

## CONTINUUM ARM MANIPULATOR REFINEMENT FOR ASSISTIVE TECHNOLOGY

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### ABSTRACT

*Rigid link robots currently dominate the market for manipulators in assistive technology, though research on continuum robots for assistive technology has been developing over recent years. These types of robots have a continuous backbone that allows them to have infinite degrees of freedom, making them highly compliant, however this brings challenges in terms of modelling and control. In this work, we describe the design for a continuum arm suitable for assistive technology applications.*

Keywords: Continuum manipulator, robotics, assistive technology, robot design

### INTRODUCTION

Assistive technology is defined as any item, piece of equipment, software program, or product system that is used to increase, maintain, or improve the functional capabilities of persons with disabilities. The research presented here focuses on using assistive technology to help with activities of daily living (ADLs). ADLs are a series of activities that are performed daily and are necessary for living independently. These include tasks in the categories of personal hygiene, dressing, eating, maintaining continence, and transferring/mobility.

With a growing number of people becoming dependent on professional healthcare services, there has been a growing interest in the use of robots in assistive technology [1]. Currently there are three different kinds of assistive robots. One type is social assistive robots that are utilized to interact with elderly patients to potentially increase health and psychological wellbeing [2]. There have also been robots, such as the MIT-MANUS, that are used for physical therapy [3]. The last kind are robots to help replace limited arm movement. They use telemanipulation to allow the user control of the robot with an

input device, such as a joystick. Focus for this research is on assistive robots to replace limited limb movement.

The assistive technology robots on the market today are strictly rigid link robots. A rigid link robot is a robot that has rigid, inflexible segments connected by several joints. The displacements and rotations defined for this type of robot is limited to certain, selected degrees of freedom. Of those rigid link assistive robotic arms currently on the market, the two most prominent are the MANUS [4] and JACO [5] arms. The MANUS has 8 degrees of freedom (DOF) and the JACO has 7 degree of freedom (DOF). Both arms are wheelchair mounted assistive robotic manipulators (WMRM) with payload capacities of about 1.5 kg each.

The MANUS arm can be controlled with a joystick, keypad, head band, or spectacle mounted laser pointer. There is also the possibility to control MANUS with other specialty devices for control with a non-disabled body part [4]. The JACO arm is controlled with a three-axis joystick. By switching into one of the three different modes, accessed by using pushbuttons, different functionalities of the arm can be controlled and utilized.

While these rigid link robots have been proven to aid in assistive technology and increase quality of life for people living with disabilities [5], there are some drawbacks that come with this kind of robot. Their rigidity makes them a potential safety hazard while interacting with humans, especially those living with disabilities that may impede on their ability to move out of the way or prevent the robot from hitting them. Another considerable downside of the assistive robots on the market today is their price, often greater than \$35,000 making them inaccessible to most potential users.

Unlike rigid linked robots, continuum manipulators do not depend on discrete, rotational joints for movement. Continuum

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robots utilize a continuously flexible backbone that allows them to exhibit infinite degrees of freedom [6]. As robot continuity lies on a spectrum, many current research efforts aim to push robotics further towards being fully continuous, while some are developing hybrid type robots, that exhibit a mix of rigid joints and flexible segments [6]. Though research in continuum robotics has been limited, multiple papers have described continuum manipulators having infinite-DOF, elastic structure, continuously bending, and lacking rigid links and rotational joints [7–11].

Continuum manipulators are growing in popularity largely because of their inherent flexibility and compliance. These types of manipulators are inspired by elephant trunks, snakes, and octopus tentacles. They theoretically have the ability to maneuver easily in challenging and dynamic environments and can utilize both their end effector and the entirety of their length to wrap around and grasp objects. These qualities have made them a target area for research in applications such as space operations and underwater operations, though they are also well known for their application in the medical field.

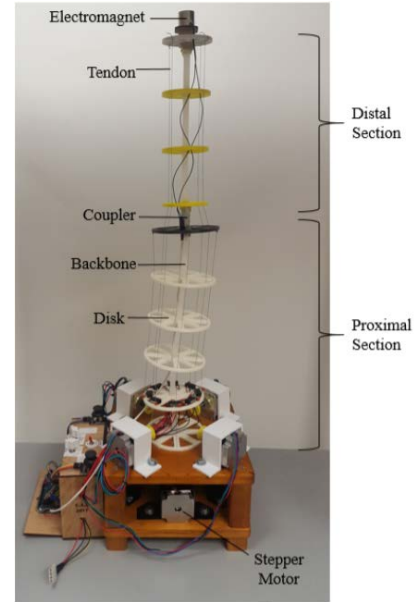
While there are many benefits to using continuum manipulators, accurate control and modelling of these types of robots is a difficulty that is often documented [8–10]. Piecewise constant curvatures [12], inverse kinematics [13], and various geometric approaches have been used to control and model such manipulators. However, many of these approaches lead to computationally intensive solutions that are not always feasible in real time.

This work presents a modified version of the tendon driven continuum manipulator, Bendy ARM [14,15], shown in Figure 1, which was the first iteration of the device to undergo user testing [16]. The new iteration of the robot has modifications to the backbone and base components to improve operation and maintenance of the robot. Limit switches are used for orientation tracking and improved operational abilities. With these modifications to Bendy ARM, this work continues with the objective of creating a low cost, continuum robotic arm for use in assistive technology.

## DESIGN

The previous iteration of the manipulator contained a backbone constructed by two separate low-density polyethylene (LDPE) rods that attached together by a metal coupler at the intersection of the distal and proximal sections. The total length of the backbone was 70.5 cm. The disks in the proximal section had a diameter of 11.4 cm and the distal section disks had a diameter of 7.6 cm. The disks were spaced 7.6 cm apart along the backbone. The tendons that run the length of the arm are made of 50 lb braided fishing line. The base was made of wood and contained two levels. Stepper motors were used to actuate the robot and were contained in the base. Each level contained four motors with the proximal section motors being in the bottom level and the distal section motors were on the top level, rotated

by 45 degrees from the bottom motors. The end effector was an electromagnet.



**FIGURE 1:** Bendy ARM functional design. Photograph available under a CC-BY license from [17].

The arm is maneuvered using two joysticks, which control the angle and direction of the manipulator's movement. The robot can be operated with one of three control schemes: Dual-Joystick, Single-Joystick Segmented, and Single-Joystick Compensative, as described in Coulson et al. [16].

## 2.1 Mechanical Refinement

The previous iteration of the robot needed to be modified mechanically to implement more advance and useful controls to help reach and benefit the target users. The LDPE's proximal sections had areas that maintained curvature from plastic deformation. Due to material fatigue, the backbone could no longer support the weight of the arm without the aid of tendons. This negatively impacted ease of driving the robot. Criteria for backbone material selection includes having high elasticity, allowing the rod to bend in the ways needed for robot movement without deformation, and being able to support itself, but also bend with a force that the motors could supply.

One material that matched these criteria is nitinol, a nickel titanium alloy. Nitinol has a super elastic property when placed under strain slightly above the transformation temperature. When under stress, martensite is formed. Once the stress is removed, the martensite turns back into undeformed austenite. This means that the material can undergo high strains without plastically deforming. However, after testing candidate backbones of nitinol with diameters ranging from 2 mm to 5 mm, no solution was found which could support the loads applied by the motors without permanent deformation due to high localized strains. Therefore, a new LDPE backbone was installed instead,

highlighting the need for a backbone material less susceptible to material fatigue.

The original base of the robot was made of wood and featured two levels where the motors were mounted. The modified design moved the motors to a single support platform (see Figure 2) to reduce the overall size and weight and to provide greater access to the motors. The base has a square wood bottom that is 25 cm by 25 cm with 4 legs attached. The middle support is made of a 3.1cm diameter rod with a length of 9.7 cm. Wood was also utilized as the material for this design because it was easily accessible and cost effective.



**FIGURE 2:** New base with a more compact design.

## 2.2 Control Refinement

Tendon slack became prevalent during operation of the continuum arm, and so hindered general use of the robot by reducing overall control of the manipulator. If the user were to prompt the robot to move forward, it might take several moments for the motors to coil the tendons, and move the robot as planned. Use of the limit switches was expanded from tightening all tendons at the end of the homing function, to keeping track of tendon tautness throughout all types of manual and automatic movement. To compensate for this tendency for slack, motor speeds constantly adjust to keep the tendons tight. The default motor speed is a slow speed. Based on the direction of the motors and communication from limit switches, it was determined that the motor speed would increase if motors are tightening tendons and the corresponding limit switch is open, or speed would decrease if loosening tendons and the limit switch is open. While motors still act in pairs by moving in opposing directions, their rotation counts and individual speeds may now differ from one another.



**FIGURE 3:** Modified Bendy ARM.

## CONCLUSION

The modified design shown in Figure 3 is a continuum arm manipulator that is a tendon-driven continuum robot that could be used as an assistive technology device for people living with disabilities. The current research showed that nitinol may not a viable solution for the size of continuum arm that is being designed. Additional opportunities exist if manipulator position can be more precisely monitored, for example, using inertial measurement units. Additionally, the tendon lengths and the Euler angles may also be used to describe the manipulator position. With further research, we believe there is a high potential to utilize continuum robots with automated tasks in assistive technology. Supplemental files including solid models and code can be found in Swanson et al. [18].

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