Improving Manipulators[1] by Imitating Arthropod Body Structures

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1 Introduction

The past few decades have witnessed the dramatic development of robotics technology, with one of which being the advanced electronic devices and programs. With the help of these developments, engineers are enabled to build complicated manipulators with extremely high accuracy, especially ones adopted for medical use. However, it appeared that people pay less attention to the design of arms for some simple tasks. For example, for the task of grabbing various shapes and different sizes of objects such as round balls or square objects, the human hand like finger design might not be the best design option in terms of functions, reliability, and cost. In this case, the imitated arthropod body structures as a pair of robot arms could be the good design option. The complicated finger design could be very expensive, and yet not as reliable as arthropod body structure in holding the objects securely. Sometimes, it is not uncommon that an object held by human like hand fingers are dropped off. Being the most successful group of animals, arthropods have a variety of body structures that can be adopted to enhance the manipulators of robots. Following the idea that manipulators can be enhanced with the nature's design, I study body structures of a few arthropods and build a pair of arthropod-imitating robotic arms that show enhanced grip and fewer opportunities of dropping off objects in practical operation experiments, especially when collecting a large amount of small objects.

2 Background of Design

2.1 Inspirations from Arthropods

Arthropods have evolved for hundreds of millions of years, becoming the group of animals that capture tremendous niches with various long-tested specialized body structures to adapt a wide collection of environments, especially versatile arms embracing a large quantity of functions. The structures of arthropods, objectively evolved and gradually perfected by nature in hundreds of millions of years, can be excellent examples for mankind to imitate when designing enhanced robotic arms for certain tasks such as grabbing objects securely.

2.2 Disadvantages of Current Prevalent Practical Manipulators

The new century begins with the new focus on electronic engineering with great achievements on programming and designing electronic parts of robots, one of which being the most popular term "Artificial Intelligence" that everyone takes interest in. Most engineers follow the trend of booming electronics and spare less effort working on traditional electronic engineering fields. However, more people give up studying mechanical engineering, thinking

[1] Because the following contents includes mainly designing manipulators based on arthropods that do not have segments defined to be distinguished as arms or hands, in this paper, both "manipulator" and "robotic arm" refers to mechanical structures for catching objects.

that mechanical designs more or less are mature in technology and have little room for enhancements, which ceased the growth of better designs of shapes and mechanisms of robot structures.

On those robots with talented designs of programs, electronics and even AI, the manipulators sometimes remain to be refined. The pair of manipulators in Figure 1[2] is a representative example of designers' trying to simplify the human-hand-like robotic arms by eliminating part of joints of fingers, but this kind of arms function worse with fingers that almost work as two plastic boards that differ from their sizes hitting each other.

Figure 1 Service Robot with Representative Unsuccessful Manipulators

Furthermore, participants of robotic competitions sometimes also make mistakes that they focus mostly on designing the strategy and programs but less on designing manipulators. Usually, those teams with complicated programs and clear strategies lose because of 1 or 2 poms their manipulators drop.

What's shown in Figure 2 is a structure that those teams often build, which is the common impression of robotic arms in most people's mind as if two sticks can grab anything just like how chopsticks work. However, such manipulators do not always function as perfect as imagine. The physical analysis points out the problem that the resultant force that the manipulator casts on an object points to the outer side, accelerating the item and pushing it away.

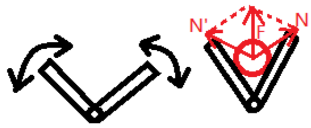

Figure 2 Diagram of some manipulators of teams

Compared with designs that could have been enhanced without losing anything, arthropods are born well designed for they have been struggling for survival for more than half a billion of years, meaning that every part of their bodies has defeated hundreds of catastrophes and emergencies, which means that there is every reason for humans to imitate arthropod body structures.

3 Introduction and Analysis of Body Structures of Arthropods

3.1 Insects

For it is the group of animals with the highest bio-diversity in both quantity of species and body structures, "Insecta" is loud enough to be brought to robotic designs. The mouth parts can be great inspirations for designing robots because they are often evolved into claws to prevent preys from escaping.

Figure 3 Antlion Larva [1]

The mouth part of the antlion larva presents excellent inspirations of designing the basic shapes of robotic arms. Hiding beneath the hole dug on sand, antlions have fewer opportunities to give an additional strike when waiting for unfortunate ants to step into their traps if those ants are clever and strong enough to dodge their first attacks. In order to prevent those ants from simply passing on their traps, antlions

[2] The robot is designed by Sinsun Company. The original website where I found this picture is down.

have long, claw-like mouth parts that are as strong as the pincers of crabs. With the assistance of those refined mouth parts, antlions can drag those ants into their sand hell in one precise shot.

3.2 Arachnids

Being the earliest animals that started their adventure from the oceans to the continents, Arachnids have evolved for almost the longest time in all existing arthropods as the elders with various bizarre but efficient body structures for grabbing that have remained unchanged for ages. While powerful pedipalps can be easily found pressing hard on struggling prey on common spiders with venom, such structures can play a more significant role in grabbing items on rarer groups of Arachnids.

Figure 4 *Phrynus Whitei* [2]

Arachnids in order *Amblypygi*, or the so called whip spiders, have pedipalps specialized entirely for hunting preys that are always ready to fight back and get rid of their deadly hugs. For they do not have powerful venoms, whip spiders rely on their arm-like pedipalps well-designed by the nature. While other whip spiders enhance their grips with only longer pedipalps and spikes, those in genus *Phrynus* posses extra pair of swift, sharp claws at the end of their pedipalps that act like barbs of arrows to penetrate the body of prey, locking their preys firmly in front of their mouth. In addition to such capability of catching items, those arms have another great advantage that they can be folded to capture maximum space even though they are usually longer than arms of other animals such as mantises and scorpions after deployed.

4 Prototype and Specific Analysis of Advantages

Because the amblypygi pedipalp imitating arms are more achievable, only the prototypes of such arms are made.

4.1 Basic analysis in designing

The same as the pedipalps of whip spiders, those imitating arms have great advantages of grabbing large items tightly, getting things stuck between the pair of arms just like those whip spiders hunting gigantic preys in the forest.

The well-designed muscle systems of whip spiders have helped them survive for hundreds of millions of years, but the basic frame of Arachnid muscles restrained whip spiders' arms to deal with things other than catching preys by limiting the angles that the arms might spin. However, humans can greatly enhance the power systems of those arms and bring to wider use with some other smaller improvements.

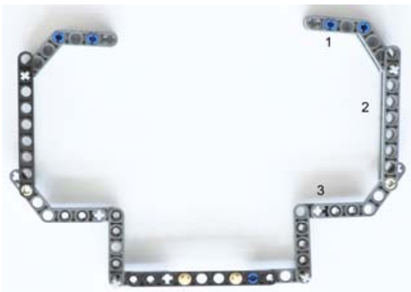

Figure 5 Basic Frame of the Arms

4.2 Prototype Design

First, we built the basic frame of the arms (shown as Figure 5). It goes without saying that even though designing the shape is hardly a difficult task, a badly designed shape can ruin all the versatile advantages of the robot. Making the shape of arms imitating whip spiders theoretically enables manipulators to grab large objects as firmly as those whip spiders do.

The most ideal condition is that sufficient amount of motors with proper size can be added to the joints of the arm, meaning that the pair of arms can move independently and the horizontal motion is hardly limited. However, in designing practical robots, both the amount of motors and parts required and the cost of the entire robot shall be considered, which points out that ineffective or excessively complex structures of the robot shall be refined to ones that are more effective and easier to operate. The problems caused by the size of motors are hardly ignorable as well.

Designing whip spider imitating arms aims to improve the efficiency of grabbing items but not operating complicated machines precisely as human hands, meaning that the most important standards to judge if the arms are made successfully are how tightly the arms can hold objects and how many objects the arms can catch at one time. Whether the arms drop items should be considered as well. Thus excessive amount of motors to control joints independently is a sign of ineffectiveness and it is necessary to simplify the power system of the arms in order to make essential improvements to simplify controls and reduce the possibility of dropping off objects without losing basic functions and advantages of the arms.

Before the “mechanical muscles” of the arms are made, the angles of the arms could be designed freely, and where to put those motors depends on practical purposes. The manipulator is designed to both catch larger items like sponge cubes and collect a large amount of smaller objects like the poms without dropping off a single one, so the manipulator does not require excessive amount of independently controlled joints for operating machines precisely and the angle of arms can be determined from my initial ideas.

The breakthrough discovery is through testing how to move two joints with the control of a single motor in order to make them spin as the angle expected.

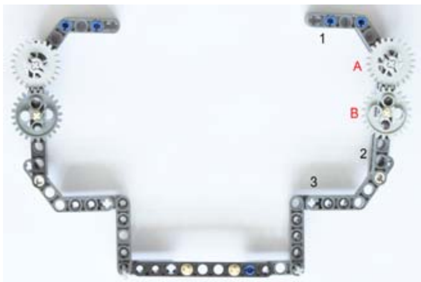

Figure 6 Basic Frame with Gear A and Gear B.

The obvious point is that arm 1 is driven by gear A activated by gear B (shown as Figure 6), so the tip of arm 1 can move in a special trajectory if gear B rotates with arm 2 spinning as the result of a combine of two motions. The first motion is the tip of arm 1 to rotate about the center of gear A and the second motion is arm 2 to rotate about the connection between arm 2 and 3.

I discovered that if the lengths of arms (pedipalps of whip spiders) and the sizes gears (the joints on pedipalps) are selected, the trajectory of the tip of arm 1 can be prescribed.

Figure 7 Completed Manipulator

The process through which engines of cars compress the gaseous fuel creates great inspirations for me to design a mechanism to activate both arm 2 and gear B. Besides the main driving gears to activate both sides of the arms (the small gears at the bottom between two larger gears in Figure 7), I use a mechanism (arm 2, 3, 4, and 5) to drive arm 2 as well as gear B, which in turn to drive gear A and arm 1 instead of using a second moto. This crank and link mechanism makes such simplifications possible by transforming circular motions [3].

I, therefore, test the arm tip motion and after several tweaks, the arms can function as designed perfectly (shown as Figure 8).

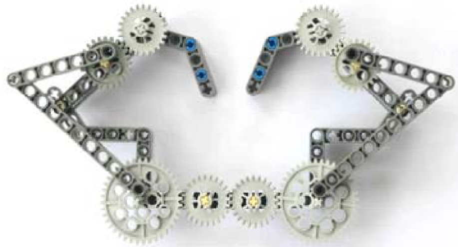

Figure 8 Sample Position of Completed Arms in Motion.

5 Practical Operation of Finished Prototype

To show what "perfect" means, I get the arms fixed on table, mark 3 points of each arm 1 and 2 points of the middle and the end of arm 2 and pose 5 phases, drawing spots at the position of points on a piece of paper in order to draw an approximate graph of the motion of the arms.

This is the graph I drew. Points at different locations use different colors to show the shape of arms at each location, and these five locations can show the general trace of motion of the entire manipulator.

Figure 9 shows that because of the special design, arm 1 spins when arm 2 is moving, locking objects(especially small ones) that arm 2 might sweep away or fail to cover if it stands alone.

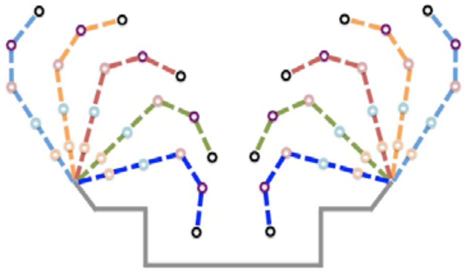

Figure 9 Connected Points Photocopied and Transformed to Digital Form.

In order to show the special advantages of this manipulator in practical use, I put it on a robot with a servo that can lift the manipulator up to test if the robot can grab poms used in Botball competition perfectly. This pair of arms is specialized for grabbing a large amount of soft objects with the new "spikes" fixed on arm 2 inspired by spikes on whip spiders.

The four phases in Figure 10 shows that the arms can crab all the five poms in range firmly and lift up all those poms without dropping off a single one, which means that my initial goal of designing this manipulator is achieved.

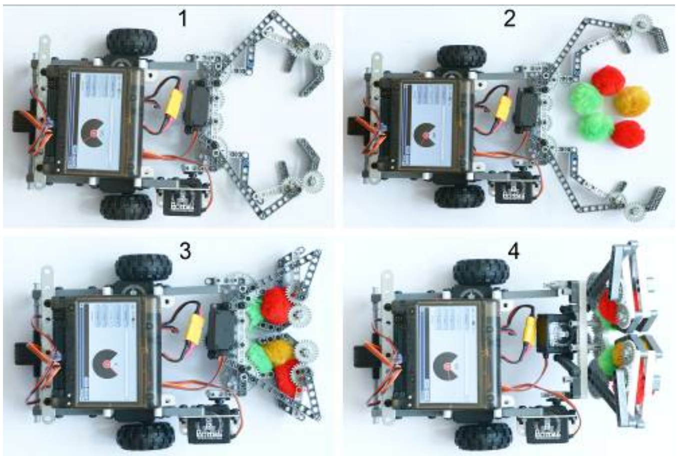

Figure 10 Practical Operation of the Manipulator

6 Conclusions

From the above discussion and analysis, it can be concluded that imitating body structures of arthropods leads to a bright future of improving manipulators to at least ones imitating whip spiders with enhanced grip and fewer opportunities of dropping off objects, not mention that there are more than one million arthropod species with various specialized body structures to bring to manipulator designs. It goes without saying that those body features can be excellent inspirations for improving all aspects of all fields of all people’s life.

As the technology of motors, sensors, programs and other components of a manipulator develops, a huge number of robot helpers built from versatile arthropods will be providing essential assistances to people’s everyday life and enhance the total technology level of all human beings. It will not be a dream that those “arthrobots” helping humans with their well-evolved bodies discovered from the nature can lead to a world of harmony where everyone finds out that those hardly welcomed tiny arthropods can be their friends just like their robots.

Moreover, the educational effect of those arthropod manipulators can hardly be ignored. People have been using the models of arthropods for teaching muscle systems in Biology classes and vice versa, the bodies of arthropods can help students have a clearer comprehension of many mechanical structures. Those versatile structures of arthropods also attract the students’ interests about studying both Entomology and Mechanical Engineering, leading to a trend of combining multiple disciplines. It is obvious that the education in the near future puts great priority on cross-disciplinary studies that can make greater achievements than studying a single subject, and those manipulators inspired by arthropods make the first solid step.

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