

Proposed Idea for an Assistive Robot to Aid with Catheter Insertion for Hand Tremor Patients

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Abstract – There is an overlap between those who need to insert a urinary catheter and those who have tremors, such as the elderly or those who have multiple sclerosis. Currently, there are no proposed solutions to aid those with hand tremors insert a catheter comfortably. The shaking motion of a tremor can make catheter insertion painful because the patient will have difficulty inserting the catheter into the small opening of the urethra. If the shaking motion of the tremor was reduced or suppressed, the catheter would enter the body more smoothly and in turn make the cathing process easier and more comfortable. In addition, an automated device would help the patient insert the catheter more steadily into the body. This paper discusses a preliminary idea for an assistive robotic device that would aid with catheter insertion for hand tremor patients. A demonstration was constructed to show how the device is intended to work, and an in depth overview was completed to select the best tremor suppression technique. Finally, further work is discussed on how to move the design forward and prepare the device for testing.

I. Introduction

A tremor is defined as an unintentional, rhythmic muscle movement involving to-and-fro movements of one or more parts of the body, and these involuntary movements affect the hands, arms, head, face, voice, trunk and legs [1]. Tremors are not only a result of aging, but can also be present in those who have multiple sclerosis, suffered from a stroke or traumatic brain injury, or have a neurodegenerative disease that damages or destroys parts of the brainstem or cerebellum. Though tremors cannot be completely cured, this disability is treated using drug therapy, physical therapy, or surgery. Though options exist to relieve tremors, they are not always effective and can present risks to the individual's wellbeing. In past research, it was found that 1) about 25% of the patients treated cannot manage their tremors effectively, 2) the drugs offered have side effects that could present health risks to the user, 3) surgery presents a risk in itself and may cause hemorrhaging and could leave the patient with psychiatric issues [2]. As a result, many who suffer from tremors still have to live and cope with them daily even with the current treatment options available.

The most common type of tremor is an essential tremor (ET) which most commonly affects the hands [3]. ET is an action tremor [3] meaning the tremor is most present when an action, such as a basic living task (eating, drinking, writing), is being completed or if the limb is outstretched from the body. The severity of the tremor varies from person to person, and can increase depending on the type of activity being performed and how much stress the person is under while performing the task. It is estimated that ET affects up to 10 million people in the US alone and affects men and women equally [3]. It is likely that if someone is suffering from a tremor, this tremor will be an ET and will affect the hands.

A urinary catheter is defined as a thin, flexible rubber tube placed in your body to drain urine from your bladder [4]. The catheter is inserted through the urethra to reach the bladder, and the urine is expelled either into a bag or into a toilet. Catheters are used if the patient is bed confined and too weak to walk

to the bathroom, which is most commonly seen in elderly patients. For those affected by spina bifida, cerebral palsy, or multiple sclerosis, the muscles needed to contract to release the bladder cannot be controlled and a catheter must be used.

As seen, those who suffer from tremors may be faced with the need to use a urinary catheter (such as elderly people or those who have multiple sclerosis). Catheter insertion can cause stress to the patient and could cause a tremor to worsen, thus making the insertion process difficult or painful. Currently, there are no proposed solutions to help those who suffers from hand tremors insert a catheter easily and more comfortably. Ideas have been proposed to reduce the effect of tremors in patients; however, each of these solutions have downfalls that would inhibit rather than aid in the cathing process. Exoskeleton solutions, such as those seen in papers [7], [8], and [16], propose a wearable device that monitors and counteracts the tremor motion. However, exoskeletons are bulky and would obstruct the patient's mobility when trying to insert a catheter. Sleeve-like or glove-like designs have been proposed where electrodes are sewn into the material to monitor and respond to the tremor [5] or a gyroscope is attached to the back of a glove to help steady the hand [14]. However, these cloth-like material designs cannot be cleaned easily and could result in the spread of bacteria and infection if used for cathing. To disinfect cloth, 1/8-1/4 cup of bleach is added to warm water [17] and the cloth is either washed in the washing machine or soaked in the solution. It would be difficult to wash cloths with electrodes or electrical equipment in them because the electronic components would be destroyed by the bleach and water, meaning the washing of cloth products is difficult and would be an impractical solution to use in the cathing process.

This paper builds upon a proposed mechanical device created to assist men with spinal cord injuries insert a catheter [6]. The cathing device seen in paper [6] is purely a mechanical device and may be difficult for someone with tremors or limited fine motor skills to use. As a result, a more automated device is proposed in this paper, in which the vibrations of a hand tremor are overcome by implementing a hands free device, thus allowing a more comfortable catheter insertion process. The following sections will discuss 1) the concept of design which includes basic sketches for the prototype of the Catheter Insertion Aide (CIA), 2) the analysis of various damping solutions and provide an explanation of why a hands free device was chosen, and 3) an overview of future work which includes sketches for the prototype of the uncoupled stand.

II. Concept of Design

The proposed design for internal workings of the CIA used a combination of electrical and mechanical components. To show how the system would operate, a basic demonstration of the system was created and can be seen in Figures 2 and 3. A motor was run using an Arduino Duemilanove, and a potentiometer was included in the design so the motor speed could be controlled if necessary. A switch controlled the direction of the motor and contained three modes: forward (clockwise), backwards (counterclockwise), and off. The speed of the motor was reduced using the appropriate gear reduction formula (equation 1) to reduce the speed of the motor (120 RPM) to the catheter insertion speed (1 RPM, or a feed speed of about 9 cm/min).

$$n_3 = \frac{N_2}{N_3} n_2 \quad (1)$$

The demonstration was build using plywood, wooden dowels, laser printed acrylic gears, and two rollers. Because the demonstration was simply a means of showing how the system should operate, simple materials could be used to illustrate the design concept. Plywood and wooden dowels were selected because wood is a cheap material. Laser printed acrylic gears were also a cheap alternative to purchasing catalog gears, but still showcased the intended operation of the design. Ten gears (3 eight toothed, 1 twenty-five toothed, 1 thirty-two toothed, 1 thirty-eight toothed, and 4 sixteen toothed) and a rack and pinion system were laser cut and arranged accordingly. The gear mesh system can be seen in Figure 1. The gears were selected based on common teeth numbers so eventually the gears could be selected from a catalog for the prototype. In addition, when initial speed reduction analysis was being completed, it was decided the gears should not exceed forty teeth so the catalog selected gears for the prototype would be on the smaller end of gear sizes, thus ensuring the overall device could be a reasonable size.

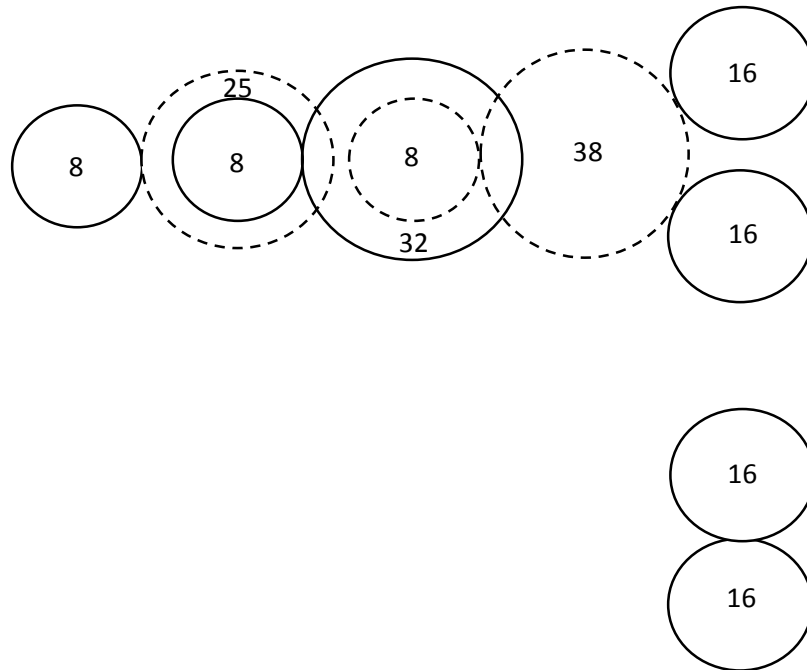


Figure 1: The diagram above shows the gear mesh system in the CIA. Note one circle on top of another indicates the gears are on the same shaft. The dotted lines indicate the gear on the bottom. The numbers in each circle indicate the number of gear teeth. The rack and pinion system is not shown in this diagram.

After setting up the demonstration, it was noted that the feed rate of the catheter may be too slow and may need to be increased by adjusting the gear ratios. However, a potentiometer switch should still be accessible to the user in the final design. A set gear reduction would reduce the speed of the motor to a set speed for catheter insertion. This set feed speed may need to be slowed depending on the user's preferences. The potentiometer switch would allow the patient to slow the motor speed and in turn slow the feed rate of the catheter. To determine a generally accepted feed speed, a medical professional, such as an occupational therapist that primarily focuses on catheter insertion, would need to be consulted.

Attached to the shafts of the corresponding gears are two rollers that feed the catheter through the device. These rollers are turned at the same speed, but in opposite directions. In the final design, tests would need to be run on the prototype to ensure sufficient contact pressure was maintained between the rollers and the catheter to ensure no slipping occurred.

In addition, a system was created to lubricate the catheter while it passed through the CIA so as the catheter came out of the device, it was lubricated and ready for insertion. A syringe and rack and pinion system was used in the demonstration to illustrate this feature. As the rack moved forward, the plunger of the syringe was pushed forward causing the lubrication to be released onto the catheter.

Though not illustrated in Figures 2 and 3 of the demonstration below, an emergency shut off button would be incorporated into the device. Different blockages exist in the body that can be hit when navigating the catheter through the urethra. Men may hit their prostate, and women may have cysts or fistulas that can inhibit the motion of the catheter. If one of these blockages are encountered, the user would be able to hit the emergency shut off to quickly power the device down. The emergency switch would work just as all other emergency switches work: when hit, the device would be completely powered off, causing the motor and the feed of the catheter to stop. The device could only come back on when a reset switch was triggered.

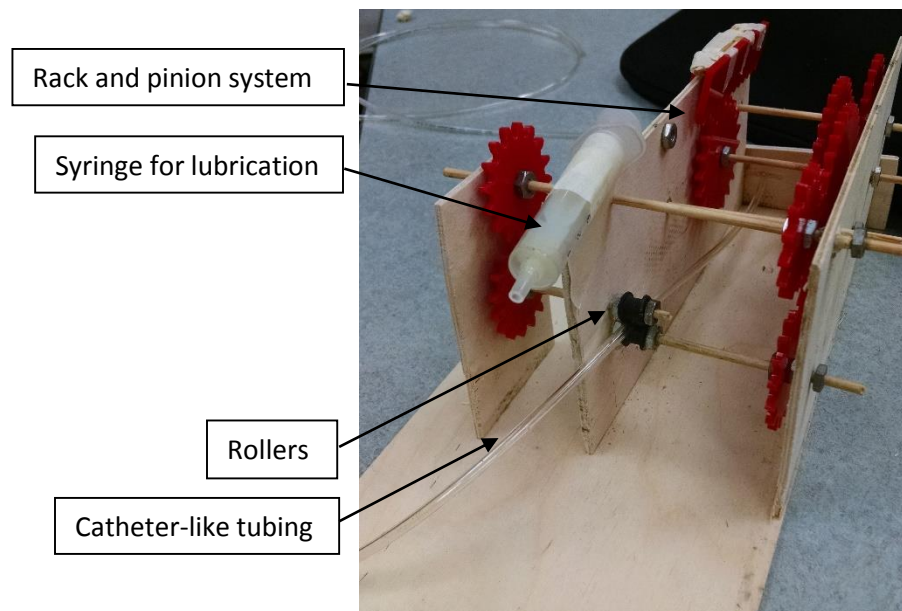


Figure 2: Basic demonstration of the interior operation of the CIA device, which included the gear train system, rack and pinion system used for lubrication, rollers, and catheter like tubing.

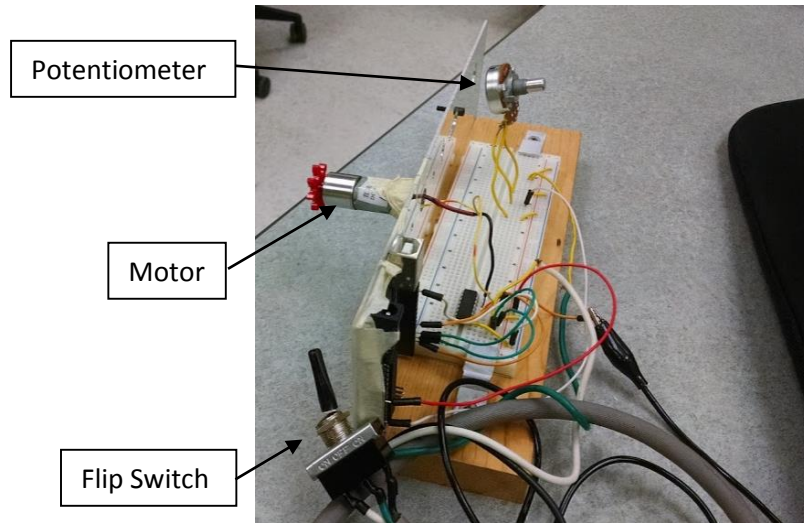
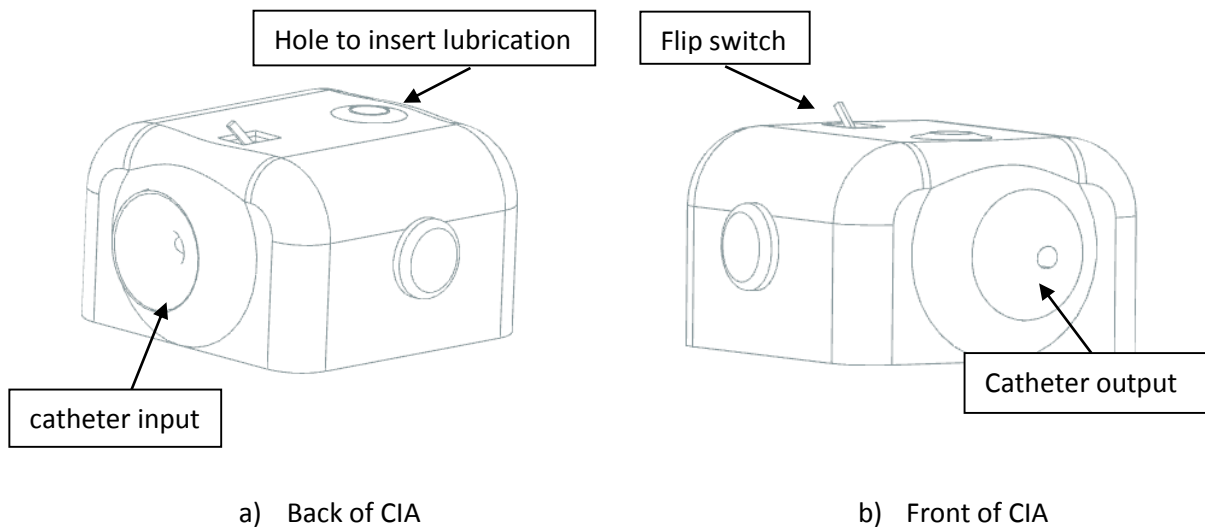


Figure 3: Motor system with flip switch and potentiometer.

A proposed outer casing for the CIA can be seen in Figure 4. This outer casing would allow the user access to the flip switch and emergency shut off button, as well as have openings for lubrication insertion and catheter insertion and exit. A funnel like design was created to help guide the catheter into the CIA. This design was selected so the tremor patient had some degree of freedom of motion while inserting the catheter into the device. The funnel shape provides a guide for the catheter while accounting for the involuntary shaking movement of the hand so the patient does not need to painstakingly focus on sending a catheter through a fine opening, which is a challenge for those who have limited fine motor skills. The lubrication opening is also a funnel design to once again allow for the error of the involuntary movement while ensuring the lubrication holder could be filled easily. The catheter output on the CIA is similar to the narrow passage on a funnel. This would allow the user to line up the end of the CIA with the opening of their urethra to ensure the catheter would smoothly be transferred from the device into the body.



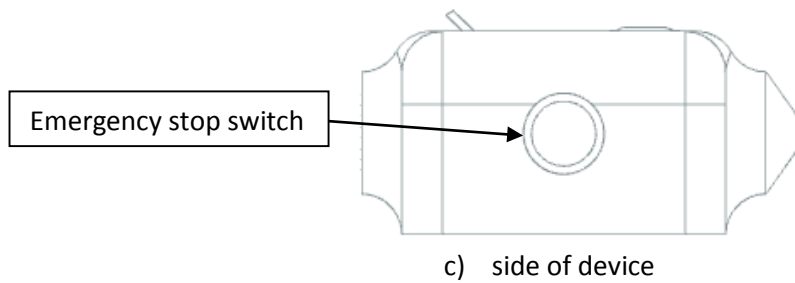


Figure 4: Proposed exterior design for the CIA.

In addition to the automation of the device, tremor suppression was one of the main focuses of this project. To counteract the motion of the tremor, the CIA would be placed on a free standing base. Further discussion on the selection of the tremor suppression method and proposed idea for the design of the free standing base can be seen in the following sections.

III. Methods of tremor suppression

Four tremor compensation mechanisms were analyzed and compared to determine which damping method would best suit the CIA. The four options include using: sensors and corresponding actuators, weight, simple mass spring damper systems, and an uncoupled device from the user. The following subsections will describe each solution and why it was or was not chosen.

A) Sensors and Actuators

Research in using sensors to provide tremor suppression have increased in recent years. This form of tremor suppression is known as active tremor suppression in which “active actuators generate an equal but opposite motion, based on a real time estimation of the voluntary component of motion, actively compensating and effectively subtracting the tremor from the overall motion” [12]. However, models such as these have a hard time distinguishing between the movement of the tremor (involuntary moment) and the movement of the limb (voluntary movement). As stated by Herrnstadt and Menon, “an impedance-controlled system that models the tremor signal may, therefore, experience fluctuation in the suppression performance due to the impedance variability” [7] meaning that trying to suppress the tremor via sensors sending an equal and opposite reaction is difficult to master and control because the voluntary movements cause the overall frequency of the system to fluctuate, and the sensors then have a hard time deciphering which part of this frequency is from the tremor and which part is from the voluntary movement. The fact that this system is difficult to master and is still being researched made this option a poor selection for tremor suppression in the CIA. Furthermore, active tremor suppression is mostly seen in exoskeleton devices, such as those seen in papers [7], [8], and [16], meaning the patient wears the device. It was decided that the tremor cancellation system should be built into CIA rather than requiring the user to put on an additional exoskeleton because, as stated previously, exoskeletons are bulky and would inhibit rather than aid with the cathing process.

The Liftware spoon, however; is currently the only known technology that uses this active tremor suppression system to cancel out the effects of involuntary movements and is not a wearable device.

The sensors monitor the motion of the hand and send an equal and opposite response to motors located near the spoon head causing the spoon head to move in an equal and opposite motion to reduce the shaking of the utensil [15]. Though the Liftware spoon suppresses some of the tremor, some shaking still occurs. Though a method similar to that used in the Liftware spoon could be tested on the CIA, a simpler method seemed more suitable for this application. In addition, though reducing the overall shaking frequency in the device would be helpful in smoothing the cathing process, eliminating the shaking of the tremor all together would be the ideal solution for the CIA, and sensors and actuators cannot accomplish this task.

B) Weights

Weight is already used in tremor cancelling devices on the market. KEatlery, for example, provides a range of weighted eating utensils, and according to reviews, works well as an assistive device for tremor patients. However, unlike eating utensils, the CIA is a larger product. If the CIA was a handheld device, it was decided it would be about the size of a glue gun, and adding weight may make the device top heavy and prone to tipping in the user's hands while trying to complete the insertion. Also, elderly people may be using this device and may not have the muscle strength required to hold a heavy object in their hands while the cathing process was taking place, thus making this device more of a hindrance than an assistive aide.

Wrist weights have been recommended by doctors or physical therapists to help reduce the effect of a tremor. Different weighted bands on the market have also been reviewed as working well for tremor patients. The patient could be recommended to wear wrist weights while using the CIA, however this makes the device a hassle to use. The patient would need to set up the device, put on the wrist weights, use the device for insertion, wait for the bladder to drain, remove the catheter, remove the wrist weights and then clean the device and wrist weights. If a machine is complicated and time consuming to operate, then a patient is not likely to use it at all. The additional time needed and the hassle of putting on the wrist weights could discourage the patient from using the CIA. Also, wrist weights cannot easily be washed and sanitized. When cathing, these weights could become unsanitary and it would be difficult for the user to clean them, which could cause bacteria to spread and could lead to infection. Having wrist weights on while cathing could cause fatigue to the hands and limbs making the cathing experience even more unpleasant for the patient. Finally, having to wear weights while using the device defeats the purpose of creating a product that helps reduce the tremor. The CIA itself should help reduce the tremor and the user should not be expected to wear an additional device to aid them with cathing.

C) Mass Spring Damper system

Adding springs and dampers in the handle of the CIA was one option put into question. For this system, springs and damper would be positioned accordingly, and when the user's hand shook, the springs and dampers would force the device to counteract the motion and stay in place. Basic mathematical models of mass spring damper systems exist and it would be easy to implement this model into the device because the mathematics behind the system have already been proven and are simple to manipulate.

Mass spring damper systems are passive tremor suppression solutions. Passive solutions are ones in which a mechanical damper is used rather than sensors and actuators, however, these systems are not the most effective solutions compared to active tremor suppression. "One of the main drawbacks of

passive systems is that the dissipative force is also loading the patient's voluntary motion. As a consequence, the user feels a mechanical resistance to the motion" which could affect the voluntary movement of the user [12]. If the dampening is too strong, the user could feel some resistance in the voluntary movements of the CIA making the device difficult to use; however, if the damping was not strong enough the system would not negate the user's tremor.

In addition, tremors have a range of frequencies (3-12 Hz) [8], [13], and the frequency can increase depending on the amount of stress an action causes the individual. This means that the spring constant and damping coefficient would need to either 1) be able to withstand this frequency range, or 2) be modified for each person. Though this range may seem relatively limited, in actuality, it is quite large and it would be very difficult to encompass springs and dampers into the system that could handle this frequency span while providing the least amount mechanical resistance to the user. The idea that a universal damping and spring constant would not work for all tremors is proven in paper [9] and the resulted were reiterated in paper [10], thus proving each device would have to be adjusted according to the patient's specific needs. Depending on how the CIA was built would determine how difficult it would be to adjust the damping coefficient. A simple knob could be available on the device to allow the user to adjust the damping as necessary, or the CIA may be constructed in a way that only a medical professional would be able to tune the device. Either way, the device would need to be designed in a way to ensure the damping could be adjusted accordingly. In addition, if the person became anxious while cathing themselves, the adjusted springs and dampers would become useless because the tremor would increase outside of the frequency that the device was adjusted for, thus requiring further adjustments to the springs and dampers.

Springs and dampers have also been found to be inefficient in reducing the motion of the tremor. As seen in paper [11] one of the initial prototype consisted of a similar design to that being considered for the CIA. Two cups were connected via springs and dampers to reduce the motion of the tremor. This design failed to sufficiently absorb the tremor, meaning the device was still shaking due to the involuntary motion. In the second design proposed by this group in paper [11], the springs caused the applicator to move with large bulk movement (ie voluntary movements), meaning that once the object was in position, the user had to wait for the oscillatory motion to cease before they could resume using the tool.

Overall, using a mass spring damper system would require fine tuning the device so voluntary motion could be completed freely, while inhibiting the involuntary motion. Though further experimentation could be done to determine if this system is possible, it seemed like adjusting the system accordingly could become complicated and would likely be overall ineffective, and thus a better solution was best suited for this design.

D) Uncoupled device

The final idea for this design was to create an uncoupled device. For this idea, the CIA would be positioned on a stand similar to a camera tripod that could be adjusted into position by the user according to each individual's specifications. Because this system can be adjusted by each person to fit their needs, this system can accommodate both men and women and bodies of various shapes and sizes. In addition, the free standing system could eventually be automated and adjusted into place using levers and buttons that control motors. This would be beneficial for those who have extremely limited fine motor skills, or have reduced use of their hands and arms.

If the CIA was on a stand, then the patient would be able to use both hands to steady their genitals. When inserting a catheter, it is pertinent that the patient holds their genitals as still as possible so the catheter can be inserted correctly. However, if an individual has a tremor, this task is going to be difficult to complete. If the patient can use both hands to complete this task, then they can position themselves in a way in which the shaking in their hands is minimized allowing their genitals to remain as still as possible and thus make the catheter insertion process easier. The use of both hands would also be beneficial to women because the urethra can be difficult to find and if both hands can be used to help find the urethra and hold the labia open, then cathing could become much simpler for them. A separate device could be created to help suppress the shaking motion in the hands, but this device would likely be an exoskeleton or a cloth based material and, as stated before, these two methods have drawbacks that would inhibit the cathing process.

This system would also prevent the user from having to hold the CIA while inserting the catheter, thus prevents the vibration of the patient's tremors to be transmitted to the device. This means that the CIA would be completely still while feeding the catheter, allowing for smooth insertion into the patient. The uncoupled device was selected as the best means to provide the most comfort for catheter insertion because the device would not be in the user's hands, thus be completely free of the shaking motion of the tremors allowing for a smooth catheter insertion into the body. This system would also free up the user's hands allowing for better control of the genitalia while the device is being used.

IV. Discussion

This basic design of the CIA, as presented in this paper, is only a preliminary model and a concept of design for the final product. Future work for the design would require constructing a working prototype and testing the device. The first tests would be completed on catheter insertion training dummies that hospitals use to teach nurses how to insert catheters into patients. When completing these tests, it would be important to see how well the catheter transferred from the CIA into the urethra and adjustments to the design would be completed as necessary.

A few aspects to consider when constructing the prototype of the stand include properly designing the base, selecting the proper joints for the system, and ensuring that the device can be compacted down to be stored.

The construction of the base must allow the CIA to be portable, meaning cathing is not restricted to home use. When designing the base, either weight or suction cups could be used to secure the device to the floor. If weight is used, the device must be heavy enough to ensure it stays grounded, but is light enough so it is still mobile. If this design is implemented, testing would need to be done to see how heavy the base needs to be to prevent tipping, but ensure that it is still light enough so the system can be lifted. Another solution to this problem would be to create a tripod stand with suction cups on the feet to secure the stand to the bathroom floor. If a tripod is used, the stand may not be as stable as a solid base and may tip over easily. Again, testing would need to be done if this design was thought to be the best to determine if tipping could be prevented. Currently, the weighted base seems to be the best option and is illustrated in the proposed prototype design seen in Figure 5.

In addition, the type of joint used to position the device would need to be carefully selected. A ball and socket joint may provide too many degrees of motion and prevent the user from properly placing the CIA. If the user has a tremor that is too severe, a ball and socket joint may be too difficult to maneuver.

To resolve this problem, two hinge joints are being considered for the design. One hinge joint that moved the device left and right would not suffice because a woman may need to be able to adjust the device to a forward and backward angle to accommodate the way they are sitting and how the catheter needs to be inserted. Thus, a hinge joint with forward and backward motion would also need to be incorporated into the design. The device must also be easy to adjust so someone with limited fine motor skills can set up the device simply. This means knobs should be avoided and a clamping system for the joints should be considered. To determine the best design, different methods could be tested among focus groups to determine the preference of the user.

Ideally, the device would be collapsible so it could either be discretely stored in a bathroom cupboard or could be transported so cathing is not restricted to the home. This device should be designed similar to a portable camera tripod that can be compressed down to a smaller size and set up to the correct height when necessary.

A basic clamping system would be used to hold the CIA on top of the free standing system. The patient would use both hands to push the clamp into place to secure the CIA. A push button would release the clamps when the user was finished cathing, thus allowing the patient to pick up the CIA so it could be cleaned and sanitized.

Finally, automation could also be considered for this design. If a patient has very limited fine motor capabilities, an automated device would be beneficial in helping them set up the CIA. Buttons or levers could be used to automatically raise and adjust the device into the corresponding position to make the cathing processes even simpler.

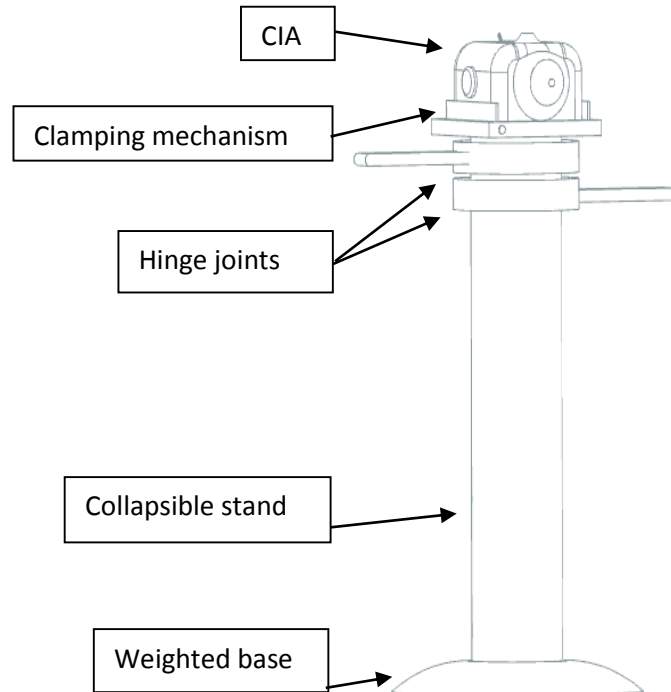


Figure 5: Sketch of proposed design for complete device.

V. Conclusion

The work presented offered a proposed idea for an assistive robotic device to aid with catheter insertion for hand tremor patients. A basic demonstration of how the device would work was constructed and proved the proof of concept by showing that a catheter could be fed through a system similar to the one constructed. Various tremor suppression techniques were analyzed to determine the best suppression method. Using past research and focusing on the type of patient in mind, a hands free device seemed to be the most suitable solution for this design because it would not be affected by the shaking motion of the tremor, and also provided the patient the ability to use both hands to stabilize their genitalia while catheter insertion took place. Finally, a sketch provided an idea of how the final design may look, and thoughts to keep in mind for prototyping were presented to help stimulate future work.

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