

Bendy ARM 2.0: Continuum Arm Manipulator Refinement and Control 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. Additionally, materials for this type of application require specific qualities. In this work, we attempt to address these problems while designing a continuum arm suitable for assistive technology applications. Bendy ARM 2.0 is a revised version of the first Bendy ARM robot to accomplish these goals. In its first iteration, Bendy ARM had limitations in its mechanical function, such as the structural performance of the backbone, which decreased the accuracy in positional control. Nitinol was tested as a new backbone material but failed during testing so a low density polyethylene was chosen. Cable conduits were added to help reduce the mechanical coupling between the proximal and distal segments of the manipulator. Motion processing units (MPU) are utilized to gather tilt angles and provide direction for automated movements. Due to the arms natural rotation, this data alone was not enough to consistently control and place the robot. With the information gathered, further consideration of backbone material and usage of MPU data is required for an automatable robot.

1 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 disabilities¹. Assistive technology can be used in a variety of scenarios that can include academic and learning aids, assistive listening devices, computer access, mobility aids, pre-vocational and vocational aids, seating and positioning, and visual aids². 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

¹ [What is AT?](#)

² [Definition of Assistive Technology](#)

daily and are necessary for living independently. These include tasks in the categories of personal hygiene, dressing, eating, maintaining continence, and transferring/mobility³.

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 (Ansari et al., 2017). 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 (Broekens, Heerink, & Rosendal, 2009). There have also been robots, such as the MIT-MANUS, that are used for physical therapy (Trafton, 2010). 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 joystick⁴. 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 freedom⁵. Of those rigid link assistive robotic arms currently on the market, the two most prominent are the MANUS (Romer, Stuyt, & Peters, 2005) and JACO (Maheu, Archambault, Frappier, & Routhier, 2011) 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 (Romer et al., 2005). 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 (Maheu et al., 2011), there are some drawbacks that come with this kind of robot, the first being that they only have the 7 DOF. This tends to limit the overall mobility and useful assistive application for these robots. It can only move at the determined joints and in specific directions. They are also very rigid and hard, making them a potential safety hazard while interacting with humans, especially ones 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. The cost of the JACO arm is relatively steep at about \$35,000 making it not very affordable or accessible for many people⁶.

³ [Activities of Daily Living](#)

⁴ [Rehabilitation Robot](#)

⁵ [Rigid Link Robot Analysis](#)

⁶ [CobotsGuide | Kinova](#)

Rigid link manipulators are most popular in factory and industrial settings. They are highly useful for accurate positioning of their end effector, having the ability to move objects, and are easily programmable and controlled. They have discrete joints, each accompanied with actuators, and solid links connecting their joints (Walker, 2013).

Unlike rigid linked robots, continuum manipulators do not depend on discrete, rotational joints for movement. Continuum robots utilize elastic material that allows it to exhibit infinite degrees of freedom (Mishra, Del Dottore, Sadeghi, Mondini, & Mazzolai, 2017). There has been a history of soft or flexible robotics which often share similar features as continuum manipulators, in that they're made of soft material, able to bend, and have at least a semi continuous backbone (Ansari et al., 2017). As continuity lies on a spectrum, many current research goals aim to push robotics further towards being fully continuous, while some research also goes into making hybrid type robots, that exhibit a mix of rigid joints and fluid segments (Mishra et al., 2017). Though research in continuum robotics has been limited, multiple papers have defined continuum manipulators as having infinite-DOF, elastic structure, continuously bending, and lacking rigid links and rotational joints (Chamberlain, Kordell, & Wall-Epstein, 2015; Renda, Cianchetti, Giorelli, Arienti, & Laschi, 2012; Togashi, Matsuda, & Mitobe, 2014; Walker, 2013).

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 may have the ability to maneuver easily in challenging and dynamic environments and can utilize both their end effector and the entirety of their backbone to wrap and grasp objects. These qualities have made them a target area for research in applications such as space operations, underwater operations among others, though they are known mostly for their application in the medical community.

For example, this technology in minimally invasive surgery would ideally bring precision, accuracy, and ability to access surgical sites delicately, with the potential to reduce required instrumentation (Burgner-Kahrs, Rucker, & Choset, 2015). While traditional robots have the precision control required for surgery, their rigidity can be considered a drawback in the medical field, and many others.

Most of the time, traditional robots, which are often large and heavy, are used in isolated environments (Walker, 2013). This is because they do not work well in dynamic situations where human safety is of concern. Continuum manipulators have been explored for reasons specifically dealing with human safety, because they're a suitable and safe alternative to rigid link robots.

Since continuum robots are inherently safer working around humans, there is a potential that they could be utilized as an assistive technology robot. The current literature presents a few examples such as a soft robot used to help elderly people while showering. The robot would help wash areas that are hard to reach, for example the back, to help increase the independence of the user (Ansari et al., 2017).

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 (Chamberlain et al., 2015; Renda et al., 2012; Togashi et al., 2014). Piecewise constant curvatures (Webster III & Jones, 2010), inverse kinematics (Neppalli, Csencsits, Jones, & Walker, 2008), and various geometric approaches have been used to understand control and model manipulators, however may often 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 (Robinson, Coulson, Kirkpatrick, & Berg, 2017), which was the first iteration of the device to undergo user testing (Coulson, Kirkpatrick, Robinson, Donahue, & Berg, 2018). The new iteration of the robot has modifications to the backbone and base components to improve operation and maintenance of the robot. Accelerometers and further utilization of the 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.

2 Design

The previous iteration of the arm 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 were 3D printed using acrylonitrile butadiene styrene (ABS) and polylactic acid (PLA). The disks in the proximal section, made of ABS, had a diameter of 11.43 cm and the distal section disks, made of PLA, had a diameter of 7.62 cm. The disks were spaced 7.62 cm apart along the backbone. The tendons that run the length of the arm are made of 50 lb braided fishing. The base was made of wood and contained two levels. Stepper motors were used to create the movement of the robot which 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 and at a 45 degree from the bottom motors. The end effector was an electromagnet.

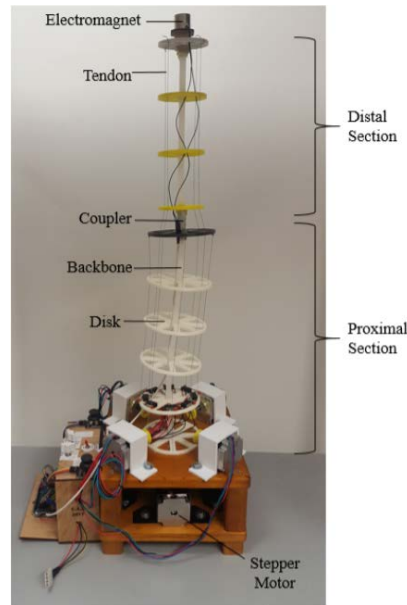


Figure 1 Bendi ARM. Photograph available under a CC-BY license from (D. Berg, 2017).

The arm is maneuvered using two joysticks, which controls 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 (Coulson et al., 2018).

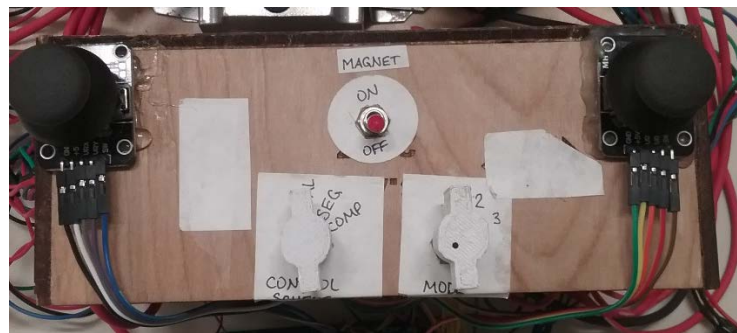


Figure 2 Joystick Configuration

In the Dual control scheme, both the left and right joysticks are utilized for maximum control of the robot, where each joystick controls a different section of the arm. In both the Single-Segmented and Single Compensative control scheme, only the right joystick may control the manipulator. The segmented scheme will enable the user to switch between modes to control different parts of the robot. Theoretically, moving each individual section of the arm will not disorient the opposing section, however in reality, movement of either segment will impact the robot's orientation. The Compensative control scheme will attempt to decouple the movements of the distal and proximal sections of the arm, so the user can control the robot as a whole, with and without

compensation. This control scheme was not completely effective, as each section will still be impacted by movement in another.

In addition to aiding in manual control of the robot, the right joystick may be pushed by the user, so the computer can read the location of the arm, and automatically 'home' the manipulator, which will bring it to an upright position. During regular operation, the motors are linked in opposing pairs. Each pair of motors move the same number of steps in opposite rotational directions. The steps of the motor pairs are recorded such that their counts will increase or decrease based on clockwise or counter clockwise rotations. This re-centering protocol is accomplished by reversing these movements, until the motor steps have reached their initial starting point.

Limit switches were placed on a disk near the base of the robot and helped indicate whether or not there was slack generated in the tendons, and would thus be used to complete the homing function. After all reconciling steps have been made, if any of the switches are open, the motors controlling the corresponding tendon will coil that tendon until the switch is pressed.

3 Mechanical Modifications

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 this disfigurement, 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 at higher than normal temperatures. Due to the unusual formation, once the stress is removed the martensite turns back into undeformed austenite. This creates a material that undergoes high amounts of strain without plasticly deforming⁷. Once nitinol was selected the size of rod to create the backbone had to be determined. The first step was to determine the amount of force that the motors could supply. The torque rating of the motors is 125 oz inch. Using a modified torque equation

$$F = \frac{T}{r} \quad (1)$$

to determine the amount of force the motors can pull on the tendons. For an axel radius of .1378 inches the force was determined to be 56 lb. To determine if the rod could be

⁷ [All About Nitinol Shape Memory and Superelasticity](#)

bent with the supplied force the amount of force required to bend a known diameter rod needed to be calculated. One way that is used to model this behavior is to model the system as a cantilever beam with a pure moment load (D. R. Berg, 2013). To determine the load required to bend the rod to a desired radius (R) the Euler-Bernoulli Bending equation.

$$M = \frac{EI}{R} \quad (2)$$

Then the moment equation

$$F = \frac{M}{d} \quad (3)$$

was utilized to determine the amount of force required to create the moment required for bending. The above calculations were completed for 2, 3, 4, and 5 mm diameter rods.

Table 1 Calculation of bending and buckling loads for various wire diameters.

Diameter (mm)	Bending Moment (Nm)	Bending Force (lb)	Buckling Force (lb)
5	12.56	74.17	.8705
4	5.40	31.89	.356
3	1.62	9.64	.112
2	.322	1.90	.099

With the data from Table 1 the 5 mm diameter rod would not work for this application due to the high amount of force required for bending. Once the bending calculations were completed the amount of force to cause the rod to buckle was calculated.

$$F = \frac{\pi^2 EI}{(KL)^2} \quad (4)$$

This helped determine the ability of the backbone to be able to support a weight on the end and can support itself. Once all the calculations were completed and the forces were compared a 4 mm diameter rod was chosen since it could support more weight and theoretically bend under the force supplied by the motors. However, after the rod was received and the robot was rebuilt there was noticeable shaking in the rod while the robot was moving. Due to this a 3 mm and 2 mm rod were ordered to test both as alternatives. The 2 mm was not stiff enough to support the operating loads and became deformed during operation. The 3mm had an appropriate stiffness but during a trial of the homing function the rod was bent close to 90 degrees and permanent deformation occurred. Though the permanent bend came from a malfunction and unusual bend it was decided that nitinol would not be an appropriate material since it could not handle

the bending that can be present in operation of the manipulator. Since the LDPE seemed to work better than the nitinol, a new LDPE backbone was ordered. The previous LDPE backbone was not used since it was two pieces connected by a bolt and a new one would allow us to see if the coupling issue between the proximal and distal sections was enhanced by having the bolt between the two sections. Once the new LDPE rod came in, one noticeable difference was the new rod could support itself in a vertical position where the original LDPE backbone could not. This could mean that the issues that were seen could be fatigue of the backbone and a new material could fix the problems in the backbone. However, conclusive evidence for this theory was not found and further testing is needed to determine if fatigue is the cause of the deformation.

As previously mentioned, the original base of the robot was made of wood and featured two levels where the motors were mounted. This used unnecessary materials and made the robot heavy. The motors on the bottom level were also mostly enclosed from the top level making it very difficult to access them for assembly and servicing. To fix this problem, the base was redesigned to reduce the overall size and weight and to provide greater access to the motors. The design that encompassed all these elements included a single platform for mounting all eight of the motors and a single support in the middle to support the backbone. The base has a square wood bottom that is 25 cm by 25 cm with 4 legs that are 4 cm by 4 cm by 1.5 cm cubes. The middle support is made of a 3.1 cm 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.

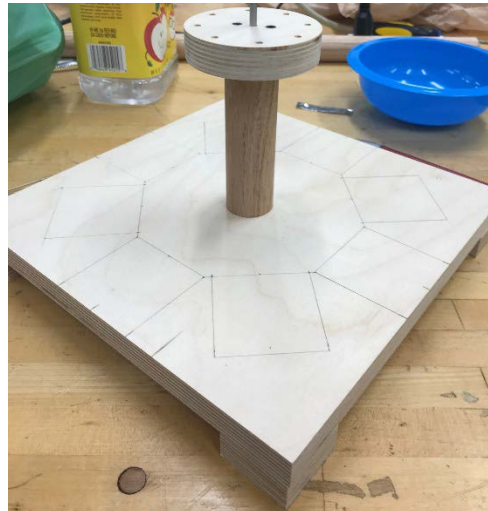


Figure 3 New Base Design

After redesigning the base and having the motors in a slightly different configuration, the brackets that hold the motors in place also needed to be modified. With all 8 motors on the same level they are arranged in an octagonal pattern, still offset 45 degrees from one another. With the motors placed so closely to one another, the space between them needed to be maximized. To do this, the new design of brackets has end flaps that overlap the adjacent motors' end flaps. The flaps had to have a big enough surface area

to fit a screw to drill in the base and small enough so that they fit nicely between the motors. The optimal shape for the end flaps was pentagonal making one of the edges flush with the side of the adjacent motor. The brackets were designed to have a square in the center that was 5.6 cm by 2.5 cm by 5.6 cm to accommodate for the size of the motors. The end flaps are 2.5 cm long with a straight side of 1.3 and the point created with a 135 degree angle to have the point in the middle of the bracket. Instead of the brackets being all one solid piece, it was decided that having the two sides of the bracket connect at the top with a screw would be beneficial for securing the motor. Then it is possible to either loosen or tighten the bolt to get the motor in or out for replacing or simple maintenance.

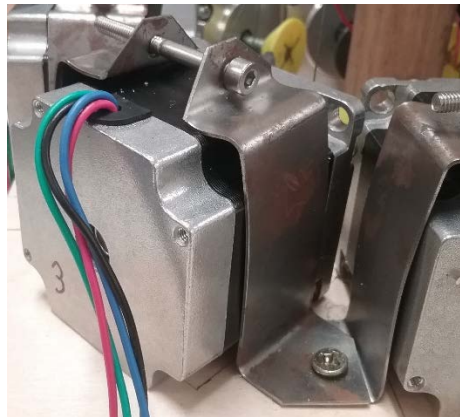


Figure 4 Brackets stabilizing stepper motors

A multi-sectioned continuum robot has all the tendons that control the distal section running through the proximal section. Due to this, any movement of the distal section will also move the proximal section. One way to allow for movement in the distal section only is the use of cable conduits. Cable conduits are made of flexible materials but not ones that can compress. This allows for them to bend without changing length so the tendon that runs through the conduit applies the force to the distal section (Vasquez, 2016). To try out the effectiveness of cable conduits, bicycle brake tubing was installed within the proximal segment of the manipulator (see Figure 6). With the tubing, there was a noticeable change in the robot's movement and independent operation of the distal section possible.



Figure 5 Bendy ARM 2.0

4 Code Refinements

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.

4.1 Automation

One of the ultimate goals of the project is to realize the potential for having enough control and precision tracking capability to automate the arm to specified positions, irrespective of the end effector's load. The arm moves on an x, y, z plane, and can also rotate on this plane. When manually manipulating the arm, the end effector can be brought to the same position with the spine bending or rotating in different ways.

Though this continuum arm can be generally controlled, accurately bringing the end effector to a target spot automatically is a challenge, particularly because the load may

heavily impact the position of the end effector. Constant adjustment and awareness of the manipulator's orientation is required. While being manually driven, if the robot does not move to the required location, the user can provide additional input to drive it there. The challenge of automation comes with closing the feedback loop, and articulating movements to ensure the manipulator ends up in the correct location.

Motion processing units (MPU) were used to retrieve data describing orientation of the continuum manipulator. These MPUs incorporate both a gyroscope and accelerometer to measure rotational velocity and acceleration on the x, y, and z plane. Two 6-axis GY-521 MPU6050 sensors were used to track movement of the arm. These 6 axis MPUs were chosen because they have easily accessible documentation and are generally affordable (under \$5 per individual sensor) and could potentially provide the required information to consistently understand the robot's orientation. Arduino's Wire library⁸ and Jeff Rowberg's MPU6050 library (Rowberg, 2011/2018) collection enables us to accurately retrieve yaw, pitch, and roll, Euler angles, and quaternion angles. This information is useful when obtaining and understanding general orientation, and rotational movements of the arm.

In this project, one MPU is placed at the top most disk to relay data about the end effector and distal positioning of the arm, and the second is placed on the last disk of the proximal section to communicate orientation about the proximal section. Both sensors are placed upside down for ease of wiring on the robot, and are mounted on soft foam rubber to reduce noise. Using the x, y, and z acceleration data provided by the MPUs, tilt angles on the x and y planes were acquired and used for determining orientation. The sensors are calibrated and offsets calculated to provide more accurate data readings. The orientation of the arm is tracked using inclination angles about the x and y plane. The raw acceleration data is transformed into a tilt angle as shown, finding the tilt about the x-axis:

$$\rho_x = 180 \frac{180}{\pi} \cdot \tan^{-1} \left(\frac{-A_y}{-A_z} \right) + \pi \quad (5)$$

$$\text{double } xInclination = RAD_TO_DEG * (\text{atan2}(-ay, -az) + PI) \quad (6)$$

One automated method we explored was to improve the previous homing function, where the robot would return to a default position by undoing its motor steps. At the home position, the arm is upright and the sensors should read both x and y angles at about 180 degrees. The left joystick may be clicked to move the arm to a desired, pre-coded position, and the right joystick may be clicked to return the arm home.

When one of the joysticks is pressed, the sensors will get the average readings of current tilt angles of both distal and proximal segments of the arm, to help filter out noise and error, and smooth the data coming in. This disregards short term variations and can utilize the long-term trend. After an average angle has been determined, the 8 motors will tighten or loosen in pair to move the arm towards the desired inclination angles for

⁸ [Arduino Wire Reference](#)

both sensors. This will loop until both segments have reached their corresponding desired angle.

The current tendon lengths will then be calculated, and the motors will coil the tendons until they've reached the lengths calculated for the given desired position. This will compensate for any further error produced when moving towards the tilt angles. Tendon length changes are calculated with the arc length about the motor axle:

$$\text{arc length} = 2 \pi r \left(\frac{\theta x}{360} \right) \quad (7)$$

where x is the amount of motor steps associated with the corresponding tendon, axis radius is .1378 inches, and θ (step size of the motor) is 1.8 degrees. The arc length gives the amount of tendon that is pulled or released from the coil on the motor axle. The initial set of tendon lengths read 15.5 inches and 27.4 inches. Lastly, all tendons are tightened to account for any remaining slack.

4.2 Automation Testing

Automation testing was done to see if inclination angles and tendon length adjustments were sufficient to drive the robot from any given position to another specified position. Automatically driving the robot from any given point to the upright 'home' position was the base point for automation testing.

When the robot is at a vertical, upright position, the x and y angles read about 180°. At any given position, inclination data will read from 0° to 360°.

While testing the sensor output data on a non-motorized, mini prototype that moved similarly to the continuum manipulator (without the rotation capabilities), the data read as expected. Once placing the MPUs on the disks, it was evident that rotation heavily impacts the inclination readings. The yielded inclination angles were not consistently reliable for returning the continuum manipulator to the vertical home position. Rotation of the arm influence the inclination angles read by the sensor and was too unpredictable to be reliable for providing accurate orientation, and so consistent movement back to the desired position was not possible.

5 Limitations and Future Research

The previous iteration had limitations in backbone material, mechanical coupling, payload capacity, and base design. In terms of backbone material, a new material has not been found that can reduce the problems that are seen with using LDPE. With the new LDPE backbone there is an opportunity to determine if the cause of the deformation issues is with regards to physical design or material selection. During future research, determining the cause of the deformation is important since it has occurred in the same area on multiple versions of the backbone. If it is determined that the cause is indeed material fatigue rather than a physical design issue, a new material

would be recommended. Some recommendations of material to investigate are thermoset rubber or a thermoplastic elastomer.

Use of a single piece of LDPE and the addition of cable conduits helped reduced the manipulator control limitations due to mechanical coupling. The choice of material for the cable conduits has showed new limitations. Since the cable conduits are only attached on one end to a disk the other end is free to move. This is to account for the elongation that occurs on the exterior tendon curve. However, when shortening occurs on the interior tendon curve, the conduits fall below the bottom disk. With the limit switches in place on the bottom disk the movement would cause the cable conduits to hit the limit switches. Due to this impact the cable conduits do not run all the way to the bottom of the proximal section. This could potentially decrease the effectiveness of the cable conduits. Future research could include finding a conduit that could be attached on both sides but still allow for the full movement of the proximal section. Also new placement of the limit switches could be investigated to allow for the conduits to run the full length of the proximal section

One of the limitations that has not been changed is the payload capacity of Bendy ARM 2.0. The arm still can only support a small weight at the end. However, the effect of replacing the disk and tendons is not suspected to help increase the payload capacity. Since the backbone is long and slender, the force that it can endure before buckling is limited. With the new material selection, an increase in the diameter of the rod could potential increase the amount of weight that could be supported at the end of the robot. This can be seen from Equation 2 as an increase in rod radius increases the moment of inertia.

The last mechanical limitation is mounting of the base onto a wheel chair. With the design changes made the focus was on ease of set up and maintenance. With the current design it is still required that the robot rest on a flat surface. With a special platform on the wheelchair the ability to have a mount on the wheel chair could be possible. However, this would extend beyond the wheelchair, so the mobility of the wheel chair would be more limited. To make the robot wheelchair mountable, the base would have to decrease in size and change configuration. Further research into ways to create the force for arm movement with a smaller actuator would be required to allow for the design of a wheelchair mountable base.

Regarding software limitations, it is recognized that the inclination angles acquired from the accelerometer data are not enough to provide complete orientation details for the manipulator. It's advised to explore rotation angles applied to the model of the continuum arm. Other research has shown that using both inclination and rotation angles as highly effective for getting accurate orientation, though can be possible to utilize rotation angles alone to gather orientation. Further testing of tendon length adjustments should be continued, especially implementing functionality so that the last known tendon lengths can be saved after shutting the manipulator off. This can be done by saving them to the Electrically Erasable Programmable Read-Only Memory

(EEPROM), so that the last known location (tendon lengths) of the robot can be known on startup.

6 Potential Applications

The presented continuum arm was designed to function as an assistive technology device to help aid those with limited to no upper body movement. Application areas include help in situations such as dressing, eating, and other activities that utilize a pick-and-place motion. This robotic arm is ideal for people who may consider safety for themselves and others as a concern. Situations where the assistive robotic arm may need to navigate compact spaces, move at abnormal angles, or in changing environments may benefit from this type of flexible manipulator. Additionally, this arm may be useful for automated, tasks where the arm must grab or retrieve objects routinely.

7 Conclusion

Bendy ARM 2.0 is a continuum arm robot that was created by making modifications to the first iteration, Bendy ARM. The basis for the design is a tendon-driven continuum robot that would be used as an option for assistive technology for people with disabilities. The current research showed that nitinol may not a viable solution for the size of continuum arm that is being designed. Also, the current material may give information into the causes of the failure in the bottom section location with further testing. Additionally, gathering the tilt angles from the MPUs does not always accurately provide the manipulator's location due to the rotation of the arm during movement. To have accurate automation, further research is necessary into using the tendon lengths and the Euler angles for describing position. With further research, we believe there is a high potential to utilize continuum robots with automated tasks in assistive technology.

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