Design and implementation of small animal surgical instruments using Arduino

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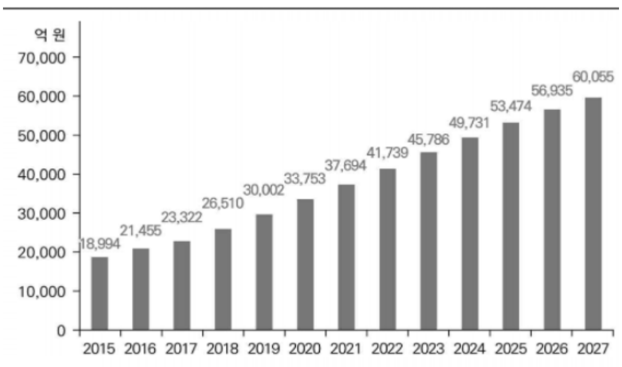
Abstract

Due to the extraordinary precision required, surgery on exceptionally small animals is often extremely difficult and time-consuming. The goal of this study is to minimize errors and damage caused by creating a device that limits hand movement to a restricted range, hence increasing stability. This device was designed so that the operation unit which the user manipulates moves at an n:1 ratio from the implementation unit which copies the movement. Potentiometers were employed on the operational unit for the joints in order to use the resistance value of each potentiometer as an input for the servomotors on the implementation unit, ensuring that the implementation unit rotates at the same ratio. The implementation unit's end was fitted with a gear and a servomotor to enable the tongs to move in response to input from the operational unit. To avoid overloading the motor, a rubber band was utilized to disperse the torque and the program was coded so that if the input value is greater than normal, the mechanism will not move. Usability can be boosted in the future by using more sturdy components and haptic feedback via vibrations.

1. Introduction

1.1 Motive



[Fig. 1] size of the pet-related industries [1]

The pet industry is a rapidly growing market. As shown in [Fig. 1], according to data released by the Korea Rural Economic Institute, the pet-related industries will reach 6 trillion won in size by 2027.[2] As a result, the surgical treatment of small animals is rising, necessitating highly precise surgery. In these surgeries, the consequences of even minor errors can be devastating. Additionally, challenging and unsafe surgical conditions have a detrimental effect on animals, doctors, and pet owners through increased difficulty and cost of operation. Therefore, this research intends to develop a mechanism that replicates hand movements at an n:1 ratio in order to lessen the likelihood of accidents occurring and minimize harm if an accident does occur. This project entails a mechanism capable of performing surgery securely by reducing the surgeon's hand movement to a restricted range, and it is through this lens that this paper will evaluate the surgical approach to small animals.

1.2 Relevant theories and components

The following are the theories and components for implementing this mechanism:

1.2.1 Hooke's Law

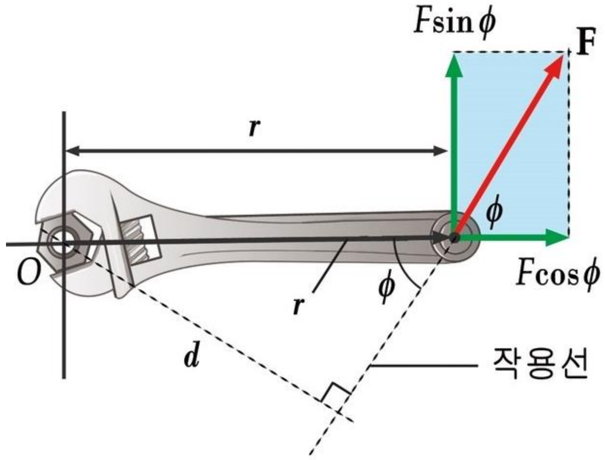
The applied force is equal to the spring constant times the displacement or change in length. (F: force, k: spring constant, x: spring stretch)

$$F = kx \tag{1}$$

1.2.2 Torque and Center of mass

The torque is a vector whose direction is perpendicular to the position vector and the force (τ: torque, $\vec{r}$: position vector, F: force)

$$\tau = \vec{r} \times F \tag{2}$$

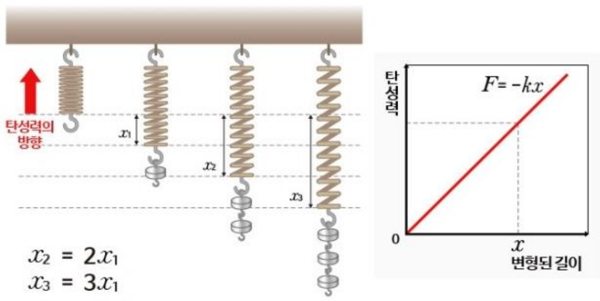


[Fig. 3] Torque[4]

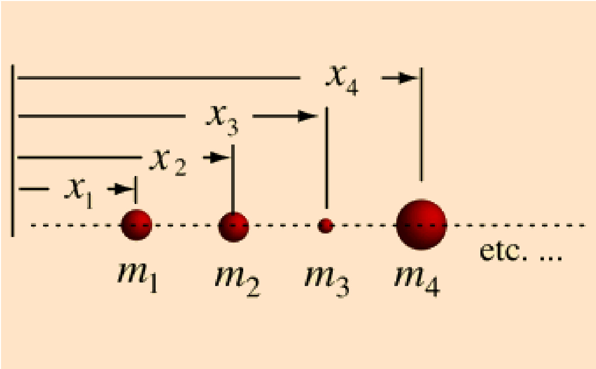
The position of the center of mass is the sum of the products of the position and the partial mass divided by the total mass based on a specific axis.

(x_{cm}, y_{cm}, z_{cm} : center of mass along each axis, M: total mass, m_i : partial mass, x_i, y_i, z_i : position along each axis)

$$x_{cm} = \frac{\sum_{i=1}^{N} m_i x_i}{M} \quad y_{cm} = \frac{\sum_{i=1}^{N} m_i y_i}{M} \quad z_{cm} = \frac{\sum_{i=1}^{N} m_i z_i}{M} \tag{3}$$



[Fig 2] Hooke's Law[3]



[Fig. 4] Center of mass[5]

1.2.3 Servomotor

A servomotor is a type of electromechanical device that generates torque and velocity in response to the current and voltage supplied. It is applied in industrial fields in accordance with the scope of the project.

1.2.4 Potentiometer

The potentiometer is part of an electric circuit that can allow various changes in current within a given range.

1.2.5 Capacitor

A capacitor is a device that stores electrical energy by interposing two metals together with an insulator. In a basic DC circuit, no current flows to the capacitor after a period of time. A parallel connection of capacitors, on the other hand, is used when a voltage is required instantly in a circuit that is unstable. The voltage does not fluctuate above a certain level while the capacitor is transmitting additional energy.

2. Main points

2.1 Initial model

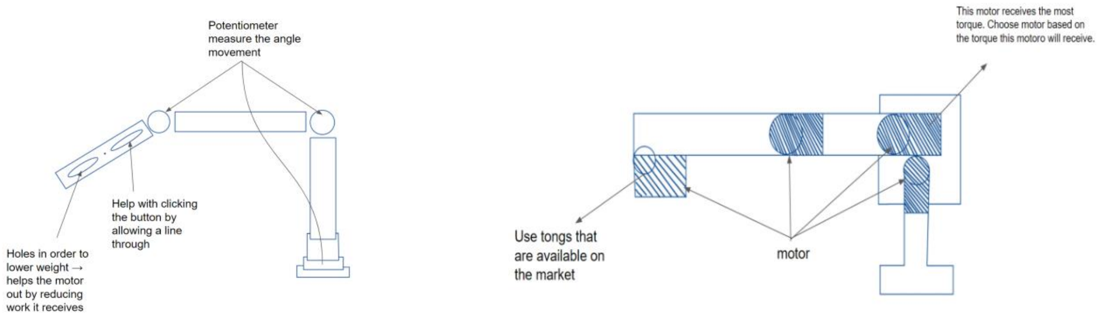
The initial model was sketched by separating the device into two parts: a handle component that is operated with the user's hand, and an operating unit which copies the movement. Initially, the handle component and the operational part was scaled to a 3:1 ratio, but this resulted in the operational part becoming too small, therefore the initial model was sketched with a 2:1 ratio.

2.1.1 Handle unit

[Fig. 5] (a) represents the handle unit. The amount of rotation is measured by variable resistance to determine the input for the handle movement. The resistance used in this model is the potentiometer B10K-R, which is readily available and frequently used, giving it the advantage of being inexpensive. Additionally, it is anticipated that the overall time to create the device will be decreased as a result of the ease with which financial resources and numerical information can be obtained through the Internet, which benefits supply and demand and reduces the time required for future modeling. Furthermore, the model is designed to create a hole in the section where the button is located for the tong movement, allowing the wire to pass through the center.

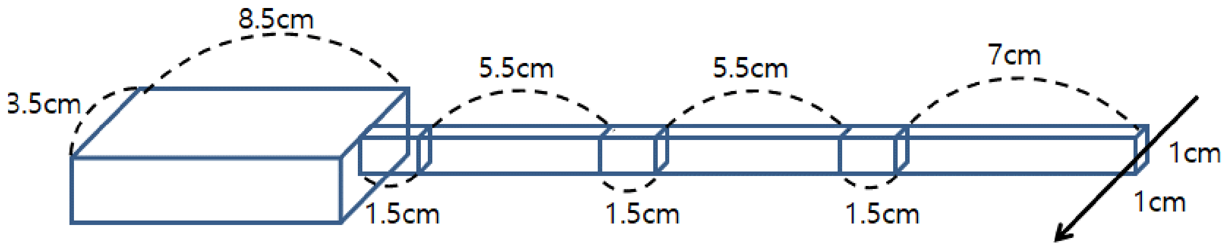
2.1.2 Operational part

[Fig. 5] (b) is a sketch of the operational part. In the location where the potentiometer was attached for the hand-held part, servo motors were attached so that the motor can turn exactly based on the inputted angle of rotation. A claw is planned to be added at the handle. It is possible to create a claw, but in order to save time, pre-existing commercial parts are to be partly used.



(a) (b)

[Fig. 5] Initial sketch of the operational part (a) handle unit (b) operational part



[Fig. 6] A schematic illustration of the instrument used to choose the motor

2.2 Motor and material selection

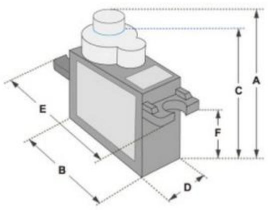
The motor was selected by calculating the torque applied to the designed model under simpler and stricter conditions than the actual conditions the motor would operate in. Then, by comparing the calculated torque to the acceptable torque of the motor, the motor was selected for this project. In order to 3d print parts of the model excluding the motor and potentiometer, PLA was selected, and the commercial claw selected was made of transparent resin. Additionally, by using the density of iron, calculations for the motor were undertaken under strict conditions. In the initial model, there were three joint parts. However, there were restrictions on copying the actual movement of the hand, so one more joint was added as expressed in [Fig 6.].

In [Fig. 6], it is assumed that the operational part has been extended to the maximum extent possible when it is not moving, and it is a structure that requires significantly more rotation than when the operational part is closed. This is the condition in which the distance between the center of rotation and the center of mass where the maximum torque is produced by each motor (the black axis in [Fig. 2]) is calculated in the manner described in [Table 1].

[Table. 1] Part table for torque calculation

Part	Center of mass (cm)	Mass (g)
Tongs	26.75	16.93
Motor 1	21.75	11.81
Motor 2	14.75	11.81
Motor 3	7.75	11.81
Operational part 1	18.25	8.75
Operational part 2	11.25	8.75
Operational part 3	3.5	8.75

Equation 1.2.2(4), when combined with the partial mass information acquired earlier, yields a torque of 1.27 kg-cm. When looking at the datasheet for the SG-90, as shown in [Figure 7], the rated torque is 2.5 kg-cm. Because the actual mechanism is not stationary, it will require more torque than the calculated 1.27 kg-cm; however, even taking this into consideration, the required torque will not exceed 2.5 kg-cm, which is almost double, therefore the SG-90 motor was chosen.



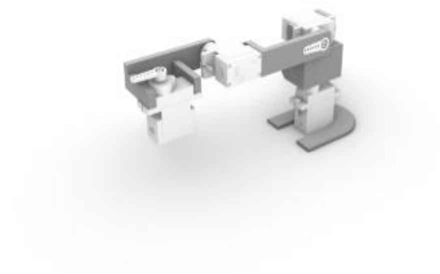
Dimensions & Specifications
A (mm) : 32
B (mm) : 23
C (mm) : 28.5
D (mm) : 12
E (mm) : 32
F (mm) : 19.5
Speed (sec) : 0.1
Torque (kg-cm) : 2.5
Weight (g) : 14.7
Voltage : 4.8 - 6

[Fig. 7] SG-90's data sheet[6]

2.3 Modeling

The mechanism was modeled using the 3D modeling software Rhinoceros. The models depicted in [Fig. 8] include three joint parts, with the second mechanism portion serving as both the operational and handle unit, and variable resistance and a motor being added to provide four joint parts. While selecting SG90 for the motor and modeling the mechanism, the mechanism was designed to be as simple as feasible by utilizing a component of the motor, not just when linking one rotation axis to another. The designed components were built using PLA on a 3D printer.

(a) handle unit

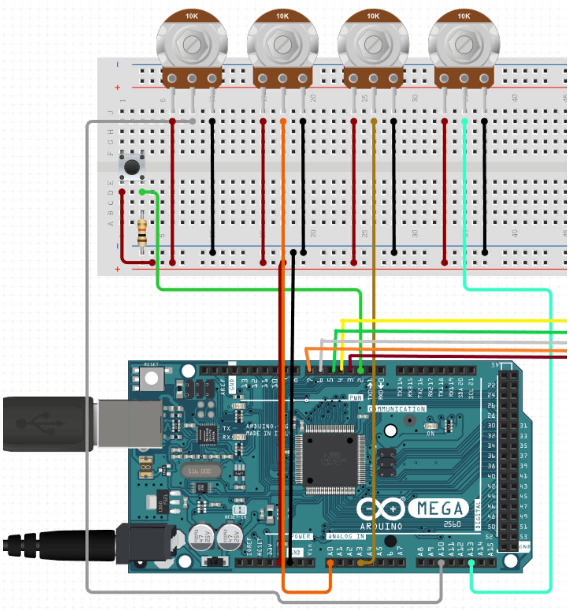


(b) operational part

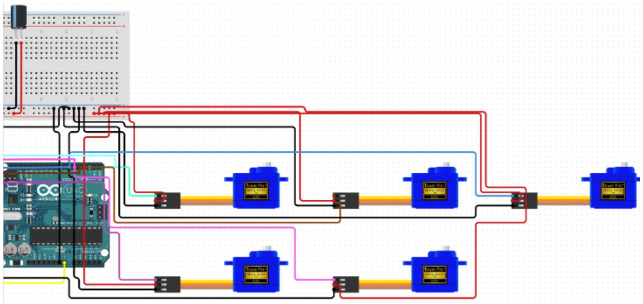
[Fig. 8] 3D Modeling

2.4 Circuit stability

When four motors, four resistors, and a switch were connected, the value jumped and the circuit did not function properly. To avoid this, as illustrated in [Fig. 9] and [Fig. 10], the voltage was first separated into an input and an output unit. Additionally, a capacitor was added to the circuit to ensure that the voltage was output smoothly and reliably.



[Fig. 9] Circuit diagram of handle unit configured with circuito.io



[Fig. 10] Circuit of the operational part configured with circuito.io

2.5 Code

Determining the motor and resistance, and designing the instrument, the hardware preparation was finished, and the code was written accordingly. Due to the fact that the SG-90 is a servomotor, the Ardui no's servo header was used, and the switch and resistance were defined appropriately in the initialization section, as they correspond to digital and analog inputs. The value entering the variable resistance ranges from 0 to 1023 in this case. Because this value needs to be converted to an angle, a map

[Table. 2] Code written using Arduino

```
#include <Servo.h>
// Data type definition
Servo mysv1; Servo mysv2; Servo mysv3; Servo
mysv4;
Servo catch1;
int sv1, sv2, sv3, sv4;int temp1, temp2, temp3,
temp4; int readValue;
void setup() {
//Initizalization
        Serial.begin(9600);
        mysv1.attach(8);    mysv2.attach(9);
        mysv3.attach(10); mysv4.attach(11);
        catch1.attach(12); pinMode(13,INPUT);
        sv1=map(analogRead(A1),0,1023,-45,225);
        sv2=map(analogRead(A2),0,1023,-45,225);
        sv3=map(analogRead(A3),0,1023,-91,179);
        sv4=map(analogRead(A4),0,1023,-25,245);
}
void loop() {
// Conversion of read values from the
potentiometer to the correct input for each
servomotor position
        temp1=map(analogRead(A1),0,1023,-45,225);
        temp2 =map(analogRead(A2),0,1023,-45,225);
        temp3 =map(analogRead(A3),0,1023,-91,179);
        temp4 =map(analogRead(A4),0,1023,-45,225);
// Protection against unstable angular velocity
values
      if(abs(sv1-temp1)<=15){sv1=temp1;
mysv1.write(sv1);}
      if(abs(sv2-temp2)<=15){sv2=temp2;
mysv2.write(sv2);}
      if(abs(sv3-temp3)<=15){sv3=temp3;
mysv3.write(sv3);}
      if(abs(sv4-temp4)<=15){sv4=temp4;
mysv4.write(sv4);}
// Debugging process looking at the values on the
serial monitor
      Serial.print(sv1); Serial.print(" ");
      Serial.print(sv2); Serial.print(" ");
      Serial.print(sv3); Serial.print(" ");
      Serial.print(sv4); Serial.print(" ");
      Serial.print("\n");
// Pressing the button closes the tongs while
releasing the button looses the tongs
      readValue = digitalRead(13);
      if(readValue==LOW){ catch1.write(90); }
      else { catch1.write(150); }
//50 ms, 20 measurements per second, minimum
time to move the motor secured
      delay(50);
}
```

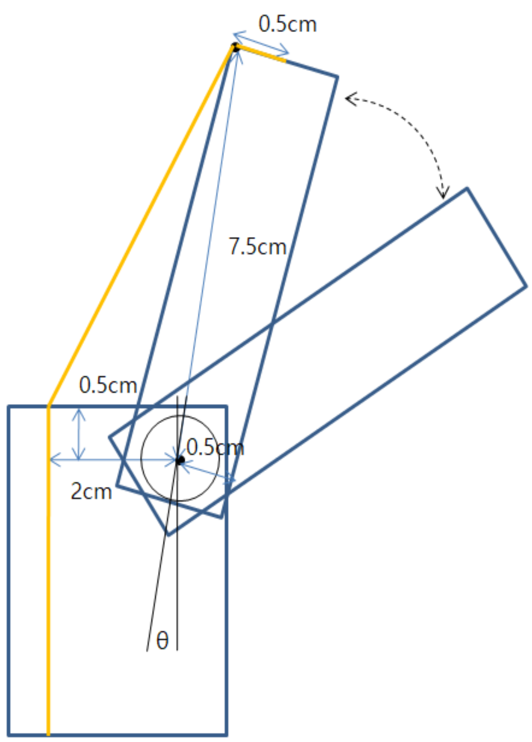
function was employed, which is a built-in function. According to the code in [Table 2], |the maximum value – the minimum value| of the angle to be converted was 270 because the variable resistance had a 270-degree operational range. However, as can be seen, each value is unique, which corresponds to the servomotor's code. The write function of the servo data type is designed to accept an input value of 0-180 degrees. As a result, when the value of the variable resistance is larger than 180 degrees or less than zero, the servomotor ceases to revolve, even if the value is input correctly. Consequently, the angle range employed by holding and moving with the actual hand was determined, and the maximum and minimum values were established to write the input angle according to this range. Therefore, the value in the code has a minimum value of less than 0 and a maximum value of greater than 180, yet the input value during operation varies between 0 and 180 degrees, causing the servomotor to move at the desired angle.

The time when the motor was running was taken into consideration by reading and operating on the value 20 times per second in the loop. The code was also used to prevent the motor from suddenly loading since the wrong values occasionally entered while reading the values; however, if the difference between the existing angle and the new value was greater than 15 degrees, the code was ignored, and as a result the motor in the moving portion was stopped from suddenly turning. The reason for setting it to 15 degrees is that the code reads values 20 times per second and the device ignores input with an angular velocity of 300/s or above. Because the user cannot turn the instrument, which is meant for sophisticated surgery, faster than 300/s, it may be determined that a value arriving at a greater than 300/s angular velocity is not the value intended by the user.

The claw was coded using the pin's LOW and HIGH values, such that when the button is pressed, the tongs are closed, and when the button is released, the tongs are open.

Additionally, for debugging purposes, each value can be accessed through Serial outputs.

2.6 Motor protection spring



[Fig. 11] A diagrammatic representation of how to calculate the torque of a rubber band.

Although the operation was normal, it was observed that when the motor receiving the most force was operated for more than 2 minutes, the temperature of the motor went up by more than 10 degrees. Although the torque required to move the instrument is within the motor's rated torque, a spring was attached to distribute the torque. Due to the small size of the operational unit, the spring used was a rubber band, and the applied torque is computed as follows:

[Fig. 11] depicts the approximate look of the rubber band when viewed from the side. The fact that a rubber band expands in three dimensions should be taken into regard, but the expanded length is tiny in all directions except the side. Therefore, the inaccuracy is predicted to be insignificant even if omitted. Thus, using the schematic diagram of [Fig. 7], one may determine the length of the elastic band stretching in the direction of the angle, which can be written as an equation using the second law of cosines. (L : length extended / α is an angle that satisfies $\tan(\alpha)=4$, $0<\alpha<\pi/2$)

$$L = \sqrt{60.5 - 7.5\sqrt{17}\cos(\theta+\alpha)} \quad (1)$$

The above equation can be used to determine the length extended for each angle, and the length extended from the rubber band's original length at 0 degrees can also be used to calculate the force applied by multiplying the Hooke's Law (1) formula from 1.2.1 by the rubber band's spring constant, which is 45N/m. Here, the rubber band has two rows on both sides, so it was doubled when calculating the force, and the value obtained by this is shown in [Table 3]. In addition, the torque can be calculated by getting the cross product with the distance between the part where the rubber band is hung and the center of the motor, which is the same as the rubber band sharing at the center.

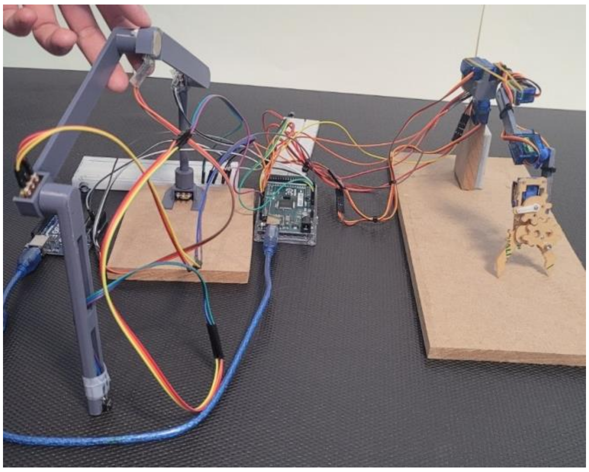
[Table. 3] Elongated length and force of the rubber band according to the angle

Angle (degree)	Δl (cm)	Force applied (kg)	Torque (kg-cm)
0	0.80000	0.07342	0.54940
10	1.15686	0.10617	0.79447
20	1.50192	0.13783	1.03144
30	1.82680	0.16765	1.25455
40	2.12444	0.19497	1.45896
50	2.38896	0.21924	1.64062
60	2.61553	0.24004	1.79622
70	2.80027	0.25699	1.92309
80	2.94018	0.26983	2.01917

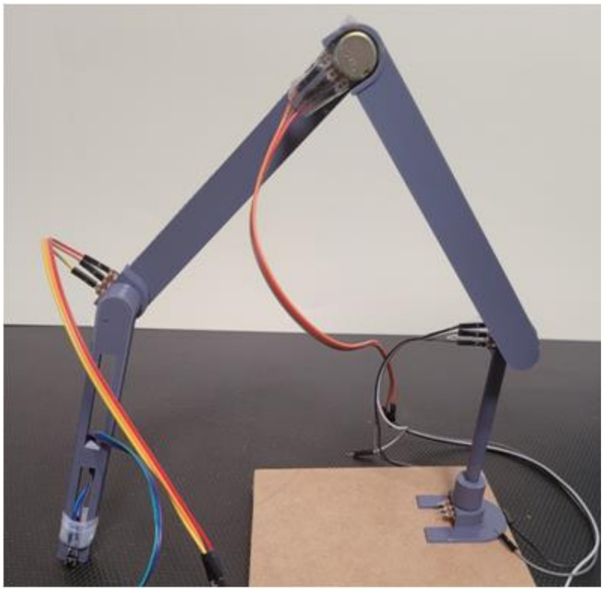
The wider the angle is, the greater the required torque, leading to a greater torque shared by the rubber band. In fact, it was discovered that when a rubber band was utilized for more than 10 minutes, the temperature soared by 10 degrees, which increased the operational time by roughly five times.

2.7 Created model

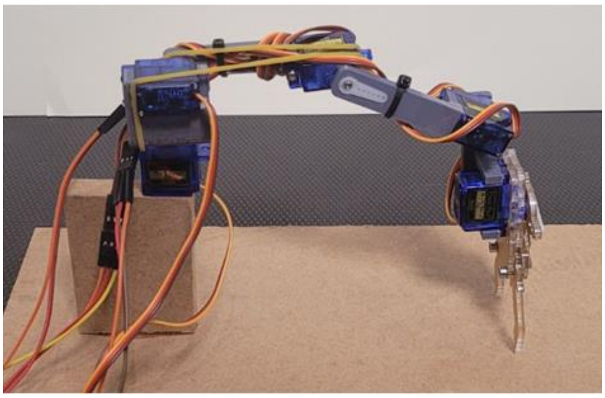
The completed model is shown in [Fig. 12] and [Fig. 13].



[Fig. 12] The completed model



(a) handle unit



(b) operational part

[Fig. 12] Actual mechanism

3. Conclusion

This research was able to consider mechanical devices for surgery on small animals through this study.

Four joints were used to construct the mechanism in this project. This refers to a device with four degrees of freedom, in which most movements can be done but some cannot be followed. Every movement of a three-dimensional object should have six degrees of freedom, so it was intended to construct the actual mechanism with six degrees of freedom, but the device was only made with only degrees of freedom due to part and interpretation limitations. It was discovered that for future models, the project would need to develop a theory that could design and interpret the joint to allow for six degrees of freedom.

The following issues were noted during the actual production process: first, the motor of the operational unit overheats far too quickly, which is a problem. If it is not operated with a cooling component that lowers heat generation, it will overheat in 2 minutes and the life of the part will be reduced; to overcome this problem, a rubber band was connected to partially distribute the load supplied to the motor.

Second, due to the intrinsic constraints of parts and instruments, there is a restriction in which the servomotor implementing the operational unit's joint intermittently splashes in addition to residual vibration. The stability of components is critical in studies aiming towards surgical equipment. This is one of the issues that must be addressed for real-world applications since it impacts delicate manipulation, and to tackle this problem, more accurate parts with higher stability and instrument design optimization are essential. Although it is more expensive, the side effects of surgery are irreversible, therefore improved parts should be secured in future studies.

Wires that were in a state of disarray were another issue. This was not considered during modeling and design, causing the mechanism to become bulkier than necessary. As a result, it takes a long time to build the model, and, if used incorrectly, the wires would become entangled during movement. There was also a plan to solder the wire together, but because the parts had to be easy to disassemble and assemble, it was revealed that future studies would have to prove that wires be included in the modeling process so that they do not become obstructive when moving.

Furthermore, a delicate grip was difficult since the force could not be measured at the tongs at the end of the motor. Controlling the holding force is important in some circumstances because it is necessary to hold the tissues of animals when surgery is conducted, however, it was hard to accomplish in this study. Thus, in future research, different levels of force should be applied based on various circumstances using a force sensor. This enables the establishment of a vibration-feedback environment in which users can feel usability like that of actual surgical instruments, hence increasing their completeness as a surgical instrument. Additionally, while only tongs are employed in the current operation section, additional equipment is necessary during surgeries. As a result, research to maintain stability without vibration or other constraints while altering this necessitates another approach. For this reason, this project would like to conduct further research on a mechanism that has the capability of changing the tool of the moving part at will depending on the operator.

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