CHAPTER 14
UNIVERSITY OF MASSACHUSETTS AT AMHERST

College of Engineering
Department of Mechanical and Industrial Engineering
Engineering Lab
Amherst, MA 01003-3662

Principle Investigators:

Robert X. Gao (413) 545-0868

gao@ecs.umass.edu

Donald Fisher (413) 545-1657

fisher@ecs.umass.edu

Sundar Krishnamurty (413) 545-0297

skrishna@ecs.umass.edu

SPATIAL RESOLUTION ENHANCEMENT IN ULTRASONIC RANGING FOR A SMART CANE

Designer: Raymond Frenkel
Supervising Professor: Robert X. Gao
Assistive Technology Laboratory
Mechanical and Industrial Engineering
University of Massachusetts Amherst
Amherst, MA 01003

INTRODUCTION

Ultrasonic ranging has been applied to obstacle detection in many assistive technology applications, including collision avoidance in electric wheelchairs, preventing automatic doors from closing on slow pedestrians, and electronic travel aids (ETA) for individuals with visual impairments. For ETA applications, high spatial resolution information is needed to be able to identify obstacles that must be avoided to reduce the risk of injuries. This design project describes a method to digitally focus ultrasonic ranging data in a constraint environment of a microcontroller, for structural integration into the thin shaft of a sensor-embedded smart long cane.

SUMMARY OF IMPACT

Obstacle identification with ultrasonic ranging is dependent on determining the spatial position of an object in at least two dimensions: distance and height. This capability is critical for a sensor-embedded long cane to distinguish overhanging obstacles from other obstacles detectable by the cane. The technique presented here can be implemented in an 8-bit microcontroller with limited memory to fit the size constraints of integration into a long cane and will make travel safer for the user.

TECHNICAL DESCRIPTION

The spatial position of an obstacle can be measured using ultrasonic echo location by transmitting an ultrasonic pulse and measuring the time of flight (TOF) for echoes that are reflected off the obstacles. The ability to detect a reflected ultrasonic pulse is governed by the energy content, E, of the transmitted pulse.

For most ultrasonic transducers, the operating frequency is fixed and the amplitude is limited. Thus, only the pulse length can be varied to increase the energy content of a pulse for improved pulse detection. However, such an approach results in a proportional loss in the spatial resolution. For example, a pulse length of 52 cycles at 40 kHz is 0.45 meters long, meaning that the spatial resolution of the obstacle detected is measured as being less than half a meter, due to the difficulty in determining accurately the beginning of an unmodulated sound wave. This is especially true when the level of weak echoes is undistinguishable from the ambient noise level.

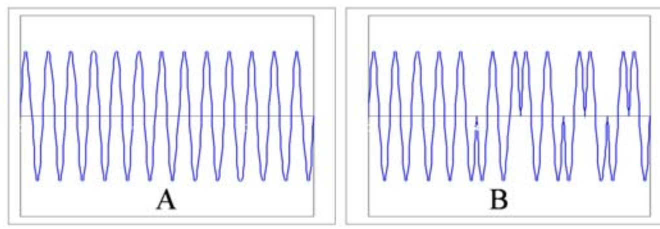


Figure 14.1. Waveforms of the carrier: A–Unmodulated, B – Phase-modulated with a 13-bit Barker Code

Pulse compression using cross correlation can overcome this drawback. Cross correlation is a measure of the similarity of two signals and shows the relative position of one signal in the other. Cross correlation is often referred to as matched filter, or the sliding dot product. Mathematically, it is the sum of the product of the elements of the signal vector, with the elements of the search pattern vector or correlation vector for successive positions

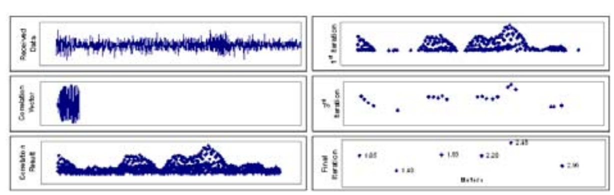


Figure 14.2. Iterative Process for Ultrasound Peak Detection

along the signal vector of length.

An ultrasonic pulse is modulated to create a pattern that can be easily correlated. Figure 14.1 shows the waveform of an unmodulated carrier and a phase-modulated carrier. The phase of the carrier is shifted 180 degrees to encode ones and zeroes. A pattern that gives a high correlation value when it is aligned with itself and low correlation values for all other positions of partial alignment is applied, by means of the Barker codes, which create binary patterns. In this project, a 40 kHz pulse was encoded with a 13 bit Barker Code (1111100110101) using phase modulation and 4 cycles per bit, resulting in a 52-cycle pulse. The waveform of the excitation signal (to a piezoelectric transmitter) is shown in Figure 14.1B. Subsequently, the piezoelectric transmitter converts this excitation signal into a sound pressure wave, and transmits it into the air, in the form of an ultrasonic pulse train. The pulse train is reflected by a control surface, which serves as a calibration object, and is converted back to an electric signal by means of a piezoelectric receiver. The received signal serves as a correlation vector. As shown in Figure 14.2, the correlation vector is aligned with the beginning of the received signal, with a time lag of zero. The result of the cross correlation operation is a vector of values representing the strength of the correlation, or match, between the ultrasound signal and the correlation vector.

The correlation peaks, shown in Figure 14.2, correspond to the time or position in the vector of the received echoes to the resolution of the sampling frequency, effectively compressing a pulse length of 52 cycles to one sample, which is less than one cycle. This solves the resolution problem for a pulse with a large enough length to be easily detected. Locating a peak is accomplished by a pulse detection operation, for which an iterative process is performed, as shown in Figure 14.2. The process considers the minimum spacing between adjacent peaks, determined experimentally, to eliminate weaker correlations, called sidelobes, without losing real matches. The process is repeated until only peaks that are further apart than the sidelobe spacing remain. The result in Figure 14.2 shows the output of the cross correlation for the received ultrasonic signal, where the peaks represent the location of pulse echoes in the received data. The timing of the peaks represents the time of flight (TOF) of the echoes at the speed of sound and therefore the range to the obstacles.

The Y-axis position of the peaks represents the relative strength of the correlation, and it is used to locate the peaks. The positions along the X-axis represent the range of an obstacle, and are measured in meters. Each dot on the graphs represents one data sample or reading of the analog-to-digital converter within a microcontroller. The final values shown in the bottom graph of Figure 14.2 are the location of the start of the detected pulse echoes converted to time, obtained by multiplying the sample number by the sampling period. This gives the TOF of all detected echoes with a precision of one sampling period. The TOF information from two receivers is combined to calculate the spatial position of the obstacle that reflected the transmitted pulse. This spatial information can then be used to categorize the obstacle. The photo in Figure 14.3 shows the experimental setup for ultrasonic signal correlation.

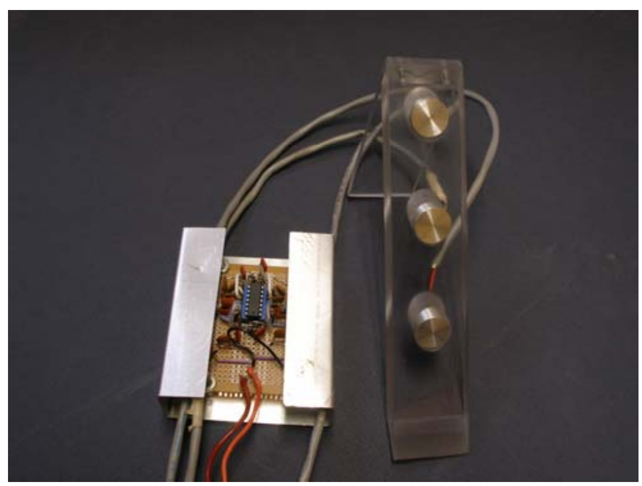


Figure 14.3. Experimental Setup, with Ultrasound Transmitter Holder and Prototype Electronics

SMART CANE MODIFICATIONS

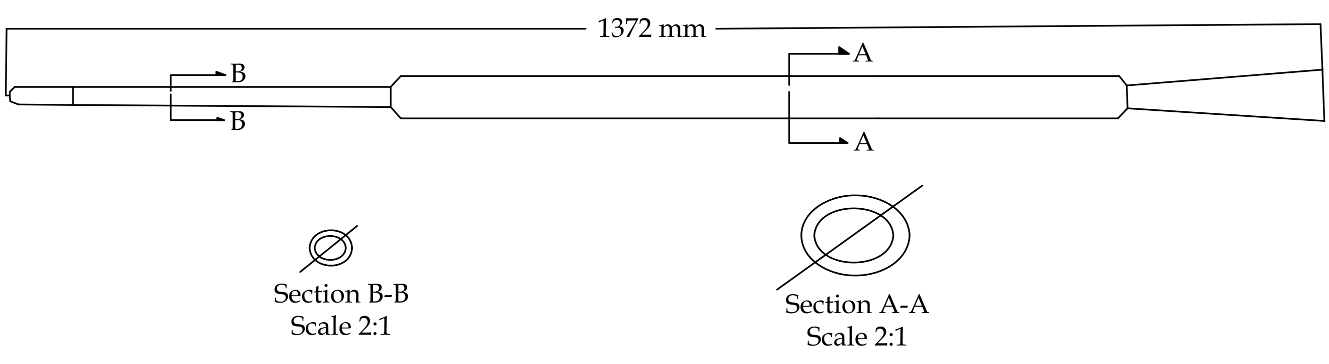
Designers: Brett Laviolette, Michael Resca, and Alicia Lemieux
Supervising Professor: Robert Hyers
Department of Mechanical and Industrial Engineering
University of Massachusetts
Amherst, MA 01003-3662

INTRODUCTION

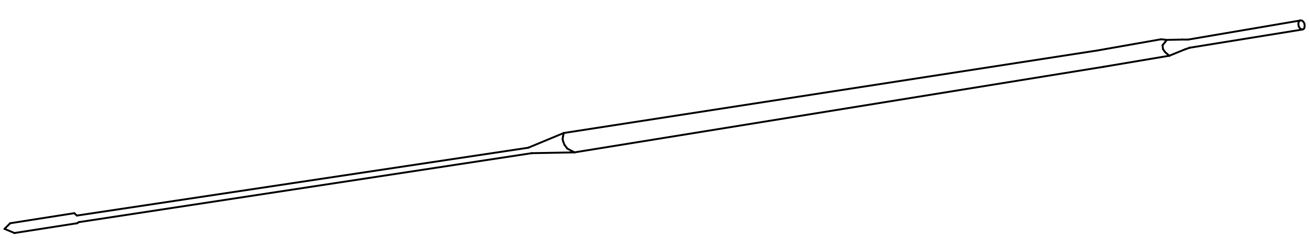
The Smart Cane utilizes specific sensors, modules, and electronics that will alert a person who has a visual impairment of the exact distance and height of an obstruction in his or her path. The objective was to design a hollow shaft for the cane that will house the miniature ultrasonic ranging module and microelectronics while maintaining the same vibration frequency as a standard cane. The current design for the cane has all the electronics mounted on the cane shaft with a bulky aluminum casing. To achieve the design goal, different design concepts were produced and evaluated based on the design criteria. Figure 14.4 shows the final design, which is a tapered hollow oak shaft with an inside diameter being large enough to accommodate the largest existing computer chip. This design was selected for its low cost, low weight and its ability to match the natural frequency of a standard cane.

SUMMARY OF IMPACT

Standard canes for people who have visual impairments only aid in detection of obstacles below the waist. The Smart Cane reveals obstacles not only below the waist but also above by utilizing signals that locate the hindrances and notify the user accordingly. The additional features of the Smart Cane require electronics to be added to a standard cane, which might alter the characteristics of the cane. Redesigning the shaft of the Smart Cane to mimic the characteristics of a standard cane will allow people who currently use a cane to transition easily from the current standard to the Smart Cane. The redesign also provides a protective housing unit for the sensitive electronics.



(A)



(B)

Figure 14.4. A: Engineering Drawing for the Redesigned Cane; B: Pro/Engineering Drawing.

TECHNICAL DESCRIPTION

The concept that was chosen for the design of the Smart Cane's shaft has an outer diameter of 56 mm. This diameter is large enough to house the largest computer chips needed for the ultrasound detection of objects and is located toward the top of the cane. Approximately 2/3 of the length of the cane will be filled with the electronics. At the end of the electronics housing section of the shaft, the larger diameter will be tapered in the remaining section of the cane. The remaining 1/3 of the cane will have a diameter of 24 mm, which is the current standard diameter of a cane. The material selected for both sections of the cane was oak. Oak was selected because the first four modes of its natural frequency match almost exactly the frequency of the standard cane made from aluminum. Also, the oak cane only weighs 0.0297 kg more than the standard cane. The small differences between the standard cane and the oak cane mean that there will be almost no difference in feel to the user. Another advantage of using oak is its low cost ($3.00/kg for perpendicular oak), which results in a cost of only $0.335 for the cane material (not including any electronics). A perpendicular grain orientation on the upper shaft was used to reduce cost. A parallel grain orientation on the lower shaft was used to provide superior strength.

DAMPER DEVICE TO PROTECT SMART CANE ELECTRONICS

Designers: Daniel Bosh, and William Savola III
Supervising Professor: Robert Hyers
Department of Mechanical and Industrial Engineering
University of Massachusetts
Amherst, MA 01003-3662

INTRODUCTION

A means of protecting the sensitive electronics housed inside the shaft of a smart cane is needed. One solution is to make a mold of visco-elastic foam. The visco-elastic foam chosen for this design is light and inexpensive, and excellent for damping vibrations. To maximize damping and minimize weight, conical bumps will be molded to create stress concentrations and increase the damping of the protective sleeve that will surround the electronics (see Figure 14.5).

SUMMARY OF IMPACT

The electronics for a cane with the capability to detect objects above the waist are expensive and delicate. By creating proper protection for these sensors the cane will be able to handle the rigors of everyday use. Additionally, this new technology will increase the safety of Smart Cane users.

TECHNICAL DESCRIPTION

Visco-elastic foam is molded to have coned-shaped protrusions on the outer surface and a groove on the inner surface, as seen in Figure 14.6.

The cones on the surface create stress concentrators, which allow for higher damping. Once the flat mold is created, it is then wrapped around the housing of the cane to make a cylinder. Next, the chip is inserted into the molded groves on the inside surface and then inserted into the cane (See Figure 14.7).

It was determined that this configuration will be able to protect the sensitive electronics from impact if the tip of the cane on the ground has a speed up to 21mph. This is based on the average cane length and arm length to give a sweeping radius of 59," while sweeping a 45 degree arc every 0.25 seconds. This is thought to be an extreme case and would cause large vibrations along the cane shaft. Using these assumptions the design group is confident that the solution presented will affectively protect the electronics in the cane even in extreme impacts at the tip of the cane.

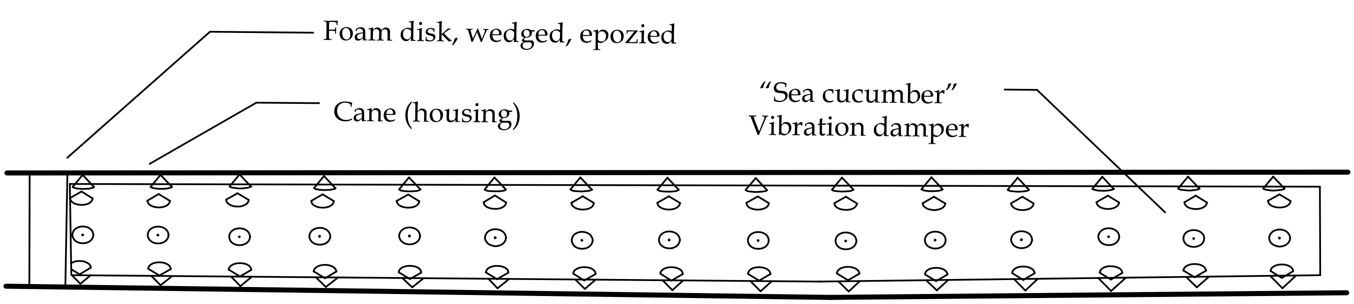


Figure 14.5. Final Geometric Design of Protective Visco-Elastic Foam

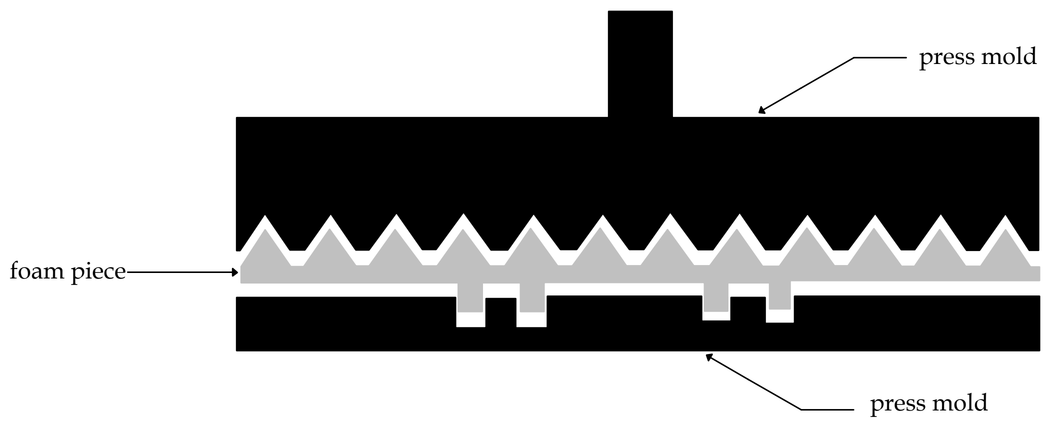


Figure 14.6. Mold for Creating the Inner Geometry of the Shaft

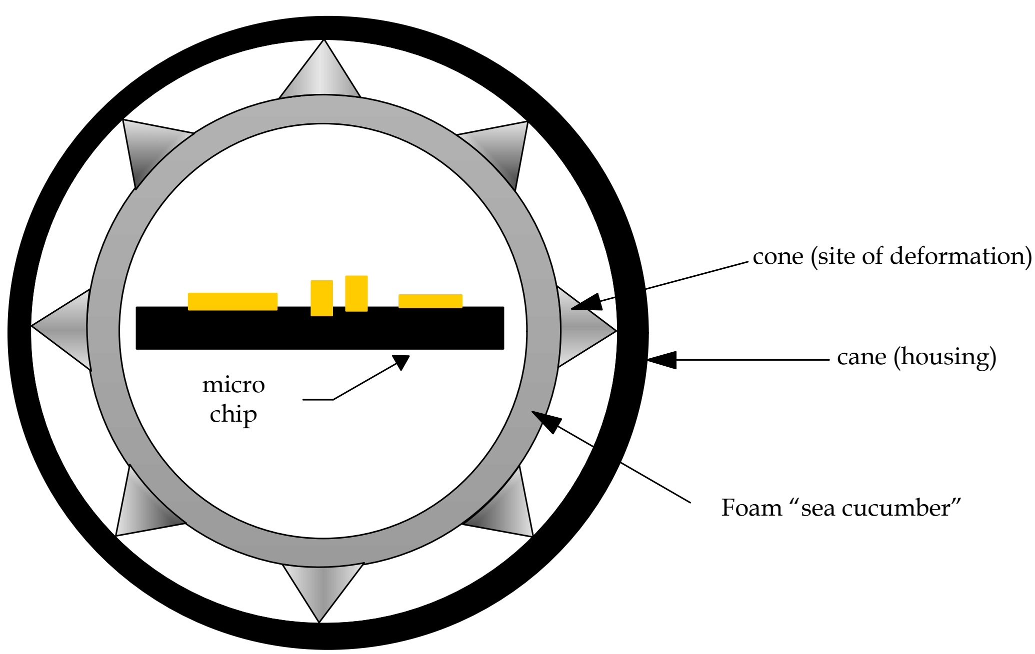


Figure 14.7. Cross Section of the Cane, Sensor and Damper

BOTTLE CAP REMOVAL ASSISTANT

Designers: Marc Attar, Steven Baj, and Andrew Werther
Supervising Professor: Robert Hyers
Department of Mechanical and Industrial Engineering
University of Massachusetts
Amherst, MA 01003-3662

INTRODUCTION

The goal of this project was to design a bottle cap opener that requires the use of only one hand and is portable. Currently there are simple solutions for opening bottles with metal caps. One is a wall-mounted bottle cap opener. Another option, which is more common in the average household, is the portable bottle opener that has a hole into which the metal cap fits at an angle. By lifting the handle upward, the cap comes off. However, the portable bottle opener requires the use of two hands, one to stabilize the bottle and the other to use the handle or lever that gives the user a mechanical advantage. This easy-to-use lightweight portable bottle opener (Figure 14.8) grips the neck of the bottle and then lifts off the bottle cap when the handles are squeezed together.

SUMMARY OF IMPACT

People who have limited use of one hand will benefit from a portable bottle cap opener that requires only one hand to use. This new design will enhance independence. Its portability will enable users to remove bottle caps when wall-mounted devices are not available, such as during outdoor activities.

TECHNICAL DESCRIPTION

The design is shown in Figure 14.8. It uses a lever, which gives a mechanical advantage to the user, reducing the force needed to pry the metal cap off of the bottle. The same basic shaped head or cap removal arm is used as the standard bottle opener, which interfaces with the bottle cap (Figure 14.9). The lever arm and the cap removal arm are linked, allowing for the proper motion to remove the cap and force transfer. The design has a claw mechanism that grips the bottle, obviating the need for a second hand. The lever mechanism removes the bottle cap (as shown in Figure 14.10).

Future redesigning and testing are required to guarantee that the grip arms and lever arm will comfortably fit in the user's hand and to ensure that the three arms are within comfortable grip capacities of a wide variety of potential users' hands.

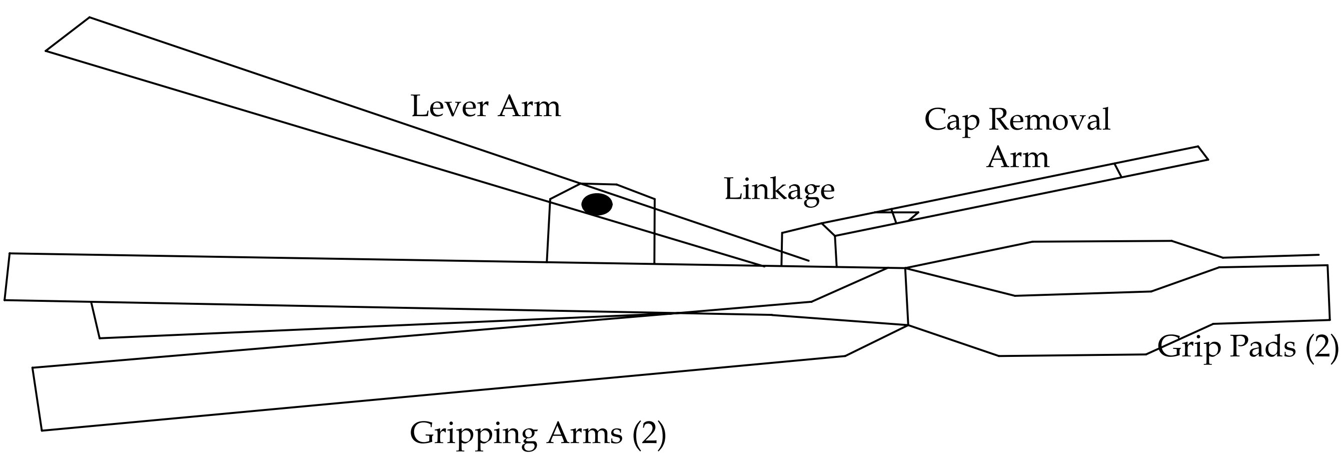


Figure 14.8. Bottle Cap Removal Assistant Design

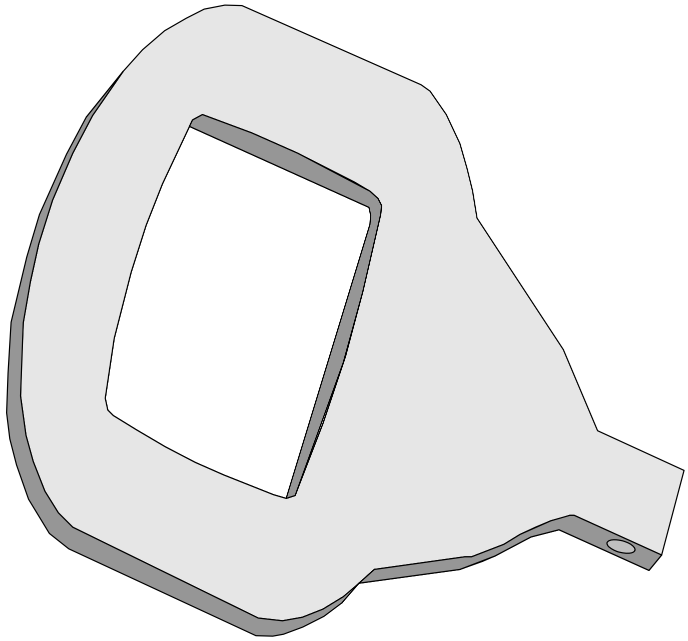


Figure 14.9. Cap Removal Feature

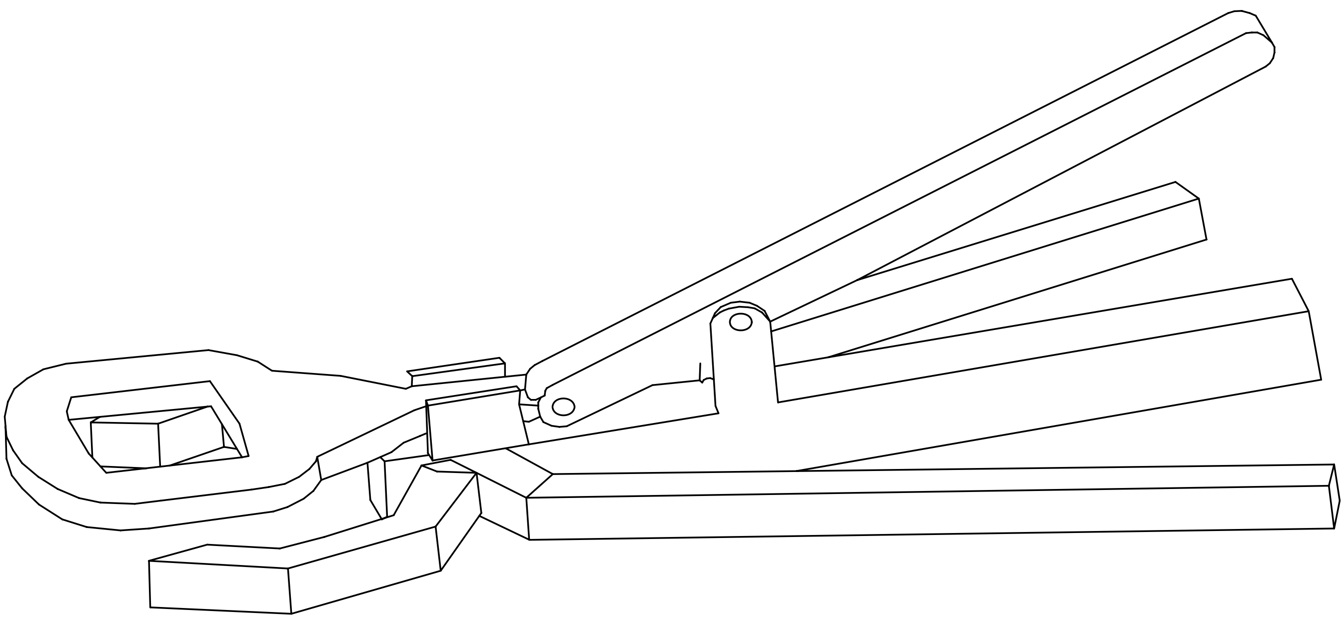


Figure 14.10. Claw and Lever Used to Grip Bottle's Neck

ASSISTIVE REACH MECHANISM

Designers: Zack Livingston, Daniel Bergeron, and Patrick Luo
Supervising Professor: Robert Hyers
Department of Mechanical and Industrial Engineering
University of Massachusetts
Amherst, MA 01003-3662

INTRODUCTION

An assistive reach mechanism for individuals with lower back problems was redesigned. A telescoped arm was designed, which makes the product easier to carry and store. The final design has a gripping claw that can pick up objects as small as a needle and as large as a can or jar. The arm brace, shown in Figure 14.11, aids in lifting the maximum five-pound load.

SUMMARY OF IMPACT

The design can help with grabbing objects that are up to four feet away and weigh as much as five pounds. People who may benefit include those with risk of falling from stools or ladders, people who use wheelchairs, people with back pain and injuries, and people who are short.

The claw allows for picking up a wide range of objects without damaging them. The shaft is strong and telescopes for easy storage. The trigger handle allows for full closing of the claw with only one full pull, and the ratchet mechanism locks the claw in place so constant force is not required. The handle trigger and ratchet will be helpful for people with hand pain or weakness. Finally, the addition of the arm support distributes the load over the arm and reduces the load on the wrist.

TECHNICAL DESCRIPTION

The functional components of the reach mechanism consist of: 1) the interface with person (handle), 2) the interface with object (claw), 3) the support mechanism (shafts), 4) the control mechanism (cable), and 5) mechanical advantage (gearing). Each of these functions were looked at individually, and the best design for each component was selected. Next, modifications were made to assure that all of the components fit and work together.

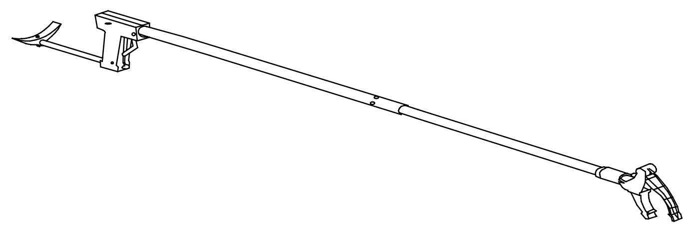


Figure 14.11. Assistive Reach Mechanism

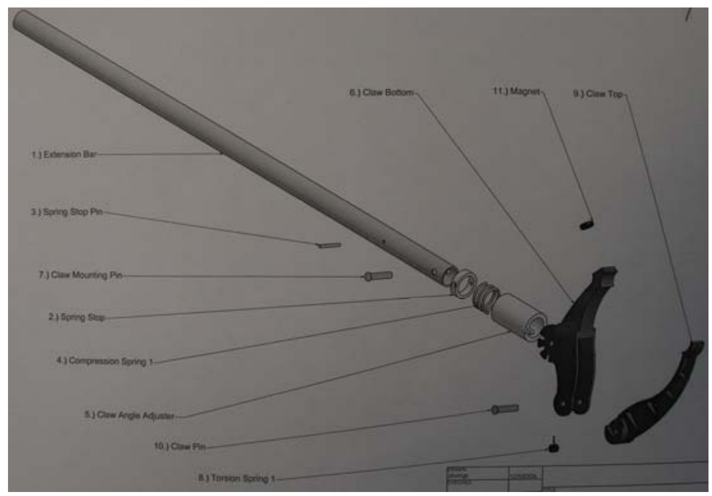


Figure 14.12: Exploded View of Claw

The claw assembly, as seen in Figure 14.12, has a lobster claw design. The claw is hinge-pinned at the top, and uses a torsion spring at the hinge to hold the claw open. The closure is controlled by a cable, which connects to the handle. The claw has two different gripping areas: 1) a larger area near the hinge joint for gripping glasses and jars, and 2) the rubber tips on the ends of the claws, which allow for grabbing objects such as needles and pins. The claw is made of cast aluminum for strength, and has a vinyl coating so the metal will not damage any of the objects being picked up, such as glasses.

The handle, which is made of ABS, plastic and gearing, uses a ratchet mechanism and a trigger handle. This configuration was used because it allows the user to close the gripping mechanism in one pull of the trigger (see Figure 14.13). The key feature of the ratchet is that it allows the user to lock the claw into place around an object.

There are two shafts in the design: one that connects the handle to the claw, and another that connects to the handle and gives support to the wrist when lifting. Figure 14.14 shows the overall design and the shafts. The shaft that connects the handle to the claw is comprised of two pieces that telescope, one inside the other. This is held in place with a c-type button when fully extended. Both shafts are made of wrought aluminum alloy with a 1-inch outer diameter and 1/16-inch inner diameter for the shaft and a 0.5-inch outer diameter and 3/32-inch inner diameter for the arm support.

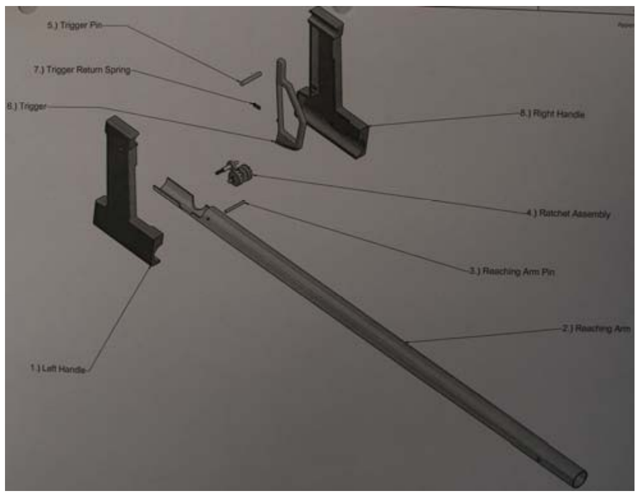


Figure 14.13. Exploded View of Handle

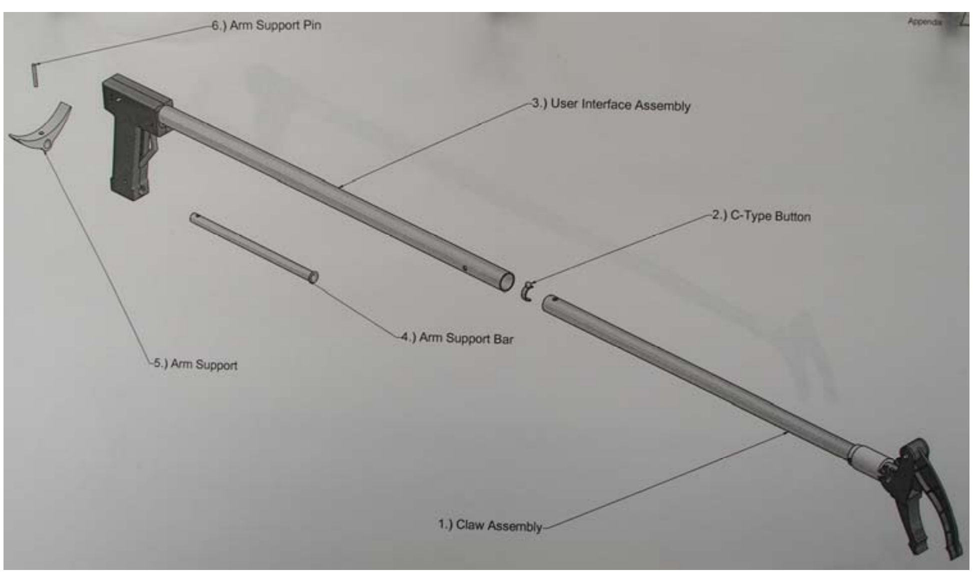


Figure 14.14. Exploded View of Telescoped Shafts

ASSISTIVE STAIR CLIMBER

Designers: Brian O'Connell, Luck Asselin, and Nathan Labarge
Supervising Professor: Robert Hyers
Department of Mechanical and Industrial Engineering
University of Massachusetts
Amherst, MA 01003-3662

INTRODUCTION

A device was designed to assist in the moving of heavy loads up a set of stairs. There are many homeowners who cannot carry or move loads up a staircase. Some individuals have trouble making the ascent even without carrying anything. Although there are wheelchair and lift systems to aid in moving loads up stairs, there are no low-cost personal assistive devices to help in these situations.

The design, shown in Figure 14.15, is a low-cost device that will transport as much as a 40-pound load up a flight of steps.

SUMMARY OF IMPACT

The device is a tread-driven vehicle with a removable self-leveling basket that is capable of

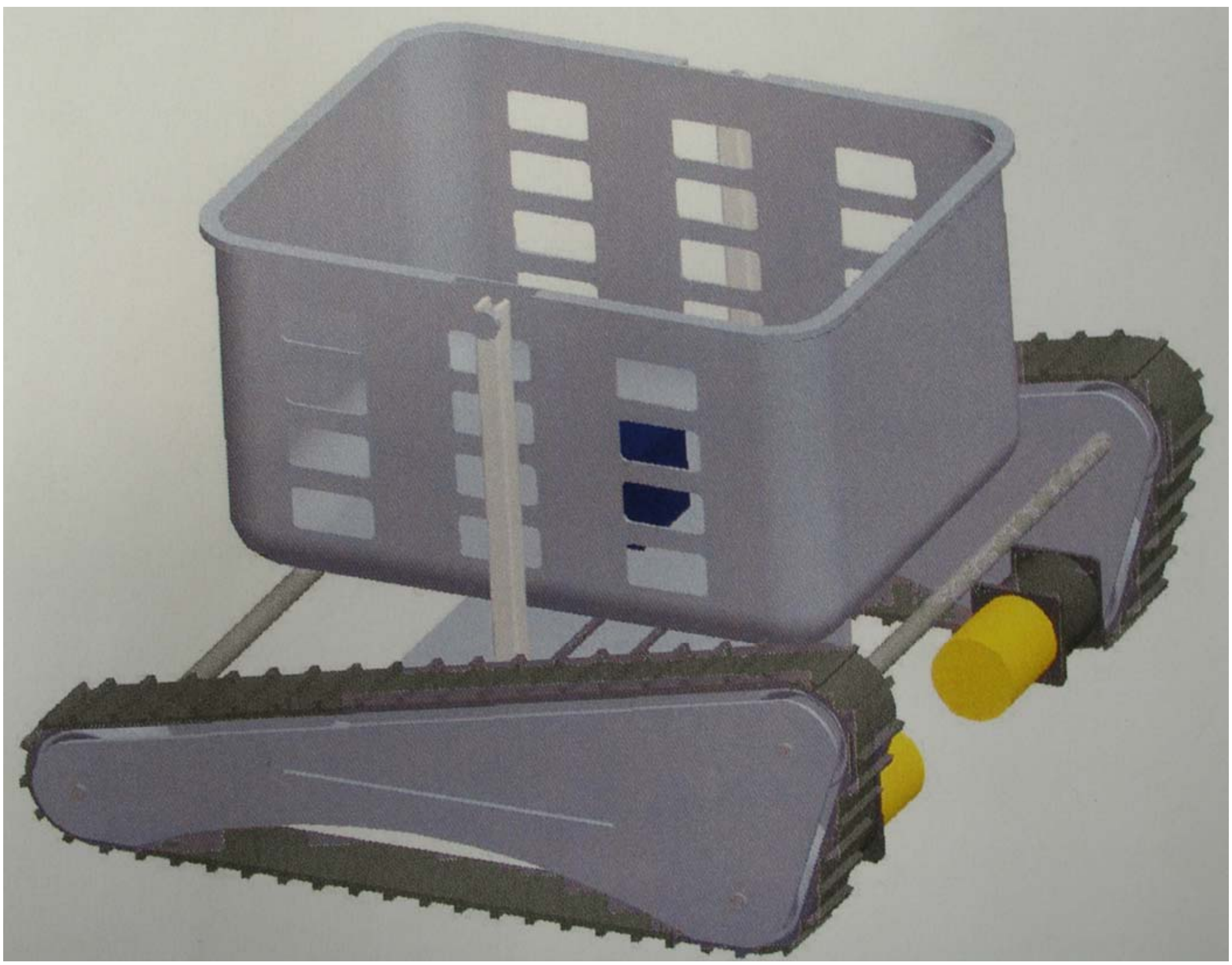


Figure 14.15. Assistive Stair Climber

running along flat ground, as well as up to a 45-degree incline. It will ascend a flight of steps in just over one minute. The device has few parts and was designed for easy manufacturing and assembly. This design will aid people in bringing groceries up and down their front steps, supplies from their basement, or even laundry to their bedroom.

TECHNICAL DESCRIPTION

The proposed design is a basket that is mounted to two arms and attached to the central mounting platform. The central mounting platform connects the two motorized tracks, the motor, battery, and the arms. The arms pivot to keep the carrying basket level while it goes up and down the stairs. The low height of the assembly and the shape keeps the center of gravity far forward and low. The location of the center of gravity keeps the basket from falling back while going up an incline.

The material indices of the plates, shafts and wheels were determined by a simple calculation, maximizing the strength against relative cost and density. PVC was chosen for the plate, while maximizing modulus against relative cost led to the selection of aluminum for the wheels and the shafts. All of the PVC parts will be joined using PVC welding, which creates a bond stronger than the PVC itself.

The belt that propels the assistive carrier and climbs the steps allows for a maximum loading weight of 100 pounds directly in the center of the bottom track, with a pretension of one inch. This allows for a maximum strain of 1.9% and causes an elastic spring force of 8.7 lbs per inch throughout the track. The Saint-Gobian Chemfab TCN 1590 Leno Weave Nomex/Fiberglass Belting Material, which has a max elongation of 2% at a loading of 40 pounds per inch, was the best match for this design.

It was determined that, for the motor, a torque of 15 ft*lb was necessary to drive the device while carrying a 40-pound load up a 45-degree angle at approximately 0.5 ft/sec. The motor selected was by HIT, and runs on a 12V DC battery at 2850 rpm and supplies 0.1562 ft*lb of torque. A spur gear head by Bayside Motion Group was chosen due to its 100:1 gear ratio with 98% efficiency and low backlash. It will provide the necessary force and speed.

The battery supply for the motor is based on the discharge time of 1.1 hours because the motor requires 1 ampere. A sealed lead acid battery was chosen based on the principle that it is able to discharge at any rate. The total weight of the battery is three pounds; it has a low-profile design, making it easy to attach to the support plate.

The expected cost for all parts (not including the belt) is approximately $200.

STOW AND GO: JOHN DEERE GATOR WHEELCHAIR STORAGE SYSTEM

Designers: Tim Smith, Sean Pringle, and Brian Swearengin
Collaborators: John Deere, PTC, Georgia Institute of Technology, University of Illinois-Urbana Champaign
Supervising Professors: Sundar Krishnamuty and James Rinderle
Department of Mechanical and Industrial Engineering
University of Massachusetts
Amherst, MA 01003-3662

INTRODUCTION

This project is the continuation of the designing and building of a prototype add-on for a John Deere 6x4 Gator (Figure 14.16). Throughout the project stages, the University of Massachusetts collaborated with Georgia Tech and University of Illinois-Urbana Champaign. The design is specific to people who use a wheelchair but wish to transport the chair easily when they are using the Gator. The UMass team's task was to design a device able to stow and retrieve a folded wheelchair on the 6′x4′ vehicle. The final design (Figures 14.17 and 14.18) is easy for the user to control by using simple on and off switches. Also, the design minimally impedes on the usefulness of the Gator as a utility vehicle, by having the wheelchair be stored on the device itself. Low cost and robustness were also priorities of this project.

Figure 14.16. John Deere 6'x4' Gator

SUMMARY OF IMPACT

John Deere has determined that there is a market for a Gator that can be used by people who use wheelchairs due to a disability affecting the lower body. This design will enable users to remain active outdoors and to be able to do some of their own yard and garden maintenance, increasing independence and quality of life.

TECHNICAL DESCRIPTION

The "Stow and Go" is designed to be durable through the use of lightweight and strong 1/8″-thick 6063 aluminum square tubing for the frame and all the hinges. A 12-volt electric linear actuator provides the motion. This low-voltage actuator allows the device to be powered by the Gator battery and obviates the need for expensive and complicated hydraulics. The wheelchair attaches to the lift via an adjustable clamp where it is securely held by an easy-to-use cam lever (as shown in Figure 14.19). This clamp holds the wheelchair handles during lifting, retrieval, and when the Gator is in use. Operation is controlled by two simple toggle switches. One controls the direction of the motor while the other controls the power. Safety cut-off switches are fully integrated into the electrical

Figure 14.17. Partially Extended Prototype

system.

This design allows for a customer to buy the product as an after-market add-on, since it is fully self-contained and only interfaces with the Gator for the power supply. The design would be easy and inexpensive to install at the factory because it can be fully assembled independently from the assembly of the Gator.

The final cost for this project is approximately $500.

Figure 14.18. Fully Retracted Prototype

Figure 14.19. Clamping Mechanism to Hold Wheelchair