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Wearable Auxiliary Robotic Forearm

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ABSTRACT

For individuals who have some type of physical mobility problem, they need rehabilitation tools that replace their limb capabilities or assistive devices that enhance their limb functions. While for most people, assistive robotic arms can be used as additional limbs to help them perform operations that cannot be conducted with one hand, extending the functional range of the human arm, such as grasping objects at heights. In this paper, a wearable forearm assistive robotic arm with multiple degrees of freedom is studied and constructed with various types of lightweight materials and is mainly composed of three parts: a mechanical arm telescoping part, a mechanical claw part and a wearing part. The interaction is carried out by button through arduino design program. The performance of this robotic arm is investigated through experiments as well as controls in the grasping and assisted handover scenarios.

1. Foreword

1.1 Research Objectives

In the present day, stroke is a disease that is highly prevalent in the elderly population. It is also becoming more frequent in the younger populations. It can lead to problems with limb flexibility or even limb paralysis. For these people with limb problems, life can be very difficult. Thus, they need a device to improve their quality of life.

Research has shown that wearable robots that fit closely to the body and work in concert with the operator's movements can enable people with certain types of physical mobility and dexterity problems to regain strength and mobility and thereby enable them to live more independently. Two types of wearable robots, prostheses and exoskeletons, have been extensively studied. Yet many technical challenges remain, particularly in the upper limbs. Prosthetics are beneficial for improving the quality of life of amputees, however, they are not suitable for hemiplegic patients, whose damaged arms and hands remain attached to their bodies. Surplus robotic (SR) devices are wearable augmentation devices that extend the capabilities of the wearer. In contrast to prostheses and exoskeletons designed to reconstruct or support existing human function, SR devices allow for enhanced coverage and provide the wearer with alternative modes of interaction with the environment. As an alternative to prostheses and exoskeletons, wearable robotic arms offer good assistance to patients and the more general population.

1.2 Related Research

Domestic and international research 1:

This study is designed as a myoelectrically controlled low-cost third thumb, as shown in Figure 1-1. It can be used for patients who have lost their thumbs or to help normal people gain an extra thumb as a way to restore or improve normal grip. Its structure is similar to a finger with a fish-line traction structure, which is somewhat flexible compared to a linkage type finger. This study envisions different positions of the third thumb, such as the outer side of the original thumb and the outer side of the little finger. The final design places the third thumb on the outside of the original thumb to better assist the gripping function and does not interfere with the normal movement of the other fingers. This mechanical finger can be used to grasp small or light objects.

Figure 1-1 Wearable Extra Thumbs

Domestic and international research 2:
This study aims to provide assistive assistance to users with small hands. SR Fingers (shown in Figures 1-2) can serve as an aid in holding objects in place when performing gripping and manipulation. Each SR finger has two degrees of freedom, respectively extension/flexion and abduction/adduction. Inertial navigation system (IMU) sensors mounted on the forearm can easily detect the elbow motion to control the opening or grasping of the manipulator. At the same time, more effective control and better grip stability can be achieved by attaching rubber pads to the finger surfaces and monitoring the contact force between SR Fingers and objects in addition to the embedded force sensors.

Figure 1-2 SR Finger

Domestic and international research 3:
This study presents a robotic extra limb, SoftHand X (SHX) as illustrated in Figures 1-3. It consists of a robotic hand, a gravity support system and different sensors for detecting the patient's intention to control the robotic hand. The system has five components: (1) a robotic hand (2) a passive gravity compensator (3) a human arm interface that allows the connection between subcomponents (1) and (2), allows the natural movement of the patient's forearm, and allows the integration of a mechanism robotic hand for supporting the posterior rotation movement (4) an input interface that the patient uses to control the robotic hand (5) a remote workstation for controlling and monitoring the system. This manipulator is also equipped with a gravity compensator that minimizes gravitational torque and the mass of the manipulator is balanced by a counterweight system. It allows for a synergistic behavior with the manual hand.

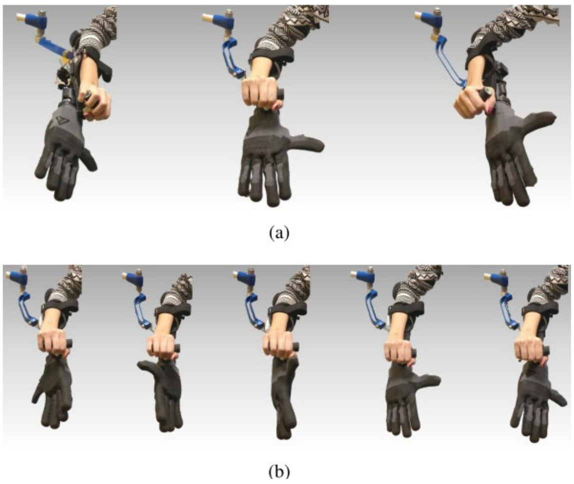

(a)
(b)

Figure 1-3 SoftHandX Extra Limbs

Summary: Research has indicated that by using mechanical devices it is possible to assist the user with a number of movements. These wearable robots can be used as rehabilitation tools to replace lost human limb capabilities, and to augment and enhance human load-bearing capabilities, as well as to extend the limb functions of normal individuals. However, since users must support the device with their own bodies, one of the main challenges in its design is to reduce the ergonomic burden on the human body while maintaining its function.

1.3 Research Assumptions

This project envisions the design of a wearable robotic arm used as an autonomous agent that the wearer can manipulate by pressing different buttons located on the front side of the wearer's arm. The arm can pick up objects that are out of the wearer's reach, help with person-to-person handovers when the wearer's hands are occupied, speed up repetitive tasks through self-handovers, and stabilize tools and objects in the wearer's workspace. The arm has a wide range of applications and can be used both for patients and for the common people. Some of the more specific activities that can be achieved with a robotic arm are: picking up objects from high places, picking up objects that are too hot or too cold through the robotic arm, and picking up objects passed by others when the hand is occupied. At the same time, in the premise of realizing such a robotic arm, the force load on the human body is analyzed and a more stable and lightweight material is chosen to reduce the burden on the human body.

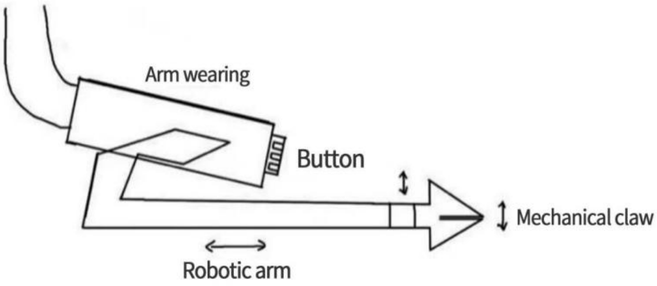


Figure 1-4 Overall Sketch

2. Approaches

This project intends to design a wearable forearm robotic arm with three degrees of freedom, which are the expansion and contraction of the slide, the up and down rotation of the wrist part, and the grasping and releasing of the robotic hand part. The preliminary structural modeling and design was carried out by autocad and solidworks, and part of the structure was made of existing materials. Circuit program design is carried out through arduino.

2.1 Structural Design

(1) Adjustable Forearm Fixer
This part is a fixer installed in the small arm part of the human, through which the robot arm is connected to the arm, as shown in Figure 2-1.

Figure 2-1 Arm fixer

(2) Robotic Arm Pulley Slide Structure

As shown in Figure 2-2, it is the base structure of the robot arm installed under the fixer. It consists of three parts. The front end of the extension is a U-shaped servo bracket that connects the manipulator with the robot arm. The overall extension uses a three-section telescopic iron structure. At the same time, a pulley structure is used to achieve precise extension of the robotic arm and retract it by means of a leather strap. The project fixed three pulleys on the extension structure to achieve the extension of each section, and connected the front end and the rear end by rubber bands so that the device could be retracted after extending to the very front end, as shown in Figure 2-3.

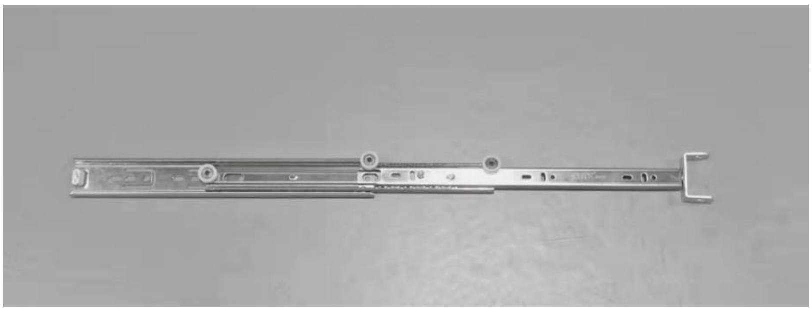


Figure 2-2 Tri-fold Rail

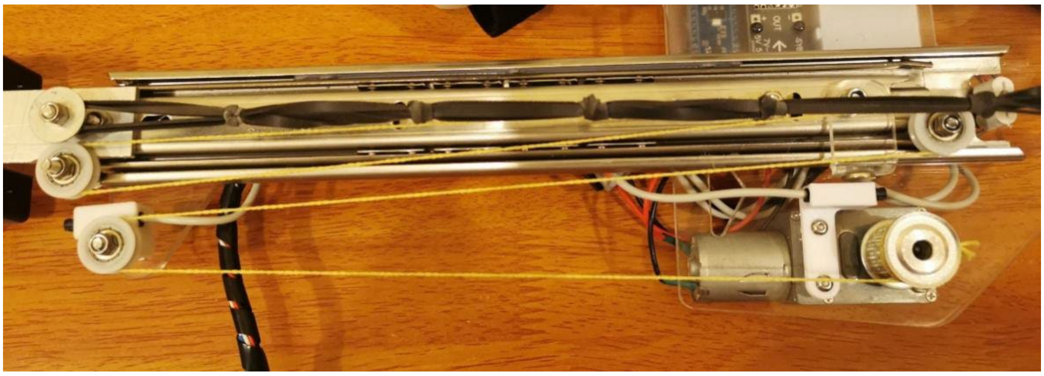


Figure 2-3 Pulley Slide Structure

(3) U-shaped Connection

As shown in Figure 2-4, it is a model diagram of a U-shaped connection, which is responsible for connecting the fixer on the human arm to the extension part of the robot arm. It is placed at the left end of Figure 2, and it is connected to the bottom of the left end of Figure 1. The entire U-shaped connection is partially hollowed out to reduce the weight of the overall robotic arm and to reduce the burden on the human body.

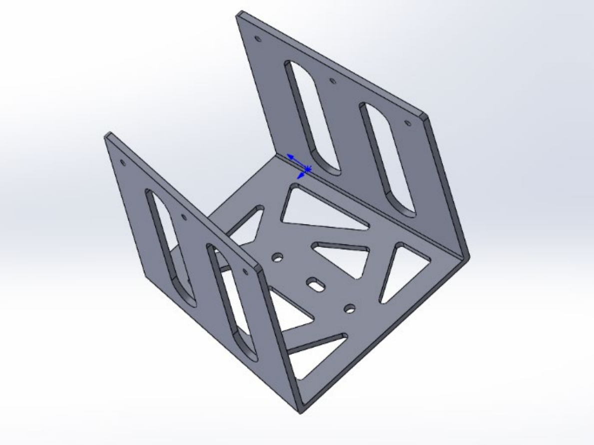


Figure 2-4 U-shaped connection

As shown in Figure 2-5, the flat design of the bottom part of the U-shaped connection. The hollow above is designed to match the connection of the motor, the connection of the slide, the connection of the pulley and the connection of the main board of the circuit.

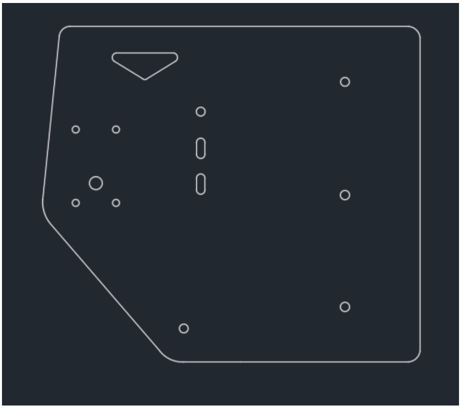


Figure 2-5 Base Plate Design Diagram

(4) Mechanical Claw

The project uses a mechanical claw structure as shown in Figure 2-6. But it will not use pneumatics for manipulation, instead it will use a rudder for manipulation. The project uses only two mechanical jaws and connects them to the self-designed servo structure. The two blue jaws and the tiller will be connected to the U-shaped tiller bracket at the front of the arm extension to play a gripping role.

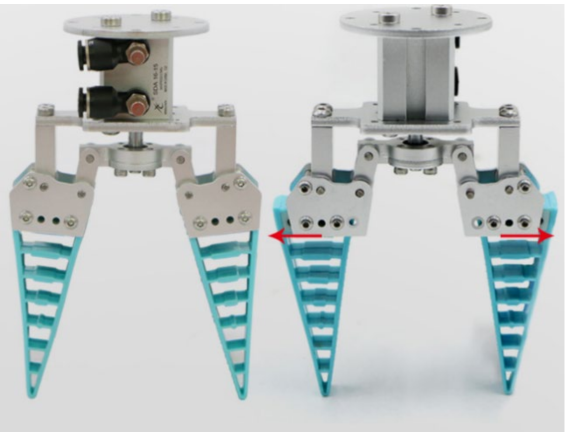


Figure 2-6 Mechanical jaws
Image Source http://www.robotanno.com/

(5) Mechanical Jaw Connection

Figure 2-7 shows the plan design of the mechanical claw connection structure part. It is mainly driven by the servo, which drives the gears to rotate, thus further driving the mechanical jaws to open and close. The two styles of straight and curved rods are designed to make the mechanical jaws close completely after measuring the angle.

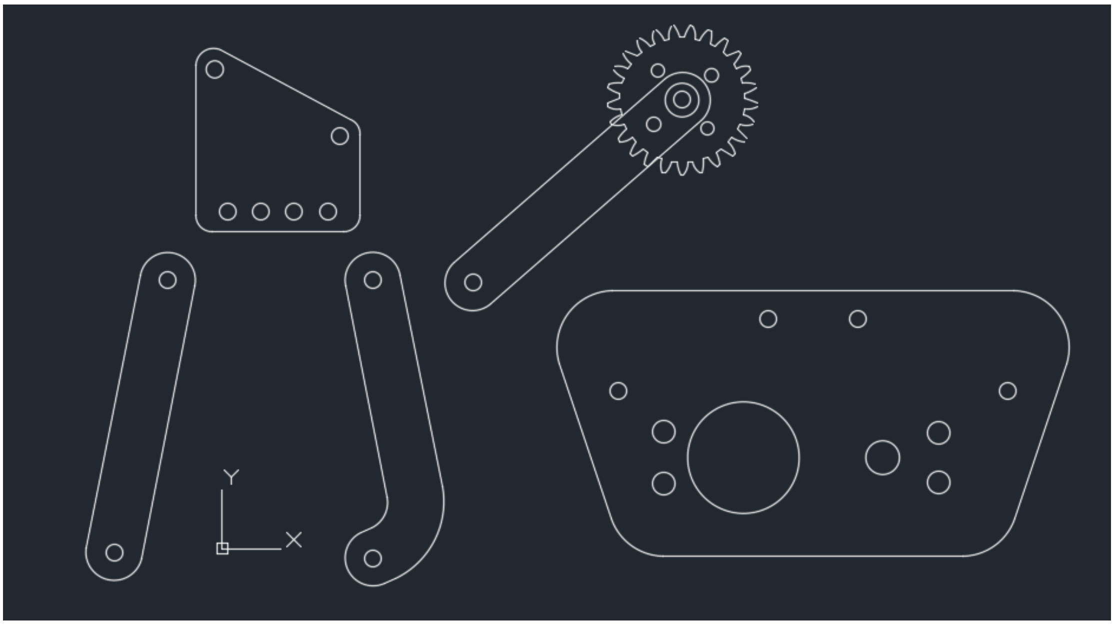


Figure 2-7 Mechanical Jaw Connection Structure Design

As shown in Figure 2-8, it is the final building effect of the connection part.

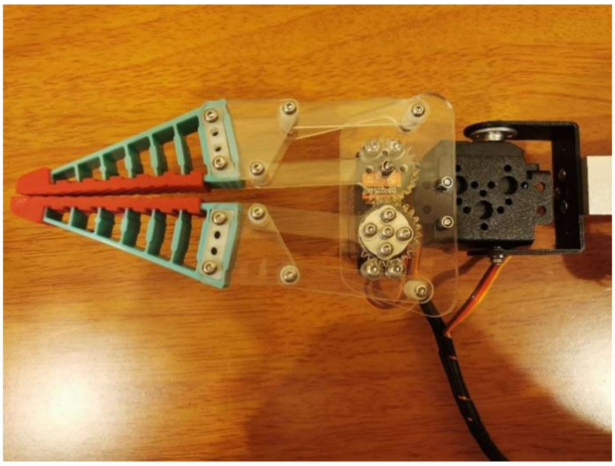


Figure 2-8 Structure Diagram of the Completed Mechanical Claw

2.2 Circuit Design

(1) Motor

As shown in Figure 3-1, this motor controls the pulley pulling wire as a way to extend the robotic arm. It is mounted on the rear side of the robot arm extension structure, that is, the other side in addition to the robot arm.

Figure 3-1 Motor
Image Source http://www.etonm.cn/

(2) Servo

Two servos are used in this project, as shown in Figure 3-2. One servo is to be mounted on the U-shaped bracket at the front of the extended part of the robot arm to control the up and down rotation of the mechanical claw; the other is mounted on the mechanical claw to control the opening and closing of the mechanical claw.

Figure 3-2 Servo

Image Source [10747258885_1460403377.jpg (1575×1575) (alicdn.com)]

(3) Electronic Control Module

Arduino is selected as the electronic control system in the electronic control module, as shown in Figure 3-3. The main reason is that it is convenient and flexible. It is easy to get started. At the same time, the development environment of Arduino is friendly and easy to combine with various motor models. It is a more suitable selection within the microcontroller.

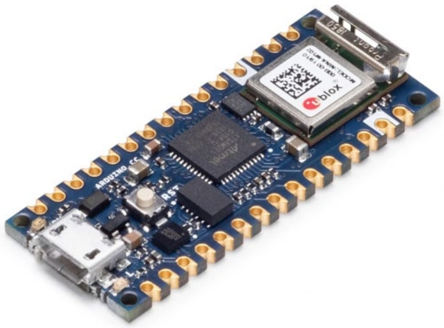


Figure 3-3 Arduino nano development board

Image Source Arduino - Home

(4) Magnetic Sensor

In order to prevent the mechanical arm from extending or retracting too much resulting in the destruction of the entire slide structure, a magnetic sensor is installed at the front and rear ends of the slide, as shown in Figure 3-4, to detect whether the slide is extended to the farthest distance or retracted to the initial position. Through the program, using the magnetic sensor, the robotic arm can stop at any position in the telescopic process, so as to facilitate the grasp of each position.

Figure 3-4 Magnetic sensor

Image Source www.directindustry-china.cn

2.3 Procedure Control

Figure 4 shows the flowchart of the programming part through the arduino software. When the whole robotic arm is powered on, the program will start and automatically initialize the values of several servos, motors, switches, and magnetic sensors. The device is mainly operated by pressing the four buttons located at the front. When the yellow button is pressed, the mechanical claw opens and closes when released. When the black button is pressed, the jaws are lifted 3° horizontally until they are lifted to 90° or the button is released. When the red button is pressed, the mechanical claw will deflect downward by 3° along the horizontal direction as a whole until it deflects by 90° or the button is released. When the green button is pressed, the mechanical claw will be extended forward and then retracted backward in a reciprocal motion. In the process keep judging whether the magnetic sensor is detected, and if so, stop the robotic arm telescoping, so as not to overstretch the entire pulley structure damage, so that the robotic arm can stop at any position in the middle. The above four buttons can be pressed and operated at the same time.

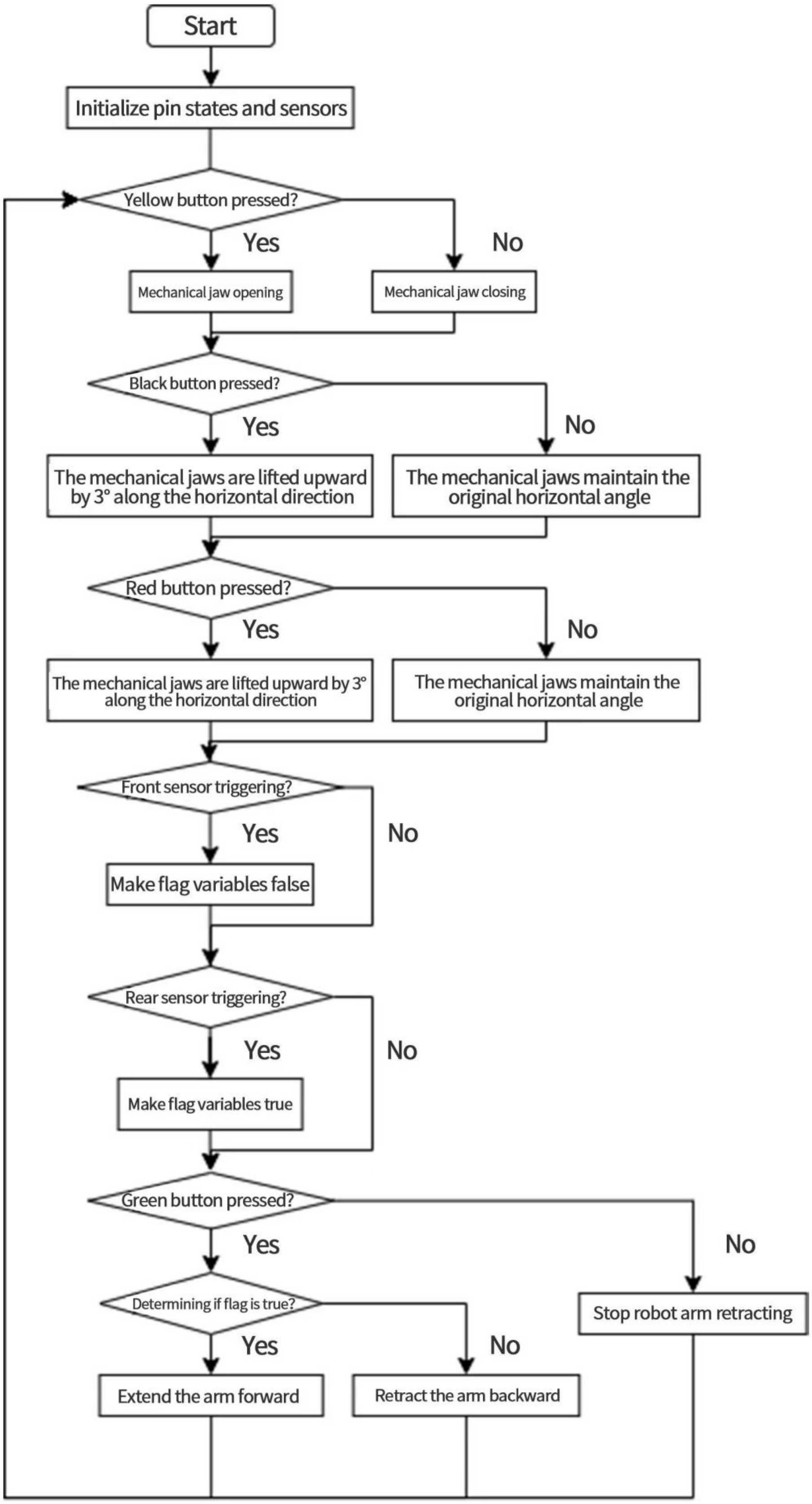


Figure 4 Flowchart

2.4 Overall Structure

The overall structure is shown in Figure 5. It is mainly divided into the robotic arm telescopic part, mechanical claw part and wearing part.

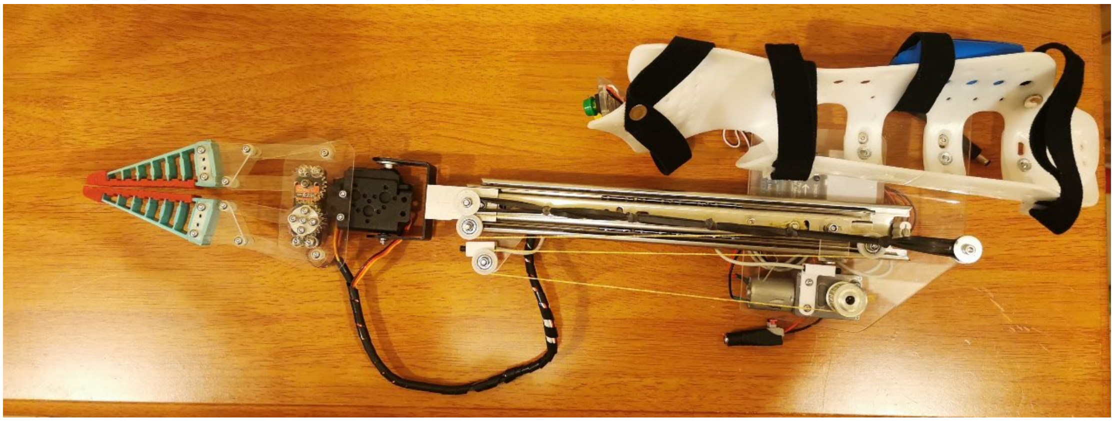


Figure 5 Overall Structure of the Device

3. Experiments and Results

3.1 Height Experiments

Experimental Purpose: One of the application contexts of the previous arm robotic arm is to grasp items at high places This experiment aims to investigate the height to which the robotic arm can steadily grasp items. Three different object picking clips are set up as control groups for the experiment and comparison.
Experimental Equipment: wearable forearm-assisted robotic arm, empty 550mL plastic water bottle, tape measure, three kinds of pick-up clips: folding pick-up clip, aluminum pick-up clip, and stainless steel fire pliers, as shown in Figure 6-1 from top to bottom.

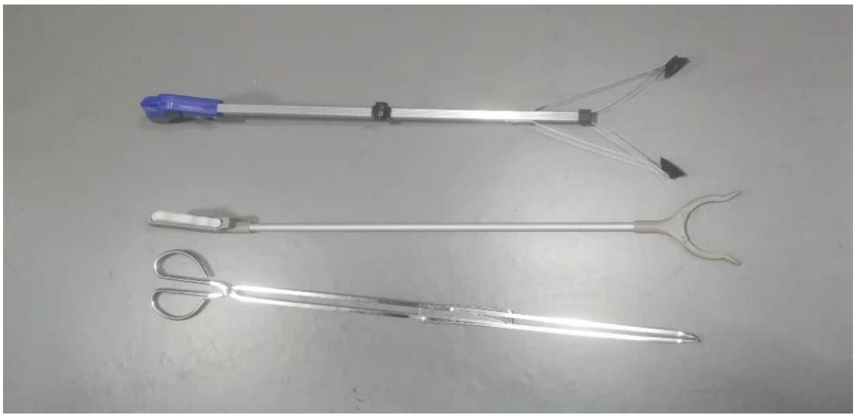


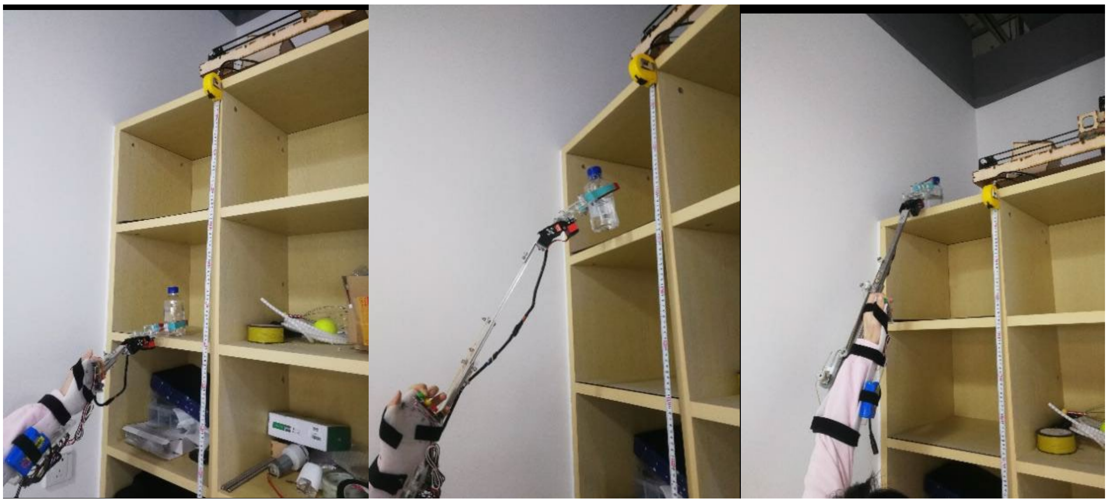
Figure 6-1 from top to bottom for the folding pick-up clip, aluminum pick-up clip, stainless steel fire pliers

The following table shows the comparison of each parameter of the three types of pick-up clips and robotic arms.

	Folding Pick-up Clips	Aluminum Pick-up Clip	Stainless Steel Fire Pliers	Robotic Arms
Weight（g）	183	147	625	1440
Height(cm)	74	77	77	64
Gripping Width(cm)	15	8	19	12
Form of Claw	Fan-shaped	Fan-shaped	Fan-shaped	Parallel
Material of Claw	Rubber	Plastic	Stainless Steel	Silicone

Experimental Procedures: The water bottles are placed on the storage shelves of different heights and the heights are measured with a tape measure. Firstly, the robot arm is used to attempt gripping, and the height of each experiment is recorded as well as the success of gripping. A total of five experiments are conducted for each height. Then the above experimental steps are repeated with three different pick-up clips. Successful grasping requires the water bottle to be moved steadily from the storage rack to the table.

Experimental Scenarios:



Experimental Record Forms:

Height (in cm)/success rate	Wearable Robotic Arm	Folding Pick-Up Clips	Aluminum Pick-up Clips	Stainless Steel Fire Pliers
150	100%	100%	100%	100%
185	100%	80%	0%	40%
220	60%	40%	0%	60%

Experimental Conclusions and Analysis: This experiment has tested three heights of 150, 185 and 220cm, and the wearable robotic arm can successfully pick up the items. Folding pick-up clips can steadily pick up items at low and medium heights. Items at high heights have a low success rate, which mainly stems from the fact that these pick-up clips are suction cup-type clips and the angle of the clips cannot be adjusted, resulting in a small contact area between the clips and the items and little friction, and the items may fall off in the process of picking up. Aluminum pick-up clips can not hold high items, primarily because its jaws are curved. If there is a certain angle with the horizontal direction when grasping, it will lead to curved can not clasp the items, thus making the items easy to slip off. The front end of the stainless steel fire pliers is straight. The higher the item is grasped, the larger the contact area and the greater the friction, which makes it possible to grasp very high items, medium height is more difficult.

Based on the experiments, several factors can be derived that affect the gripping success rate: weight and gripping angle. Compared to the robotic arm designed in this study, the two types of pick-up clamps and fire pliers cannot adjust the gripping angle, which will result in the inability to grip objects at high heights. It relies on the grip force exerted by the hand and the upward lifting force provided by the wrist, which will impose a greater burden on the human body and cannot grip objects with high weight. The robotic arm can complete the grasp of high objects that can not be taken by hand without the use of tools by adjusting the mechanical claw upward and downward tilt angle. In addition, it relies only on the force of the arm. It can rely on grip force. It has a larger grasping range than the pick-up clips, which helps to grasp heavy objects in a more stable manner. However, when facing a higher height, it is required to cooperate with the human arm extension, and the load on the arm will increase, which will cause some difficulties for some of the wearer's use. Such height conditions can not guarantee the success of the grasp each time. Such problems can be improved by increasing the length of the slide rail and the lightweight structure.

3.2 Weight Experiments

Experimental Purpose: The weight of the object is an important factor limiting the use scenario of the robotic arm. This experiment hopes to measure how much weight of the object can be successfully grasped by the robotic arm for subsequent optimization.
Experimental Equipment: Wearable forearm-assisted robotic hand Water bottle Measuring cup Electronic balance
Experimental Procedures: Measure different weights of water from the measuring cup, fill it into the water bottle, and try to operate it through the robotic arm. The success of this experiment is based on the fact that the robotic arm can grip the water bottle and lift it 20cm from the desktop height, and then place the water bottles on the desktop 100cm apart. Experiment to observe and record the weight of the water bottle and the success of the experiment or not.
Experimental Scenarios:

Experimental Record Forms:

Weight (g)	100	200	300	400	500	600	700	800	900	1000
Success or Not	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No

Experimental Conclusions and Analysis: The robotic arm can grasp objects up to 700 grams in weight, which is sufficient for most grippable objects. Many overly heavy objects will not be able to complete grasping due to poor gripping, slipping or excessive handling time resulting in excessive body load, which can be improved by selecting more massive mechanical jaws, as well as the lightness of the structure to grasp more heavy objects.

3.3 Success Rate of Grasping Different Items

Experimental Purpose: To test whether the robotic arm can successfully grasp different kinds of items, namely the use scenario planning for robotic arm grasping. Also three different kinds of object picking clips were set as the control group for the control experiment.

Experimental Equipment: wearable forearm-assisted robotic arm, various kinds of items (cushion, toothpaste, grapefruit, apple, cell phone, cream, plush toy, clip, book, chocolate box) as shown in Figure 6-2.

Figure 6-2 Various types of items to be grasped

Experimental Procedures: Firstly, the different items are grasped one by one by the robotic arm, and each item is grasped five times in total, of which the number of successful grasps is recorded. Then, the above experimental steps are repeated by using three different pick-up clips for clamping respectively. The success is judged by lifting the item from the table and maintaining it for 5 seconds, and putting it back to its original place after 5 seconds.

Experimental Scenarios:

Experimental Record Forms:

Item Name/Success Rate	Wearable Robotic Arm	Folding Pick-Up Clips	Aluminum Pick-up Clips	Stainless Steel Fire Pliers
Cushion	100%	80%	100%	0%
Toothpaste	100%	100%	100%	100%
Grapefruit	0%	0%	0%	0%
Apple	100%	80%	0%	40%
Phone	0%	0%	0%	0%
Face Cream	100%	80%	0%	20%
Plush Toy	80%	100%	100%	80%
Clips	100%	100%	100%	100%
Books	20%	0%	0%	0%
Chocolate Box	60%	20%	0%	60%

Experimental Conclusions and Analysis: This experiment has tested ten types of objects with different hardness and thickness of objects, such as cream. Mechanical claws are very easy to grasp and will not fall. But fire pliers and aluminum mechanical claws are very difficult to grasp. For soft items, mechanical claws can also successfully achieve the grasp. When placed flat on the table, mechanical claws can not grip such no thickness items such as cell phones. Some easily deformable objects, such as paper structures, can be partially grasped, but will cause damage to the item itself. It is recommended that the mechanical claw be used to grip hard items with thickness, or completely soft items.

Control Experiments

Experimental Conclusions and Analysis.

(1) For the analysis of the three kinds of pick-up clips themselves

Folding pick-up clip itself is lighter, which is beneficial to clip heavy objects. Aluminum pick-up clips own weight is small. It is easy to operate. Stainless steel fire pliers have heavy weight. They are more difficult to open, so it is not easy to use. Their jaws are in the form of fan-shaped, where the stainless steel fire pliers can open the largest angle, grasping a larger range of items. The angle aluminum and folding pick-up clips opened is smaller, grasping a smaller range of items.

(2) For different items of grasping

In the experiment for different materials and different shapes of items, the folding clips perform well, but there is still the case that they cannot pick up heavy items. The aluminum pick-up clip has the problem of not being able to grip due to the small jaw gripping width, such as a wide drawer paper. Also, it is unable to grip heavier items, such as cans. For different types of items, stainless steel fire pliers can also be successfully grasped. Its main problem is the self-weight is too large. It relies on the force given by the human hand to open the clamping pliers, and is able to grasp items of lighter weight. The grasping process is very burdensome to the human body, which may lead to items falling in mid-air because of insufficient grip.

3.4 Conclusions and Outlook

The device is able to perform auxiliary operations after being built for initial test use and is summarized as follows:
(1) The wearable robotic arm can grasp objects at high places by telescoping;
(2) The wearable robotic arm can assist the wearer in handing over objects;
(3) Wearable robotic arm can adjust the angle of mechanical claws to facilitate the grasping of various scenes and angles of objects;
(4) Wearable robotic arm is more convenient to put on and take off, not limited by the use of location.
In the process of testing there are also many places in the device that can be improved:
(1) The overall weight of the device can be further reduced to obtain a more comfortable wearing experience, and the material used in the slide structure can be optimized to achieve a lightweight material;
(2) The length of the track and the size of the mechanical claw can be adjusted to accommodate a larger gripping range;
(3) The use of pressure sensors to detect the pressure of the toes, instead of button interaction, so that the robotic arm can run away from the left hand;
(4) The robotic arm can be used in the future as an additional limb in the space field to assist astronauts in the space environment to complete their tasks.

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