for delivering food has raised concerns about carbon monoxide emissions. Furthermore, the limited number of delivery drivers has made it difficult to collect reusable food containers, leading to a higher reliance on disposable plastic containers.



[Fig. 1] Numbers of motorcycles in Korea by year

To address these concerns, companies are studying truck-type delivery robots that can cross simple obstacles such as wide and low-rise stairs and curb stones. However, such structures have limitations when operating on rough terrain like mountains. To overcome this issue, this paper proposes the development of a six-legged robot that is capable of rotational motion.

[Fig. 2] MOBINN's M3 climbing outdoor stairs

The project aims to assess the effectiveness of a six-legged walking mechanism in navigating challenging terrains such as stairs and steep terrain.

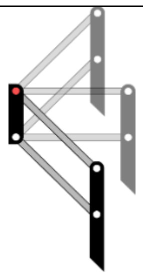
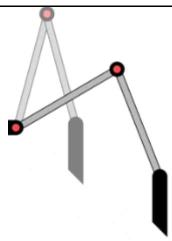
Furthermore, the project seeks to evaluate the driving speed and energy efficiency of existing truck-type delivery robots. This development will provide a more sustainable and cost-effective solution for food delivery, as well as a novel approach to emergencies such as distributing emergency kits to individuals in hazardous circumstances.

2. METHODS

2.1 Theoretical Background

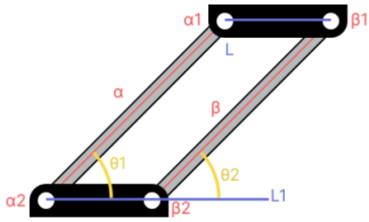
2.1.1 Parallel Link Mechanism

Most arachnoid bots require two actuators for the vertical movement of a single leg. However, with the use of ***Parallel Link Mechanism***, the entire leg can be controlled with a single actuator.

	
(a) Leg with ***Parallel Link Mechanism***	(b) Leg without ***Parallel Link Mechanism***

[Table. 1] Comparing the count of the actuators(redpoint)

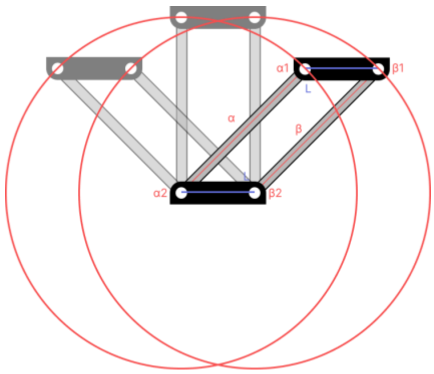
Parallel Link Mechanism is a structure in which more than two link mechanisms are placed in parallel.



[Fig. 3] Sample of ***Parallel Link Mechanism***

In [Fig. 3] α_1, β_1 are moving points, and α_2, β_2 are fixed points. Let us set $\overrightarrow{\alpha_2\beta_2}$ as L_1. Then set the angle between $\overline{\alpha_1\alpha_2}$, L_1 as θ_1 and the angle between $\overline{\beta_1\beta_2}$, L_1 as θ_2. When $\overline{\alpha_1\alpha_2}$ and $\overline{\beta_1\beta_2}$ have the same length and are in parallel, $\square\alpha_1\alpha_2\beta_2\beta_1$ becomes a parallelogram, and due to the isotope in two parallel line segments, the size of θ_1 and θ_2 is same.

When the value of θ_1 changes, the locus of α_1 becomes a circle where α_2 is the origin and the length of $\overline{\alpha_1\alpha_2}$ is the radius. Since $\square\alpha_1\alpha_2\beta_2\beta_1$ is a parallelogram, as the value of θ_1 changes, $\overline{\alpha_1\beta_1}$ follows the locus of α_1 maintaining parallel to $\overline{\alpha_2\beta_2}$.



[Fig. 4] Movement of ***Parallel Link Mechanism***

As a result, when the link structure becomes a parallelogram, by changing the value of one angle, the facing frame can move in a specific orbit.

2.1.1 Arc-shaped Wheel

To enable driving, the robot requires specific mechanisms such as ***Caterpillar*** or ***Wheels***. Nonetheless, ***Caterpillar*** has limitations when it comes to walking, while ***Wheels*** with wide radius is unable to climb narrow stairs.

A breakthrough was achieved by dividing the Wheel into multiple Arcs, allowing for simultaneous walking and driving. To ensure stability, an error range of $60°$ was set to create an ***Arc-shaped Wheel*** with a center angle of $240°$.

[Fig. 5] Sample of ***Arc-shaped Wheel***

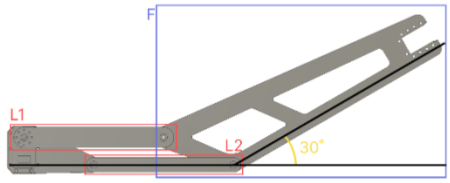
By stepping on a 'point', ***Arc-shaped Wheel*** enables one to climb stairs efficiently regardless of the radius of the wheel. This is achieved by the ***Arc-shaped Wheel***'s unique shape, virtually covering the hollow part of the wheel themselves, making a 'perfect' wheel that allows stable driving.


(a) ***Arc-shaped Wheel*** stepping on a point
 
(b) ***Arc-shaped Wheel*** placed on the opposite position

[Table. 2] Examples of ***Arc-shaped Wheel*** used in SCONE

2.2 System Design

To hold deliveries, the body frame was modeled $270mm \times 150mm \times 120mm$ space inside.



[Fig. 6] 3D modeling of SCONE's leg

Parallel Link Mechanism is implemented at the leg frame F at [Fig. 6]. To lower the body, F is tilted by $30°$.

[Fig. 7] Leg of SCONE

At [Fig. 7] $L1$, $L2$ are the link frame and leg frame, respectively. $H1$, $H2$ are the vertical height of $L1$ and $L2$, respectively. Let us set the leg's height from the ground as x and set the range of angle θ_1 from $-100°$ to $40°$.

$$H2 - H1 \leq x \leq H2 + H1 \ (\ H2 \geq H1 \geq 0\ )$$
$$-100° \leq \theta_1 \leq 40°$$

$$H1 = \cos(90° - \theta_1) \times L1 = sin\theta_1 \times L1 \cdots (1)$$
$$H2 = cos\theta_2 \times L2 \ \cdots (2)$$

Since at **2.4.2** the stairs have a height of $200mm$, the vertical moving range of the leg known as the subtraction of the maximum value and the minimum value of x should have a bigger value than $200mm$.

$$(H2+H1)-(H2-H1)\geq 200$$
$$2\cdot H1\geq 200$$
$$H1\geq 100\cdots(3)$$

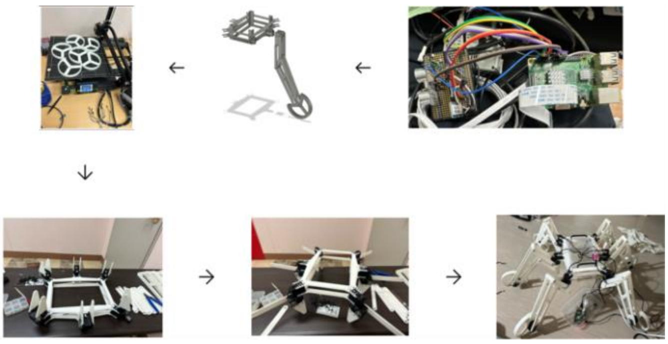
Since $L1$ and θ_1 are inversely proportional, the maximum value of $sin\theta_1$ is required to calculate the minimum value of $L1$. After setting θ_1 as $40°$, substitute equation (1) into (3).

$$sin\theta_1\times L1\geq 100$$
$$L1\geq\frac{100}{sin\theta_1}$$
$$L1\geq 134.207(\approx\frac{100}{sin40°})$$

By this method, the length of $L1$ is set to $150mm$ while the length of $L2$ is doubled to distribute the center of gravity.

2.3 System Assembly

To begin the process, the sensors and camera were attached to the Raspberry Pi. Next, SCONE was 3D-modeled and printed using PLA with a 25% fill inside. Once all the frames were printed, they were assembled.



[Fig. 8] Assembly sequence of SCONE

2.3 System Control

2.3.1 Computer Vision

‘MobileNet SSD’ model was used to classify objects detected by Raspberry Pi camera. Given the high hardware resource requirements for classifying videos of the original resolution, the resolution of the video captured by camera was reduced to $640px\ \times 400px$.

2.3.2 Motion Control

Once each actuator’s IDs were assigned from 1 to 18, custom-made driving motions were implemented for forward, backward, left and right turns.

2.4 Preparing Tests

2.4.1 Stairs

The stairs that were used in this test have 200mm height and 200mm width.

2.4.2 Steep Terrain

The test environment of steep terrain had the grade of 30 degrees.

2.4.3 Battery Power Source

The actuators were powered by three 11.1V 1000mAh battery cells connected by a parallel connection, and Raspberry Pi was powered by a 5V 3000mAh external battery pack for cell phones.

2.4.3 External Power Source

The actuators were powered by a 12V 5A adapter, and Raspberry Pi was powered by a 5V 3A adapter.

3. RESULTS

3.1 Test on battery power source

SCONE experienced difficulty maintaining its idle position and was unable to execute any movements without repeatedly collapsing to the ground.

3.2 Test on external power source

Forward and backward movements were successfully performed showing the walking speed of $0.5m/s$ and the driving speed of $0.7m/s$. However, there were instances of motor overload during rotational motion and while ascending stairs. Additionally, slipping occurred while climbing steep terrain.

These observations were made based on comparison data from various models including ROBOTIS's il Gae-Mi, NEWBILITY's NewBie, MOBINN's M3, and BAEDALEUMINJEOK's Deli.

[Fig. 9] Result of SCONE and Comparisons

4. DISCUSSIONS

4.1 Trials and Errors

4.1.1 Weak body frame

The original body frame was made of a single 4mm high frame that tended to bend due to its low height. To address this issue, a new body frame was designed with a height of 10mm and placed both above and below the actuator for improved stability.

4.1.2 Weak connection between leg and body

Previously, the leg and body frame were a single metal frame that was directly installed to eh actuator's driving unit. However, this caused the actuator's driving unit to bend vertically. By replacing the metal frame with a plastic frame and adding an extra supporting axis, one was able to prevent any unexpected transformation of the leg.

	
(a) Before (Metal frame)	(b) After (Plastic frame)

[Table. 3] Enhanced connection between leg and body

4.2 Analyzing Results

4.2.1 Low Battery Voltage

The low voltage of the battery resulted in insufficient torque output from the actuators, making it difficult for them to move.

4.2.2 Less Friction with floor

Due to the PLA composition of the Arc-shaped Wheel, it has a friction coefficient of $0.47\mu K$. This small value of friction caused SCONE to repeatedly slip while climbing steep terrain.

4.2.3 Actuator overload

Given that SCONE weighs 3.75 kilograms and has a total of 6 legs, each leg has to support a weight of 0.625 kilograms. With the length of each leg being 450mm, the torque load on the motor can be calculated as $2.75625\ N \cdot m.$

$$Torque = Distance \times Force$$
$$T = 0.45 \times (3.75 \div 6) \times g = 2.75625\ N \cdot m$$

However, the actuator responsible for vertical movement was only capable of lifting 2.5N·m at maximum power input, ultimately causing issues with SCONE's movement capabilities.

4.3 Improvements to be made

4.3.1 Centralize Arc-shaped Wheel

The attachment of the ***Arc-shaped Wheel*** to the driving unit of the actuator caused the center of gravity to shift to one side. Transforming the leg frame in order to place the ***Arc-shaped Wheel*** and leg in a straight line enabled SCONE to be driven stably without leaning to one side.

4.3.2 Airless Tires for more friction

SCONE was unable to climb steep environments due to the lack of friction between the ***Arc-shaped Wheel*** and the ground. This was solved by attaching an ***Airless Tire*** to ***Arc-shaped Wheel***, increasing stability by providing a better grip on the floor.

4.3.3 Inefficient Parallel Link Mechanism

Parallel Link Mechanism was implemented to expand the range of motion using only one actuator. However, this increased the horizontal distance between the driving unit of the actuator and the leg's end, resulting in increased torque load and ultimately leading to test failure.

Since the main reason for test failure was caused by torque overload of actuators, it was suggested that changing the ***Parallel Link Mechanism*** to a single frame and making a smaller body would help with lowering the torque load. Additionally, increasing the radius of the ***Arc-shaped Wheel*** would compensate for the reduced range of motion caused by removing the ***Parallel Link Mechanism***. The issue of lower driving speed can be solved by using a high-torque low-rpm actuator.

5. CONCLUSIONS

Despite SCONE's limited success during testing, approaching with the ***Arc-shaped Wheel*** showed the potential of a robot capable of both walking and driving. However, it was discovered that the actuators used on SCONE did not meet the necessary specifications, and that the ***Parallel Link Mechanism*** was not being used appropriately.

By applying the improvements mentioned above, SCONE has the potential to expand its capabilities beyond food delivery and become a valuable resource in diverse fields such as emergency medical response, military supply, and construction material transportation.

6. REFERENCES

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- [Fig. 2] : Picture from News One, "Cross the crosswalk and walk the stairs"… Hyundai Motor's in-house venture's delivery robot, 2023.04.11. 05:40, Available at : https://www.news1.kr/articles/?5008996