UNIVERSITY OF CONNECTICUT

School of Engineering

Fall 2019 Senior Design Project

"Mighty Cane"

August 12, 2019

Wilbur Cross Building

An electronic device that connects physical therapist and patient through the Internet of Things to help patients walk better, increase therapist outcomes, decrease non-compliance, reduce recovery time, patient stress and health care cost.

Revision G Monday, August 12, 2019\

Richard C. Davids, author.

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EXECUTIVE SUMMARY.

There are over 2 million amputees in the United States. Over 185,000 lower extremity amputations occur annually in the United States due to diabetes, accidents, stroke, and trauma. We have 2.2 million wounded warriors; many use a cane. Increased demand for physical therapy will come from the aging baby boomers who may be more susceptible to health conditions, such as strokes, diabetes and spinal injuries. A shortage of physical therapists is predicted.

Ensuring that patients and therapists maintain that life-saving vital connection not only in face-to-face sessions but in real time using simple, low cost technology maximizes manpower and skills. To improve the therapeutic connection between doctors, therapists and patients requires using the Internet of Things – sensors, Wi-Fi, and smartphone connectivity – to maximize the opportunity to provide quality care to lower limb trauma patients.

The University of Connecticut School of Engineering is proud to team with our School of Orthopedics and Sports Medicine and the Department of Veterans Affairs to research, design and develop a tool to proactively prepare patients for lower extremity surgery and reactively assist amputees with learning to walk after knee or hip surgery or other types of injuries. It will help them walk better by providing feedback sooner and quicker.

This is the first electronic cane with multiple functions. This device is low cost, easy to use and maintain and can function as either a cane or crutch. It allows the patient and therapist to interact even though separated by distance and time. Called ‘Mighty Cane’, this tool enables the therapist to monitor patient orthotic use, set limits and recommendations for therapy, and track compliance to protocol through interactive graphic displays.

PRIMARY GOAL.

To design and build an electronic programmable cane that connects a patient to their therapist anytime and anywhere by using sensors, a microcomputer, and wireless technology.

SECONDARY GOALS.

1. To investigate and design an electronic cane using simple, inexpensive and readily available COTS hardware and software.
2. To evaluate the advantages of an orthotic device to monitor patient gait, force, location and distance.
3. To investigate how the patient supports and balances weight using either the cane or crutch mode with either or both hands.
4. To research the benefits of haptic (tactile) and Text-To-Speech (TTS) feedback regarding patient performance and adherence to therapist protocol.
5. To investigate the effects of thermal and vibration therapy in a specific modality to alleviate the pain and discomfort of osteoarthritis (OA) in the hands.
6. To identify other possible applications of remote technology to orthotic devices like a walker, wheelchair, or a helmet.

RATIONALE.

There are over 2 million amputees in the United States. Over 185,000 lower extremity amputations occur annually in the United States due to diabetes, accidents, stroke, and trauma. It is estimated that India alone has over 1 million amputees. Below-knee amputations are the most common amputations, representing 71% of vascular amputations; there is a 47% increase in below knee amputations from 1995-2020. Low back pain and pain from hip and knee surgery can be alleviated by using a cane.

Increased demand for physical therapy will come from the aging baby boomers who may be more susceptible to health conditions, such as strokes and diabetes that require physical therapy. According to the American Physical Therapy Association there may be a shortage of up to 26,696 over the next five years depending on how many physical therapists leave the workforce.

The name 'Mighty Cane' is a phonetic compression of the original name 'My Therapeutic Cane' or 'My T Cane'. It fills that gap between regular therapeutic sessions by enabling more therapists to interact with their patients in a timely basis regardless of time or physical location. It is a tool that records and transmits data to a therapist, enabling the therapist to monitor and advise the patient about their progress in therapy. By using Internet of Things (IoT) sensors embedded in an orthotic device to connect rehabilitation patients (amputees, orthopedic patients, land mine victims) with a therapist without being physically present.

APPROACH.

SYSTEMS ENGINEERING METHODOLOGY.

A classic systems engineering methodology developed by the aerospace engineering industry will be followed to research, design and develop the prototype device with the student team. The following list of activities identifies our approach.

- Research orthotic devices uses and applications.
- Research mobility, capabilities, limitations of cane users.
- Use a cane to understand desirable and undesirable features.
- Interview physical therapists about cane use, limitations, possibilities.
- Identify primary and secondary functions.
- Develop system and detail design level requirements.
- Develop Concept of Operations (CONOPS) scenarios.
- Develop system schematics.
- Develop candidate designs.
- Perform tradeoff studies. See the Appendix for trade study issues.
- Use human computer modeling to visualize cane / user interfaces.
- Identify or develop user interface guidelines for the smartphone application.
- Use Usability Experience (UX) methods and testing of smartphone interface.
- Develop ‘bread-board’ functional electronic prototype.
- Use 3D modeling and printing to create a full-scale prototype parts, as needed.
- Develop full-scale functional model(s) using furniture grade PVC and Commercial-Off-The Shelf (COTS) electronic components and software.
- Perform verification and validation (by analysis, test, demonstration or inspection).

An important fundamental activity of systems engineering is identifying both system and detail design requirements. A preliminary list of both types of requirements is in the Appendix. Student engineers will review the list and further define system and detail design level requirements.

Another key systems engineering activity is performing tradeoff studies. For instance, some tradeoff studies might be: (1) heat dissipation, (2) cane color, (3) mechanical connection between modules, and (4) one use or rechargeable power pack. Sample Microsoft Word and Excel spreadsheet trade study forms are included in the Appendix. The Excel spreadsheet is an inserted picture and not interactive. A workable Excel spreadsheet trade study form is available.

THREE PHASE ITERATIVE DESIGN.

Three phases are anticipated – Conceptual, Developmental and Production.

The Conceptual design phase is a technical demonstration project to build one functional prototype plus the smartphone application prototype. The smartphone application may be partially or fully functional depending upon the complexity and resources. This phase will answer questions like:

1. Is haptic and audible feedback effective in modifying patient care?
2. Can an inexpensive microprocessor and sensor technology be integrated inside a cane?
3. Can a smartphone application communicate with an orthotic device with multiple sensors?
4. How effective is vibration, heat and cold delivered in this modality effective on osteoporosis in the hand?

The project will focus on developing an orthotic devices; it will not attempt to build a specific prosthesis. The conceptual design phase is scheduled for Fall, 2019 through Spring, 2020. Only budget estimates for the conceptual phase are presented here.

The Developmental phase concentrates on refining the architecture and building 3 – 5 test units that will be distributed to selected physical therapist or clinics in the area. Developmental units will undergo more rigorous and systematic field testing under real world conditions. Feedback from therapists and doctors will be recorded and iteratively designed into the next generation.

The Production Phase will focus on developing logistical and manufacturing plans to manufacture and distribute the electronic canes. No large-scale production is anticipated. Less than 10 would be built and field tested at Connecticut rehabilitation clinics, hospitals and Department of Veteran Affairs facilities.

NOTIONAL FUNCTIONS.

There are two main functional subsystems or segments in this system – the electronic cane and the smartphone. Each segment performs several functions.

ELECTRONIC CANE FUNCTIONS.

The electronic cane performs measurement, physical support, and wireless connectivity. To achieve these functions, it contains a power supply (battery), sensors (tactile pressure, GPS, accelerometer), a microcomputer, antennas, and thermal / vibration inserts.

Tactile pressure as indicated by downward force is measured by a pressure pad in the base of the cane. Depending upon severity and timeline, downward pressure should decrease during therapy as the patient relies less on the cane for support. Or it might remain constant which could indicate a more complex condition. These data will be essential to therapeutic remediation and intervention.

Distance is measure by a Global Positioning System (GPS) component (shield). GPS is a time-stamped indication of distance traveled. Greater distance and use imply more exercise and cane use. A drop off in distance or an abrupt change could indicate an emergency condition which would alert the therapist to an intervention. For instance, if the therapist sees a long duration, long distance segment, the that would indicate a walk. Likewise, if only short duration, short distance segments are seen, then this might indicate limited intermittent use which might not follow the therapy protocol.

Acceleration or motion is measured by an accelerometer in the lower segment of the cane. Acceleration or motion is a key indicator of gait. Gait is important indication for the therapist since an increase or irregular gait increases the risk of falling or exacerbating the injury. The microprocessor with memory records sensor data and transmits it to the therapist's smartphone via built-in Wi-Fi and Bluetooth capabilities.

In addition to providing the therapist with real time connectivity to the patient, a hybrid model of Mighty Cane includes separate vibration and thermal (hot and cold) inserts in the handle to alleviate the discomfort of osteoarthritis. The hot and cold inserts are heated in a microwave or cooled in a freezer, respectively, to either increase blood flow or reduce swelling. A vibration insert provides additional stimulation for blood flow in the hands suffering from osteoarthritis. These therapeutic inserts are envisioned as standalone devices and not connected to the main electronic subsystem.

SMARTPHONE FUNCTIONS.

The smartphone application connects the electronic cane to the therapist. Several functions will be investigated and incorporated into the overall design. One function to investigate is to use a smartphone calendar function to set up a real time session for the therapist to monitor the patient's orthotic use. Another function would use COTS Text-To-Speech (TTS) technology to alert the patient to modify gait, force or movement. The TTS message is transmitted via the Wi-Fi connection from the therapist to the patient and announced using a small speaker and audio function in the cane. These are a selection of the possible research activities.

There are several smartphone functions to investigate to provide the patient with feedback regarding orthotic use. One possibility is for the therapist to call the patient when a prolonged out-of-tolerance condition is detected. This occurs because the smartphone enables the therapist to program the cane microprocessor with gait (acceleration), force (pressure), and distance (GPS) limits. When a prolonged out-of-limit condition exists, i.e., excessive force or downward pressure, is detected, the microprocessor compares limits in the database and sends a message to the therapist via the built-in Wi-Fi or Bluetooth capability. The therapist can call the patient to advise.

The Appendix contains a notional list of primary functions.

BENEFITS.

Mighty Cane allows the therapist to track rehabilitation progress via smartphone connection and offer advice via text-to-voice messages or haptic (tactile) feedback. Either text-to-voice messages or pre-recorded voice messages are possible. This approach increases patient/therapist interaction time which should decrease therapeutic period and increase patient satisfaction. Fewer setbacks translates to higher success rates.

The mechanical design uses dual handles 180 degrees apart which allows the patient to lean on the cane, supporting total body weight with both hands and larger muscles of the shoulders. A vertical post between the handles provides more of a walking stick function. It is possible that this dual handle design feature was first used by Quakers around 1770 but fell out of favor for the simpler single handle cane.

Table 1 - List of Mighty Cane Features and Benefits

FEATURE	BENEFIT
Thermal inserts	Alleviates discomfort and pain from OA

FEATURE	BENEFIT
Vibration insert	Stimulates blood flow in hands suffering from OA
Dual handles	Allows patient to lean on the cane using both hands to reduce stress.
Vertical post	Enables user to exert more downward force directly through the vertical shaft to easily stand from a seated position.
Crutch adapter	Easily transforms cane into a crutch without major modification or cost.
Smartphone interface	Enables therapist to connect with the patient anytime and anywhere over Wi-Fi or BT
Text-To-Speech (TTS)	Allows therapist to deliver voice messages via the cane to the patient without using a smartphone. Saves time, more convenient.
Measures acceleration	Allows therapist to see gait data
Measures distance	GPS module shows therapist distance traveled and time stamped data
Measures pressure	Allows therapist to see downward force exerted by patient
Replaceable or rechargeable power supply	Uses low cost replaceable (or rechargeable) power supply to minimize maintenance cost.
Modular sections	Enables assembly and repair without disassembling the entire cane.

METRICS.

Two classes of metrics are planned during the Conceptual, Developmental and Production phases.

For the Conceptual Design Phase, at least three primary technical metrics are planned. They are:

1. Connectivity between the cane and smartphone as demonstrated by connection time, Text-To-Speech capability.
2. Robustness of the mechanical structure as demonstrated by a drop test, ease of assembly and disassembly.
3. Ease of use as demonstrated by usability of the smartphone interface.
4. Subjective feedback regarding alleviation of discomfort of OA.

For the Developmental and Production phases, at least three primary therapeutic metrics are planned. They are:

1. Orthotic use measured by time and distance. Orthotic use should increase because the therapist can monitor continuously patient behavior and offer advice concerning usage and encouragement (positive feedback).
2. Rehabilitation recovery time should decrease because the patient is following therapy protocol more closely.
3. Patient satisfaction should increase as measured in subjective evaluation since therapeutic progress is more positive.

RESOURCES.

This project involves University of Connecticut Senior Design students from the School of Engineering Biomedical, Electrical and Computer Engineering to research, design, prototype, test and build one orthotic device, a cane, to validate the concept and functions. The technology developed can be migrated to other orthotic devices.

The Conceptual Design team consists of five (5) senior engineering students. The team is a mix of bioinstrumentation and computational systems background so well suited for the project. A senior leader from Biomedical Engineering (BME), Dr. Patrick Kumavor, will be the technical advisor. The Conceptual Design phase is scheduled to last 36 weeks during the academic year (2019 – 2020). Additional staff may be solicited to provide technical advice to the students.

The University of Connecticut School of Engineering is composed of nine (9) departments. Three departments are expected to support this project: Biomedical Engineering, Mechanical Engineering, Electrical and Computer Engineering. During a typical academic year, over 600 senior engineering students participate in a Senior Design. Each of these three departments sponsor between 27 and 35 team projects. Each team consists of between 2 and 5 students.

The University of Connecticut Health Nayden Rehabilitation Clinic is staffed with 33 therapists and provides rehabilitation for a variety of patient needs including: Orthopedic injuries, Sports medicine Injuries, Total joint replacement, and Post-surgical. An advisor from the Nayden clinic will participate on a part time basis (4 hours per week) to review concepts, applications and implementation.

The University of Connecticut Department of Orthopedics and Sports Medicine staff of 31 nurses and doctors who specialize in rehabilitation, sports medicine, injuries of the spine, shoulder, hands and feet. It is one of New England's premier facilities for sports medicine and orthopedics. An advisor from the Department of Orthopedics and Sports Medicine will participate on a part time (4 hours per week) basis for 36 weeks.

Connecticut or Rhode Island Department of Veterans Affairs. A point of contact at the office may provide critical design evaluations based on intimate knowledge of a specific user population – injured veterans.

NOTIONAL MODELS.

Four (4) notional models are proposed. Dividing up functionality among four models enables more internal real estate for components, improves usability and increases user population.

1. Electronic clinical model for therapists and clinics.
2. Hybrid, with thermal / vibration inserts, for clinics and pharmacies
3. Mechanical for everyday use.
4. Steampunk model for everyday use.

In the electronic model, discrete electronic components and wiring are mounted in the cross fitting and shaft modules as shown in Figure 1. The electronic model has no inserts. This separation of functionality was done to avoid compromising safety and increase internal volume needed for discrete electronics. Plus, the electronic model and hybrid model serve different user populations which makes separating functionality more sense. The Steampunk mechanical model is much simpler than either electronic or hybrid models and serves a much broader user population – one that does not suffer from OA or require therapist intervention and monitoring.

Both the electronic and hybrid models are built from 1.25 inch inside diameter PVC. This allows more internal capacity for electronic components and the inserts. The Steampunk mechanical is constructed of 1.00 inch inside diameter.

ELECTRONIC CLINIC MODEL

In an electronic cane, the notional design is to have a main shaft composed of either three (3) modules or a single shaft. In the modular model, each shaft module houses a discrete set of electronics, for instance, a replaceable battery in the power section. Additional sections include the lower sensor section and an upper microprocess section / antenna section. No fasteners, nuts, bolts, adhesives or hardware are anticipated to attach sections. Each section or module allows for assembly prior to final assembly and test. Figure 1 shows the notional design.

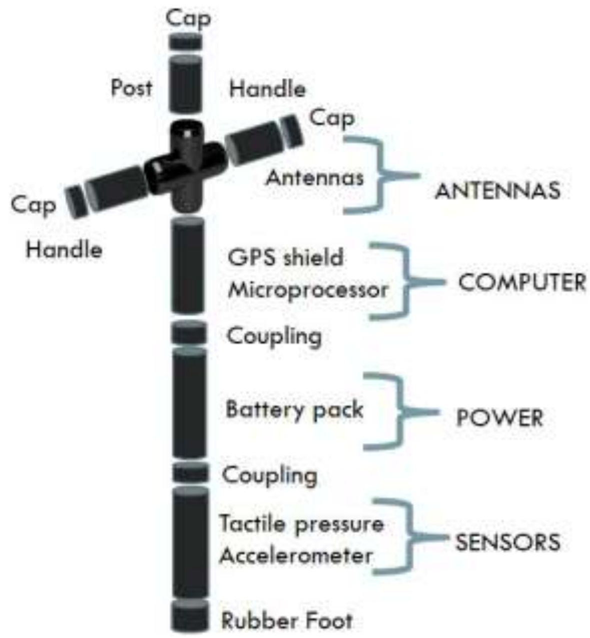

Figure 1 – Notional Electronic Model Design Concept

An electronic Mighty Cane is built of six (6) pieces of 1.25 diameter (inside) PVC pipe, plus assorted fittings, couplings, internal dome caps plus a size 8 rubber stopper. It is extremely strong and does not crack or splinter. A size 8 stopper has top diameter of 41mm a height of 25mm and a bottom diameter of 33mm with a durometer of 45.

The selected electronic components in the Preferred Parts List (PPL) are small enough to fit inside the electronic Mighty Cane modules. Additional wiring and connectors are needed. The following figure shows a clear PVC cane with the electronic components mounted on a cardboard ‘sled’ which is one way to internally mount the components.

Figure 2 - Electronic clinic model with electronics mounted in shaft

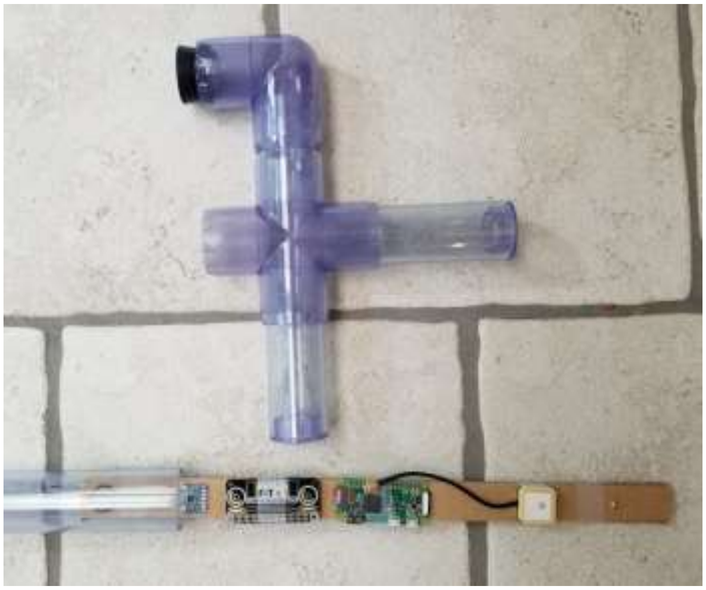

Figure 3 - Electronic clinic model showing components on sled

The prototype is approximately 39 inches long from the rubber pad at the toe to the top of the vertical post. It is approximately 35 inches from the rubber stopper in the toe to the midline of the handle. This size accommodates a 6-foot high adult. The PVC pipe is easily cut to accommodate 5th percentile female to 95th percentile male patients. This prototype weighs about 1.00 lbs.

Figure 4 - Steampunk canes - electronic top and basic mechanical bottom

A crutch or staff module can be inserted into the top vertical post using a external coupling, a short section of PVC, a tee section and two (2) short sections of PVC pipe with caps. Thus, the Mighty Cane can be an inexpensive dual function mobility aid. Cost for a mechanical non-electronic cane without crutch adapter is approximately $20.00 US. Estimated retail material cost for the crutch section is approximately $6.00. Thus, total material cost for a cane with crutch is approximately $26.00.

HYBRID CLINIC MODEL

The following figure shows the hybrid model with the thermal inserts that slip into the handle. Three inserts are anticipated: cold, hot, and vibration. These inserts measure about 1 inch in diameter and 10 -12 inches in length. The operational concept is to remove the cap, slip in one of the three inserts, slip on the cap and experience the alleviation of discomfort from OA.

Figure 5 - Hybrid model with color coded inserts

MECHANICAL EVERYDAY MODEL

A non-electronic mechanical Mighty Cane is built of four (4) pieces of PVC pipe, one cross fitting, three (3) internal dome caps, a 90-degree angle fitting and two (2) rubber stoppers. The shaft is a single piece of PVC pipe with one cross fitting, two 5-inch pieces of PVC pipe as handles, and a 5-inch piece of PVC pipe as a vertical hand grip or post. One handle is fitted with a 90-degree fitting with a rubber stopper at the downside end. This design feature allows the cane to be leaned or rested against a smooth surface like a countertop without sliding or slipping off.

The optimal notional design of a mechanical cane uses 1.00 diameter (inside) PVC material. A size 5 rubber stopper serves as the toe. A size 5 rubber stopper (29 mm x 22 mm x 28 mm long) fits the toe of the 1.00-inch diameter cane.

Figure 6 – The mechanical model

STEAMPUNK EVERYDAY MODEL

A fourth model, called the Steampunk, enables the user to hang the cane on the back of a chair or countertop without sliding or slipping off. Wikipedia defines steampunk as: a subgenre of science fiction or science fantasy that incorporates technology and aesthetic designs inspired by 19th-century industrial steam-powered machinery. The additional 90-degree fitting to the handle gives the cane a more industrial appearance. Thus, the only modification is a 90-degree fitting on one handle and an additional size 8 or 5 rubber stopper depending upon the PVC pipe diameter.

The following figure shows the Steampunk model.

Figure 7 - Steampunk Model

The following figures show a steampunk model balancing on a countertop, hung on a doorknob and used by Julie.

Figure 8 - Steampunk cane balanced on a countertop

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Figure 9 - Steampunk cane hung on a doorknob

Here’s a photo of Julie with the first Steampunk Mighty Cane.

Figure 10 - Julie with the first steampunk lightweight Mighty Cane

COLORS

The furniture grade PVC pipe and fittings come in ten (1) vivid colors. See the following figure for available colors. Clear furniture grade PVC offers an advantage in that it shows the interior components, but the clear PVC is twice as expensive as solid color PVC. Using clear PVC for the cross fitting allows for an array of LED indicators can be mounted inside the cane and be visible to the patient and therapist but not be susceptible to damage.

Figure 11 – PVC available in several colors

ELECTRONIC CANE – NOTIONAL DIMENSIONS AND COST

The following table identifies the different modules, approximate lengths and the total vertical height.

Table 2 – Electronic Cane Dimensions

Electronic Cane Description	Length (inches)	Real Vertical Height
PVC lower module	11.0	11.0
PVC middle module	12.0	12.0
PVC upper module	11.0	11.0
PVC accessories (couplings) (2)	0.25	0.50
PVC fitting (cross)	4.75	1.75
PVC vertical post	5.00	3.50
PVC handles (2)	5.00	0.00
PVC internal dome caps (3)	0.25	0.25
Overall vertical dimension (20pprox..)		**40.0**

The following table identifies the approximate costs for the various sub parts for an electronic Mighty Cane.

Table 3 – Total Cost Estimates for Electronic Cane Cost – Retail

Electronic Cane Description	Retail Cost	Total Cost
PVC pipe	$9.10	$9.10
PVC accessories (couplings) (2)	$1.85	$3.70
PVC fitting (cross)	$2.70	$2.70
PVC internal dome caps (3)	$1.25	$3.75
Raspberry Pi Zero WH (with pre-soldered header)	$13.00	$13.00
Adafruit Round Force-Sensitive Resistor (FSR) – Interlink 402	$7.00	$7.00
Adafruit LIS3DH Triple-Axis Accelerometer	$5.00	$5.00
Adafruit Ultimate GPS Module – 66 channel w/10 Hz updates or Adafruit Ultimate GPS Weatherwing	$37.00	$37.00
Speaker pHAT	$13.00	$13.00
Adafruit GPS Antenna – External Active Antenna – 3-5V 28dB 5 Meter SMA	$14.00	$14.00
Slim Sticker-type GSM/Cellular Quad-Band Antenna – 3dBi uFL	$3.00	$3.00
Adafruit Power Boost 1000 Charger – Rechargeable 5V Lipo USB Boost @ 1A	$18.50	$18.50
LiPo/LiIon power supply shim	$11.00	$11.00
Lithium Ion Polymer Battery – 3.7v 1200mAh	$10.00	$10.00
Total Cost (Estimated)		**$175.05**

MECHANICAL STEAMPUNK MODEL – NOTIONAL DIMENSIONS AND COST

A non-electronic cane consists of the following components. A non-electronic cane does not have the shaft modules that house the electronics. It does have the same height post and handles. Total height is approximately 39.0 inches. The following table identifies the approximate lengths and total vertical height of a notional cane. Note: cane height can vary based on user height.

Table 4 – Non-Electronic Cane Dimensions.

Non – Electronic Cane Description	Length (inches)	Real Vertical Height
PVC shaft	34.0	34.0

Non – Electronic Cane Description	Length (inches)	Real Vertical Height
PVC accessories (couplings) (2)	0.25	0.50
PVC fitting (cross)	4.75	1.75
PVC vertical post	5.0	3.50
PVC handles (2)	5.0	0.00
PVC internal dome caps (3)	0.25	0.25
Total vertical height		**40**

The following table identifies the notional retail cost for a non-electronic cane.

Table 5 – Total Non-electronic cane Retail Cost

Non-Electronic Cane Description	Retail Cost	Total Cost
PVC pipe	$9.10	$9.10
PVC accessories (couplings) (2)	$1.85	$3.70
PVC fitting (cross)	$2.70	$2.70
PVC internal dome caps (3)	$1.25	$3.75
Rubber stopper	$0.75	$0.75
Subtotal		**$20.00**
Crutch shaft (16 inches)	$2.50	$2.50
Tee fitting	$1.90	$1.90
Internal dome caps (2)	$1.25	$2.50
Total Cost Estimate		**$26.15**

Considering that a separate crutch and a cane cost at retail about $130.00, Mighty Cane offers an alternative to separate metallic canes and a single crutch for 80% less for materials alone.

In special cases a longer shaft length is desirable. Approximately, five (5 inches should be added. Thus, in a non-electronic cane, the main shaft should be 39 inches for a total vertical dimension of 44 – 45 inches. A special case is characterized by someone who grabs the cane with both hands, swings the cane in front of the feet and steps forward; thus, creating a tripod with the cane and feet.

SMARTPHONE APPLICATION.

The Android platform is the primary platform due to open source software, non-proprietary software, and simplicity. The smartphone application allows therapist to view progress and cane use using simple graphic displays. It allows the therapist to communicate with the electronic cane using TTS or haptic feedback. Figure 6 is a notional display that shows force, location, and acceleration over time to inform the therapist of progress.

Figure 12 - Sample smartphone displays.

User Interface Development

User interface (UI) development of the mobile smartphone application follows established methods of developing the UI. We will start with a functional analysis and progress through requirements definition, task analysis, procedure, step and action. A ‘story board’ may be developed, also, to show top and lower level functions. The type of dialogue (menu, function key, Q and A, etc.) will be explored in developing the task analysis. Guidance regarding the UI will be obtained from established UI guides such as, Apple, IBM, or GNOME.

System feedback (message, state change, modality) is extremely important and will be included in analyses. The following list is a sample of the general methods we will use.

1. Ensure that input or user focus is clear and obvious by using some method of coding.
2. Use a dialog box or prompt to inform the user of the outcome of an action.
3. Use a method of coding controls so that the user knows where they are in the hierarchy and pathway.
4. Use on-screen prompts to help the first-time user and guide experienced users through less frequent tasks.
5. Locate a simple prompt at either the top or bottom of the screen that informs the user what is the next common action.
6. Always use explicit selections that follow the 'object-action' sequence.
7. Indicate when the system is processing a request.
8. Check for valid type of input (numeric, alphabetic) whenever user tabs out of a field or goes to the next screen.
9. Provide field masks (yyyy/mm/dd) to indicate the format of data.

NOTIONAL ARCHITECTURE.

The figure below shows the notional architecture of both the cane and smartphone. There are two main subsystems – the cane and smartphone. The cane contains the power supply, sensors, thermal / vibration inserts and microprocessor.

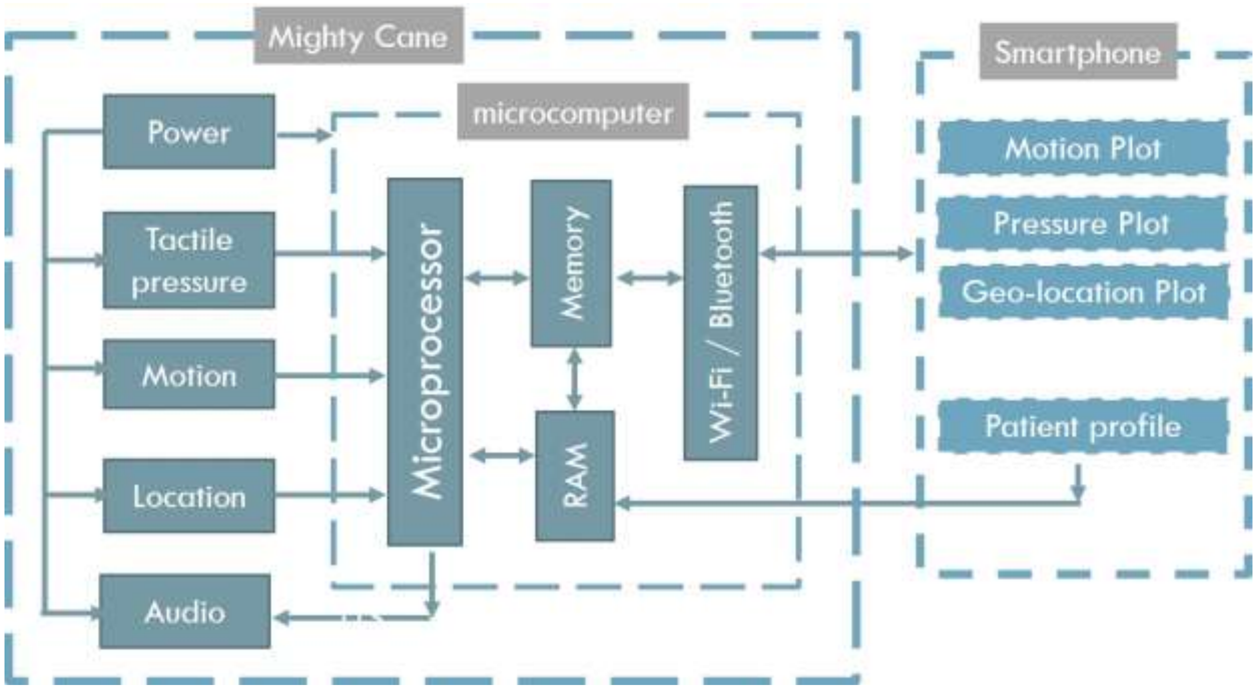

Figure 13 - Notional architecture.

The smartphone application developed by a student team communicates with the cane over Wi-Fi or Bluetooth. The smartphone application sends patient profile data to the cane that identifies the limits of force, distance and motion. Snapshots of cane use are sent to the smartphone either on-demand or at scheduled intervals. Patient data is graphed for the therapist to examine. Out-of-tolerance conditions might be identified by color code for easy recognition. The therapist can either send a Text-To-Speech message to the cane or call the patient and advise depending upon the patient preference and resource. A rugged microphone might be used to provide a voice interface for the patient to the therapist using brief voice to text messages.

COMPONENT SELECTION.

The electronic sensors and microprocessors selected for the Conceptual Design phase are readily available from ThePiHut, an electronic component distribution company in England, Mann Enterprises LTD Homefield Road Haverhill, Suffolk CB9 8QP. Most are Adafruit components distributed by ThePiHut. Lead time is about two (2) weeks.

The cane structural components are available from COTS distributors and commonly available in standard sizes, lengths and fittings. Formufit is the most well-stocked and least expensive supplier of PVC pipe, fittings and accessories. The smartphone test platform is an inexpensive Android device. The vibration and thermal insert materials and devices must by constructed.

KEY PERSONNEL – CONCEPTUAL DESIGN PHASE

LEADERSHIP.

Charles Maric.
Director, Senior Design Business Development, Office of the Dean. Mr. Maric is the point of contact with senior leaders at UConn involved in the project.

Figure 14 - Charles Maric

Dr. Patrick D. Kumavor, Ph.D.
Assistant Professor-in-Residence, Biomedical Engineering. Dr Kumavor specializes in ultrasound imaging, photoacoustic imaging, and transducers to detect deep cancer. Dr. Kumavor is responsible for advising student engineers regarding technical matters. He is the main Point-of-Contact (POC) with the University of Connecticut School of Engineering and will refer student engineers to a secondary source of technical expertise.

Figure 15 - Patrick Kumavor

Richard Davids, Sponsor.
Mr. Davids is the inventor of Mighty Cane. He is a retired senior staff human factors engineer with Lockheed Martin Missiles and Space Systems, Sunnyvale, California, 1974 – 2007. He applied human factors engineering principles and design standards to mobile shelters, large facilities, missiles, ships, planes, spacecraft, command centers, transportation systems, railcars,

support equipment, and computer human interfaces. He worked with mechanical and electrical engineering, systems engineering, specialty engineering, manufacturing, training, logistics, parts, materials and processes, facility and field engineering, DOD and special customers. He taught Specialty Engineering, CONOPS, human factors engineering classes and is a Certified Human Factors Engineer #529. Since 2011, Mr. Davids has sponsored 10 Capstone Engineering projects at the University of Rhode Island and Roger Williams University.


Figure 16 - Rick Davids and Julie Yingling

John Forbes, Software Consultant
John Forbes, software engineer, retired.


Figure 17 - John Forbes, software consultant

STUDENT TEAM - MEMBERS

An outstanding team of student engineers from the University of Connecticut School of Engineering possess the skills and knowledge to design, develop and test Mighty Cane functions. The team combines biomedical engineering and computer science skills necessary for this project. They are:

Wissam Afyouni. A Biomedical Engineering undergraduate student focusing on Bioinstrumentation. Accomplished chess player.

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Figure 18 - Wissam Afyouni

Jay Dalal. A Department of Physiology & Neurobiology undergraduate. Member of Zhong Research Lab, School of Pharmacy.


Figure 19 - Jay Dalal

Tiffany Sarmiento. A Biomedical Engineering undergraduate. Proficient in Python and NI LabVIEW.


Figure 20 - Tiffany Sarmiento

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Venoude Valmyr. A Biomedical Engineering major in the School of Engineering with a minor in anthropology. Participated in the McNair Scholors posters session, 2018. Proficient in MicroSoft Office applications. Avid volunteer.

Figure 21 - Venoude Valmyr

Shun Yi Li. Biomedical Engineering scholarship award winner, Team QSI, 2017. Society of Women Engineers, Honors Scholar, McNair Scholar, Engineering Ambassador. Proficient in SolidWorks and AutoCAD.

Figure 22 - Shun Yi Li

STUDENT TEAM – SKILLS

The University of Connecticut School of Engineering Senior Design program is an established and systematic program that pairs industry with academic resources. Every Senior Design Project is a two-semester course required for all School of Engineering seniors to graduate. Each team of 3-5 seniors is mentored by Engineering faculty collaborating with the sponsor. Our students learn how to work collaboratively in a real-world setting, while producing periodic reports on their ideas, strategy, techniques and progress. Here is a list of the types of skills we develop in our students.

- Creativity to design.
- Analyze a problem.
- Brainstorm potential solutions.

- Research the product/process.
- Identify the analytical and experimental elements of their approach.
- Design analysis.
- Technical skills.
- Explore solutions within the project scope.
- Experimentation.
- Use of leading CAD and analysis software.
- Analysis-based innovation and decision making.
- Make oral presentations.
- Conduct a peer design review.
- Communication with industry advisor, a faculty advisor, and team members.
- Teamwork in interdisciplinary teams.
- Maintain contact with their industrial and faculty mentors.
- Write a report at the end of each semester.
- Present their project results at Senior Design Demonstration Day.

SCHEDULE.

The schedule shown in the following figure is for the Conceptual Design phase only. This 28-week schedule builds on fundamental functional analysis early in the conceptual design phase. System and detail level requirements are identified. Notional designs and tradeoff studies are engaged. We use Solidworks prototyping to visualize the structural design. A full-scale mockup is developed. Electronic components are assembled and tested. Reporting is done on a weekly and quarterly basis to track progress.

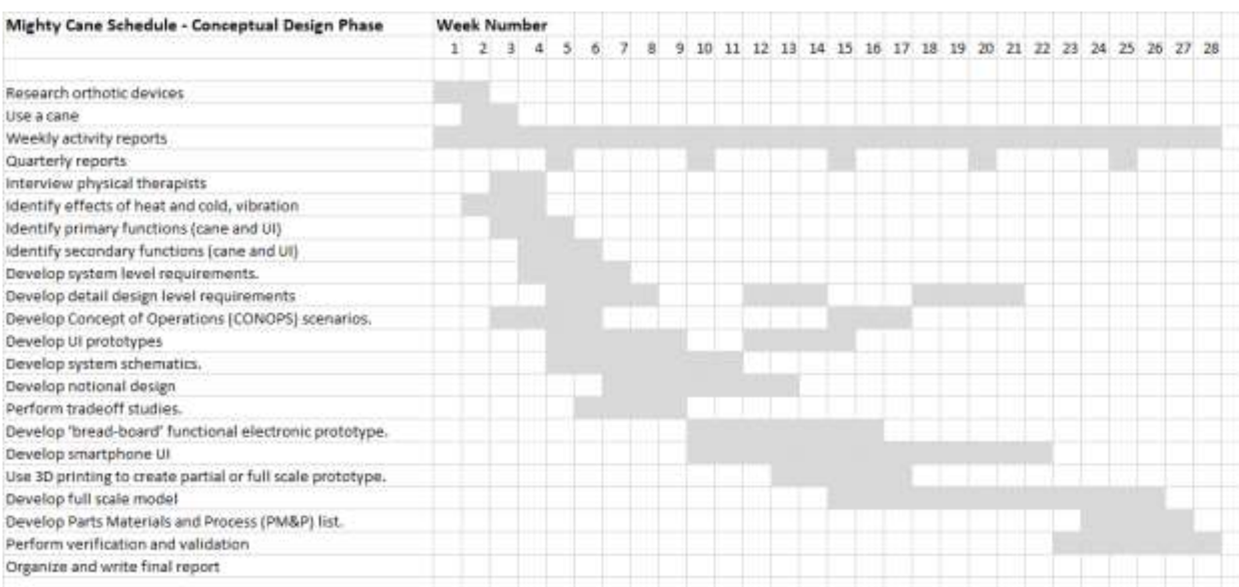


Figure 23 - Notional schedule.

Mighty Cane Senior Design Project.

NOTIONAL DELIVERABLES.

Notional deliverables include one mid-term report and a final report, weekly activity reports, one or more technical interchange meetings (TIM), a Concept of Operations (CONOPS) document, perhaps a formal design review (conceptual, developmental, or final) and a scholarly article for a magazine / web site.

The mid-term report describes preliminary research about electronic orthotic devices, the team's approach to designing Mighty Cane, a preliminary design, tradeoff studies, functional and task analyses, rationale for choosing a design, system and detail design requirements, and plans for testing. The final report at the end of the year describes in detail the final design, focuses on the results of verifications, estimated cost, important issues, mechanical and software design.

Weekly activity reports are expected to track progress and problems. A weekly activity report from each member might be only 2 or 3 sentences. It might describe acquisition of materials, software development, interviews with personnel at a rehabilitation or orthopedic clinic, sensor programming and integration, experiments with using the device, etc.

A Technical Interchange Meeting might be held once a month in Storrs, Connecticut, where the sponsor, a representative of the School of Engineering, and the student team meet for less than one (1) hour to discuss progress, problems, approach, next activities, etc. The TIM might be conducted as Skype, Facetime or another type of video conference. If a problem or discrepancy arises that cannot be solved quickly, then an Action Item (AI) is assigned to a team member. A form will be provided to track the AI and closure.

A CONOPS document communicates a story from the of user's point of view on What, Who, When, Where, Why, and How a product is used throughout its life cycle. It is written in the users' language in a narrative style. It uses diagrams, illustrations, graphs and story boards whenever possible. It describes the users' general system goals, mission, function, and components. It contains a series of scenarios from different viewpoints like the user or therapist. Scenarios might describe turning the cane on/off, sending a message, walking or storing the cane, any feedback mechanism, smartphone interface and use. It is written very early and drives the design because it describes functions and tasks.

At least one design review might be held. A conceptual or preliminary design review would focus on system and detail requirements and a notional design. Any Solidworks or CAD models might be presented and analyzed.

One scholarly article should be written that describes the project and outcome. The format can be very similar to the one-page articles in the UCONN Senior Design Demonstration Day volume or according to the journal format. Candidate journals include Physical Therapy Journal or Perspectives Magazine.

BUDGET ALLOCATION.

The budget estimated for the Conceptual Stage is presented here. The goal is to build one and perhaps two working electronic prototypes of Mighty Cane. The budget supports a 28 week-long effort to fund both student teams and University of Connecticut staff in the School of Engineering and Orthotics / Sports Medicine who will advise and assist the student team.

Table 6 - Cost Estimate for Conceptual Design

CONCEPTUAL DESIGN PHASE – ITEMS AND BUDGET		
ITEM	**DESCRIPTION**	**ESTIMATED BUDGET**
Electronic Components	Sensors, adapters, cabling, mini-microphone, microprocessors (2 canes), setup boards, spares, lab equipment, 5 sets of electronics	$3,550.00
Structure	Mechanical enclosures (2 canes)	$550.00
Thermal inserts	Vibration, heat and cold thermal units	$500.00
Software	Python, UX builders, web site host software (multiple copies), licenses	$2,000.00
Smartphone	Android development devices (2)	$600.00
Web hosting, server software	Hosts libraries, server software	$2,000.00
Faculty Stipend	University of Connecticut staff	$10,000.00
Travel	Travel to DVA, clinics, hospitals, symposiums.	$2,500.00
Lab equipment and consumables	3-D printing supplies	$2,800.00
Total		**$24.500.00**

APPENDIX

SYSTEM LEVEL REQUIREMENTS – PRELIMINARY LIST

- The system shall accommodate 5th %tile female to 99th %tile male users.
- The system shall include modular interchangeable units.
- Switches shall be protected from inadvertent activation.
- The system shall include a smartphone communication interface.
- The system power shall be either replaceable or rechargeable with a 110-volt interface.
- As a goal, the system shall have a vibration unit.
- As a goal, the system shall have a cold thermal unit.
- As a goal, the system shall have a hot thermal unit.
- The system shall provide audio feedback through the cane.
- The system shall provide a voice interface on the cane using a microphone.
- The system functions for the patient shall be programmable by the therapist.
- The user interface shall follow an established style guide, such as Microsoft, IBM, or another web style guide.

DETAIL DESIGN LEVEL REQUIREMENTS – PRELIMINARY LIST

- Cold and hot units shall retain 50% thermal property for 5 minutes.
- The structure shall sustain a 250 lb. vertical load for 5 minutes without yielding.
- The total cane system shall not exceed 1.25 lb.
- Vibration, hot and cold units shall be replaceable in less than 15 seconds.
- Vibration, hot and cold units shall not require tools.
- System components shall be either replaceable or rechargeable.
- The vibration unit shall have a 5-minute timer.
- Controls shall be accessed by either the grasping or alternate hand.
- Switches shall be protected from inadvertent activation.
- The device shall be rechargeable using a common 110-volt interface.
- Status of electronic components shall be visible without disassembling the cane.
- The cane shall withstand 10 successive drop tests from 5 feet without damage.
- Rubber stopper pull test shall be performed to measure yield.

NOTIONAL FUNCTIONS. TASKS, AND FEEDBACK - CANE

Table 7 - Notional Functions, Tasks, and Feedback - Cane

CANE			
Function	**Task**	**Action**	**Feedback**
Turn cane ON	Activate switch	Press button, switch	Power light on;
Turn cane OFF	Deactivate switch,	Press button	Power light off
Receive request to send data	Verify request	Collect data based on time, date, patient, etc.	Return request
Receive request to delete data	Verify request	Collect data based on patient profile and delete from database	Return request, haptic
Perform power check	Verify battery power sufficient		
Send data to smartphone	Verify Wi-Fi or BT connection		Signal light blink, haptic
Delete patient data	Delete patient profile data, name, etc.		Signal light blink
Perform system check	Check sensors status, battery power, connections		Signal light blinking

NOTIONAL FUNCTIONS, TASKS, AND FEEDBACK - SMARTPHONE

Table 8 - Notional Function, Task, and Feedback - Smartphone

SMARTPHONE			
Function	**Task**	**Action**	**Feedback**
Open application	Find application widget	Press Open App widget	State change
Enter new patient name	Open new patient form	Enter name, profile data, age, etc.	Text fields
Baseline Patient - Enter new patient parameters	Enter therapy protocol data – gait, distance, force	Fill in text fields, select limits, etc.	Text fields. Requires therapist to test run patient on 3 parameters
Change existing patient data	Find patient name	Select patient name from list	
Save patient data	Find save button	Press save button	Verify
Display patient data	Find patient name in list	Select 'display' data	Data displayed
Display average patient data	Select patient name	Select data, select average	Display data
Display cumulative patient data	Select patient name	Select data, select cumulative	Display plot data
Calculate distance, gait and pressure parameters	Select parameter	Select function (average, total, etc.	Display results

CONCEPT OF OPERATIONS – SCENARIOS - EXAMPLES

These Concept of Operations (CONOPS) scenarios are based on the functions identified in the top-level functional analysis. Some of the lower level tasks identified in the corresponding function are included in the appropriate CONOPS scenario. These scenarios offer up some issues that must be considered for tradeoff studies.

Turn Cane On

The patient picks up or grabs the cane. The cane might be stuck up right in a corner or hung on the back of a chair. Most likely the cane is very close to the patient's bed so they can use it to get out of bed in the morning or after taking a nap. The patient is most likely to pick the cane up near the top part, on the T-section portion. There is a membrane button or recessed switch in the top T-section; this switch or button is the ON button. The patient presses the button. Since the cane has a built-in speaker, the cane announces, "Cane On". The cane is pre-programmed with a set of pre-recorded short messages like "Cane On", "Cane Off", "Power Low', "Recharge", "Change battery". These messages provide the patient with feedback about the state or status of the cane. Another message might be "Call therapist". Using the built-in speaker reduces the need for another 'power on' or 'power off' status light which complicates circuitry and complexity.

One issue to investigate is: should the patient be allowed to turn the cane off? In a case of work person compensation, it the patient can turn the cane off, this could indicate 'non-compliance' to the therapist protocol which would negate compensation. Thus, if the cane is used in a work compensation case, then the ability to turn the cane off is not enabled at the cane level. Perhaps the therapist controls the cane ON/OFF states during patient setup. Another issue to investigate is power consumption. If the cane is always 'ON' in a compensation case, then the battery power will be drawn down quicker. Thus, the need for a 'motion detection' capability that turns the cane off after a period of inactivity (10 minutes) might be incorporated into the software architecture. The accelerometer would provide the signal input.

Turn Cane Off

After a treatment session, or routine use such as walking from a car to the front door or from the bathroom to the kitchen, the regular (not a compensation case) patient decides to turn the cane off to save power. The patient 'parks' the cane near the bed or chair and turns the cane 'OFF' and then sits down or climbs into bed. The cane responds, "Cane OFF".

It is worth considering doing a tradeoff study on including a 'power on/off' LED on the cane. This feature would allow the patient to see the status of the cane at any time rather than relying on memory recall if the cane is OFF or ON.

Enter New Patient Data

Since one therapist will have multiple patients using different canes, each cane has a unique identification ID that is paired to the therapist smartphone (or computer). The therapist opens the Mighty Cane app, logs in and selects 'New Patient' from the drop-down list of patient names. A form appears with several text fields as follows: first name, last name, height, weight, age, description, gait (short, medium, long), distance (feet), force (lbs.), patient phone number, address, therapy period, cane ID (where and what is the cane ID?), and any other data required. Certain parameters (force, distance, gait) might be selectable from a dropdown list. Other information will require using the built-in keypad on the smartphone. The exact list of new patient data needed will require consultation with experienced therapists.

Change Patient Data.

Call Patient Cane.

Establish Bluetooth Connection Between Cane and Phone.

TRADE STUDY APPROACH

Trade studies will use a quantitative Kepner Tregoe Analysis (KTA) form to identify criteria and design alternatives. We will use a Microsoft Excel spreadsheet form to process the trade studies.

The following bitmap of one of the Excel spreadsheets shows some candidate criteria to evaluate cane color. Criteria are listed in the left-hand column. Each criteria are assigned a weight. Each team member is assigned a number as you can see in the upper right corner.

This type of systems engineering analysis offers guidance. It is a systematic method of identifying issues and figuring out the importance of the criteria. It is by no means the final answer. But it gets you to put down what you think is important about some of the issues and getting a consensus from the team. Seven is about average number of criteria but not to exceed ten (10).

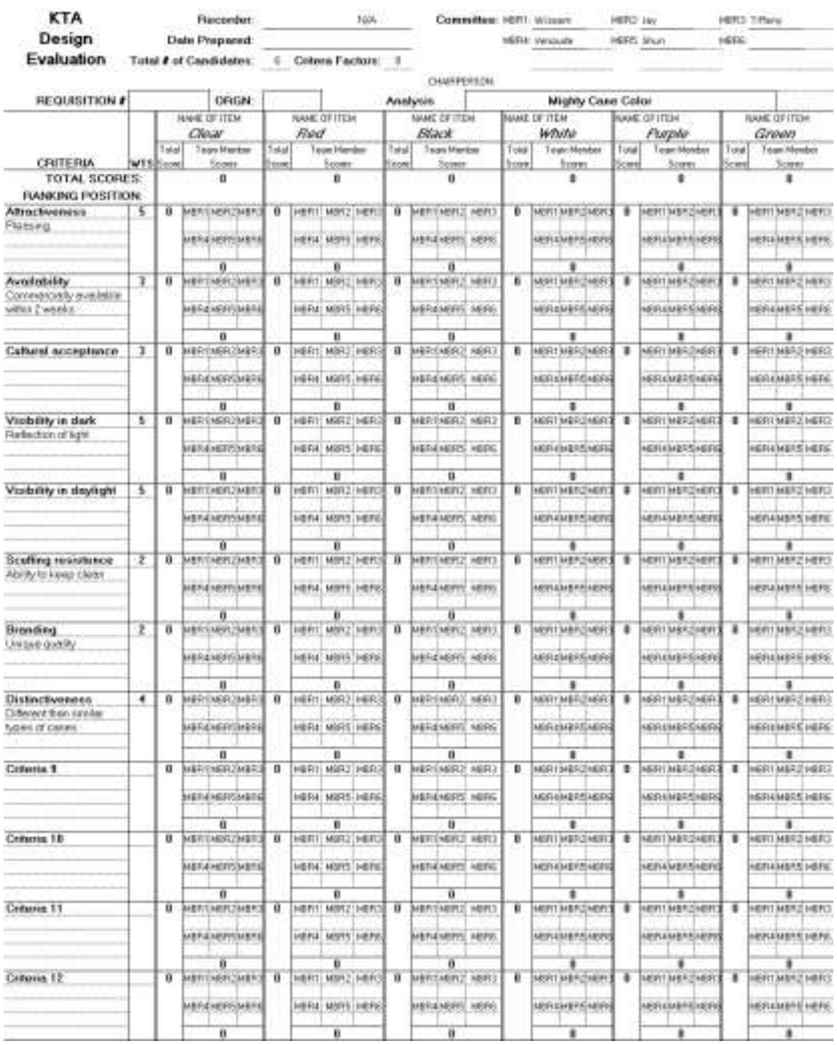


Figure 24 - Sample KTA Excel spreadsheet form

Four (4) preliminary trade off studies are planned. These are critical to the integrity of the Mighty Cane design. The candidate initial trade off studies are:

1. Heat dissipation.
    a. Vents
    b. Liquid nitrogen
    c. Water coolant
    d. Heat Sink
    e. Fan
2. Color
    a. Clear
    b. Red
    c. Black
    d. White
    e. Purple
    f. Green
3. Mechanical connection.
    a. Glue
    b. Tape
    c. Drill / Pin
    d. Nut / Bolt
4. Mounting electronic components.
    a. Blown foam
    b. Glue
    c. Foam strips
    d. Sand
    e. Bird seed
    f. Removable sled

Typical criteria for the various trade studies are ease of assembly, ruggedness, durability, safety, simplicity, attractiveness, visibility, accessibility for operation / maintenance.

The following form will be used to describe each trade study approach, issues, and outcome.

Trade Study Form 1

Trade Study Title:

Date_________________

TITLE:

AUTHOR(S):	**REVIEWED/APPROVED BY:**
Originator: *Date:*	*Lead:* *Date:*

OBJECTIVE:

ASSUMPTIONS:

RESULTS:

CONCLUSIONS:

REFERENCES:	**KEY WORDS:**

IMPACT ON SYSTEM DESIGN: Insert (Y)es, (N)o, (TBD) below, as applicable.

	Performance		Supportability
	Physical Characteristics		Design Criteria
	Interfaces		Materials
	Reliability		Affordability
	Maintainability		Computer Resources
	Environmental		Logistics
	Safety		Personnel & Training

Trade Study Form 2

ABSTRACT:

1 or 2 paragraph synopsis of Trade Study. Should contain scope of effort, approach, and significant results and recommendations.

INTRODUCTION:

i.e., scope, purpose, background information, outline your approach and why you are writing the Trade Study.

DISCUSSION:

Discuss criteria, tradeoff issues, considerations.

SUMMARY:

Succinctly summarize your technical data, conclusions and recommendations contained in the body of the Trade Study.

RECOMMENDATIONS:

As a minimum, this section should include which option you think is best based on your criteria.

ACTION ITEM FORM

This Action Item (AI) form is intended to record issues that require additional investigation during the research, modeling, prototyping and testing. It is intended as a short, brief method of recording what, who, and when an issue needs to be resolved. Action Items are assigned to a team member during a design review or technical interchange meeting.

Engineering Review Action Item	
Program Name:	Mighty Cane
Type of Review:	Technical Interchange Meeting
Name of Reviewer:	
Date of Review:	
Discrepancy:	
Action Required / Compliance:	
Due Date:	
Assigned To:	
UCONN Staff Agreement:	
Action Completed Date:	
Staff Signoff:	

PREFERRED PARTS LIST - ELECTRONIC.

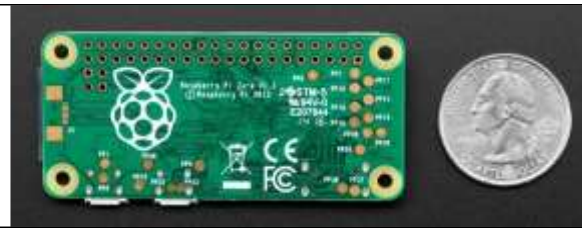
The following components were selected as the notional preliminary electronic preferred parts list (PPL) with associated retail costs. Lower costs are anticipated based on evolved selection of electronic components.

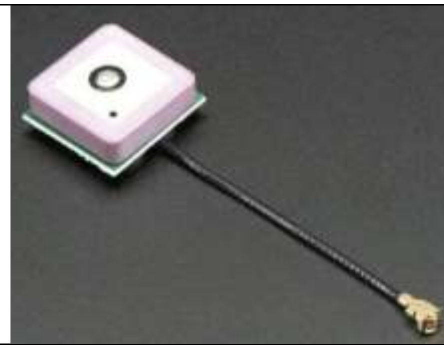
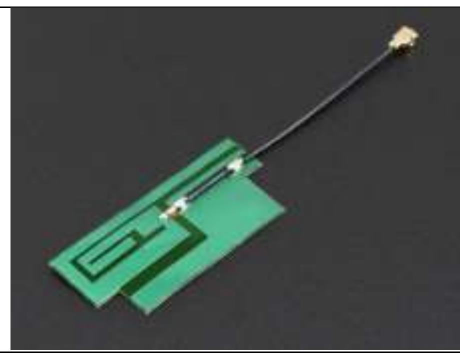
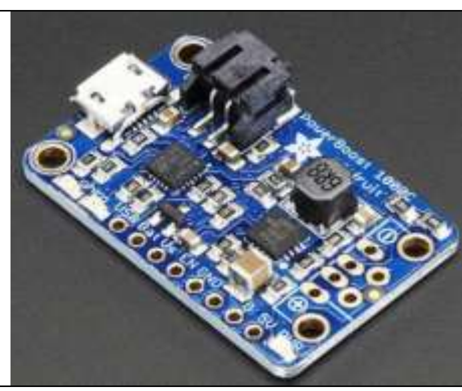
Table 9 – Electronic Preferred Parts List

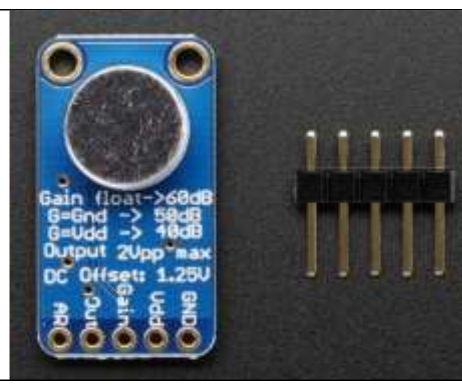
ITEM	DESCRIPTION	RETAIL COST
Raspberry Pi Zero WH (with pre-soldered header)	Brain of the cane	$13.00
Adafruit Round Force-Sensitive Resistor (FSR) - Interlink 402	Detects force on a specific area	$7.00
Adafruit LIS3DH Triple-Axis Accelerometer	Detects motion and acceleration	$5.00
Adafruit Ultimate GPS Module - 66 channel w/10 Hz updates or Adafruit Ultimate GPS Weatherwing	Detects location	$37.00
Speaker pHAT	Plays audio	$13.00
Adafruit GPS Antenna - External Active Antenna - 3-5V 28dB 5 Meter SMA	Used if passive antenna not exposed	$14.00
Slim Sticker-type GSM/Cellular Quad-Band Antenna - 3dBi uFL	Cellular GSM antenna	$3.00
Adafruit Power Boost 1000 Charger - Rechargeable 5V Lipo USB Boost @ 1A	Power supply.	$18.50
LiPo/LiIon power supply shim	Power controller	$11.00
Lithium Ion Polymer Battery - 3.7v 1200mAh	Power	$10.00
Miniature electret microphone	Microphone	$1.50
Electret microphone booster	Microphone amplifier	$13.00
Total		**$146.00**

Table 10 – Electronic Preferred Parts List - Description and Photo

ITEM	PHOTO

Raspberry Pi Zero WH (with pre-soldered header)	
Adafruit Round Force-Sensitive Resistor (FSR) - Interlink 402	
Adafruit LIS3DH Triple-Axis Accelerometer	
Adafruit Ultimate GPS Module - 66 channel w/10 Hz updates [ADA790]	
Speaker pHAT	

Adafruit GPS Antenna - External Active Antenna - 3-5V 28dB 5 Meter SMA	
Adafruit Passive GPS Antenna uFL - 15mm x 15mm 1 dBi gain	
Slim Sticker-type GSM/Cellular Quad-Band Antenna - 3dBi uFL	
Adafruit Power Boost 1000 Charger - Rechargeable 5V Lipo USB Boost @ 1A	

LiPo/LiIon power supply shim	
GPS Shield	
Miniature Electret Microphone	
Electret Microphone Amplifier	

LINKS.

The following links are offered to provide the reader with greater insight into the detail nature of orthotics, wireless technology, electronic components and other technologies.

Text-To-Speech

https://play.google.com/store/apps/details?id=com.google.android.tts
Wikipedia, Pew Research
https://en.wikipedia.org/wiki/Orthotics#Foot_orthoses
https://en.wikipedia.org/wiki/Prosthesis#Types
https://www.pewsocialtrends.org/2011/11/08/for-many-injured-veterans-a-lifetime-of-consequences/
https://www.providencejournal.com/news/20170110/providence-va-leads-national-study-of-veterans-amputation-needs
https://www.orlandosentinel.com/news/lake/os-lk-lauren-ritchie-free-canes-for-veterans-20161001-column.html
https://walkingsticksandcane.com/collections/orthopedic-canes

ADAfruit

https://www.adafruit.com/?q=raspberry%20zero
https://thepihut.com/collections/adafruit-sensors/Motion
Overview | Adafruit Ultimate GPS featherwing | Adafruit Learning System
https://thepihut.com/collections/adafruit-wireless/products/adafruit-slim-sticker-type-gsm-cellular-quad-band-antenna-3dbi-ufl
https://www.dfrobot.com/category-36.html

Raspberry Pi

https://thepihut.com/collections/raspberry-pi-store
https://thepihut.com/collections/adafruit-sensors
https://learn.adafruit.com/adafruit-ultimate-gps-featherwing
https://www.adafruit.com/category/105
https://pimylifeup.com/category/raspberry-pi-sensors/
https://thepihut.com/products/speaker-phat
https://traxxas.com/traxxas_lipo_batteries
https://www.dfrobot.com/blog-447.html?gclid=EAIaIQobChMIv66wxM_u4gIVk6DsCh2LsAcCEAAYASAAEgK0mvD_BwE

PVC – Mechanical Structure

https://www.pvcfittingsonline.com/by-application/pvc-furniture-fittings.html
https://pvcpipesupplies.com/pvc-fittings/pvc-furniture-fittings/tee-pvc-furniture-fittings
https://formufit.com/

Relevant 2018 UConn Senior Design Projects from Demonstration Day Volume

1. “Data Visualization integrated with wearable technology to identify alternate motor control strategies”.
2. “Development of a SPINE Mobile Application to improve low back pain self-management”. “Implementation of a Real-Time Haptic Feedback System for Laparoscopic Surgery”.
3. “Localized Vibrational Therapy of the arm for people with movement disorders.”
4. “Synchrony Financial Voice Experience.”
5. “HuskyTrack: GeoLocation Tracking Mobile Application.”
6. “Remote Server Automation and Configuration of Amazon Web Services Technology.”
7. “TRUMPF Onsite: A Mobile App for Field Technicians.”
8. “An Evidence-based Clinical Decision Support System for Exercise Prescription among Adults with Multiple Cardiovascular Disease Risk Factors.”
9. “Real-time and Secure Wireless System based on Software Defined Radio”