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SYDE 362: Final design report
Step Sense gait analysis cane

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Abstract

Current gait analysis devices are primarily isolated to assessment in the laboratory, whether it may be testing on a treadmill to walking on a specialized mat. One method of gait analysis can be done by measuring the loading effects within an assisting device such as a cane or a walker. The proposed solution is the Step Sense cane, a device that will measure the loading and orientation of a cane over an extended period of time, outside of the laboratory and during a patients daily life. This device will collect data that will allow clinics and researchers to determine if a patient is using a cane correctly, and when their cane is needed most. Long term collection of data can expose trends in gait measurement not visible over a short period of time. Data collection outside the lab also eliminates the bias present when patients are being observed.

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Introduction

When a person is walking, there are different characteristics to their style of movement, determined by the velocity, contact pattern and weight distribution in the limb, called gait. Studying gait typically occurs in a laboratory, taking measurements over a short period of time to accurately determine the characteristics of the subjects gait.

Special interests to gait studies and gait researchers are patients who have difficulty walking. Patients recovering from fractures, sprains, stroke or recovering from damage to soft tissues may have difficulty moving when unassisted. The injured, elderly and bariatric may all use assistive devices, such as canes to improve their ability to walk [1]. Gait studies can be done on patients using assistive devices to ensure that the appropriate level of assistance is delivered. For example, when a stroke patient is recovering, it is important that they exercise their injured side.

In order to study the motion of gait or the loading of the assistive device, studies are normally restricted to the laboratory. These studies typically use devices such as sensor mats or camera tracking of the joints. While this provides accurate data while in the lab, once the patient leaves the laboratory and uses their assistive device in real world settings, they may use their device incorrectly, or they may have difficulties with specific terrain that maybe difficult to reproduce in the lab.

One of the most common assistive devices is the cane [1]. Canes are often used as they are very portable and allow a good amount of stability without being intrusive and large (such as walkers). In order to gather long term statistical data associated with a cane, it would be beneficial to know how the patient is loading the cane and correct their methodology if using it incorrectly. Currently, most devices associated with measuring loading are meant for a short term measurement only, and cannot be taken home by a patient to gather more extensive data. The device that will be outlined in this report will function as a cane with the ability to gather gait data over a longer period of time. Using this data, researchers could analyze loading trends, which enables them to determine the risk of the patients abandoning the use of the cane/walker, whether they are using it effectively, and assess their actual need for walking-aid devices through loading data.

2

Background

2.1 Purpose of walking canes

A crucial part of human mobility of is the ability to maintain balance. If a person has a movement disorder/disability, whether due to age or other complicating factors, walking and moving from one place to another can be difficult. As such, walking canes are used as an aid for a person to increase their balance and also their walking ability [2]. Canes are not designed to hold all the weight of a person, they are merely used to provide some relief to weight-bearing legs. Canes can also provide a person an additional contact point with the ground, which assist balance and provide stability [3].

Canes are typically used because of a physical limitation, where a person requires an assistive device to walk or maintain balance; however, the use of a cane does not mean that a person has a low quality of life. The correct use of an assistive device can allow a patient to continue with their normal daily activities [2]. More importantly, the user should be assessed to determine whether they truly require the device while assuring that the assisting device is used as efficiently as possible. Using an assistive device when not required may cause the patient to develop issues with their gait due to over-reliance on the device. In order to determine an appropriate mobile aid solution, a data-supported strategy must be developed to recommend patients techniques for gait and mobility improvement.

2.2 Prior art

Many existing devices use large fixed equipment such as exercise equipment and motion-sensing cameras to track the movements of their targets. A few existing systems are described below:

2.2.1 Outwalk

Outwalk has created a system, designed to measure lower limb kinematics during gait outside of the lab. Inertial and magnetic measurement systems were used in this system and are positioned on the test subject's thorax, pelvis, thighs, shanks and feet. This allows the measurement of the orientation of each part of the body that has sensors on it. Although this system is able to take measurements outside of the lab, sensors must be mounted directly onto the body of the tester and cannot be used on a daily basis to collect data [4].

2.2.2 Medical Motion

Medical Motion uses video analysis software to analyze gait trends. They have developed a portable lab system that allows users to be able to collect data outside the lab. Data is collected through a combination of a laptop, camcorders, remote controls, tripods, software, cables and accessories that are battery powered for up to 8 hours at a time, allowing this system to be used outside of the lab [5]. This device must have an operator to record a patients gait.

2.2.3 Assistive cane

Within the laboratory, there have been developments on assistive devices that measure the force distribution of the user's gait. In the University of Waterloo, Professor William McIlroy's team created a cane that determines the user's loading force and angle by attaching a measuring device about the handle of the cane. The results of this measurement method was were not conclusive due to many difficulties such as the inability to co-relate the moment in the handle of the cane to the loading force exerted by the patient; however, poor selection of the measurement apparatus can be attributed to these results [6].

2.2.4 Assistive walker

The University of Toronto also designed a gait analysis system mounted on a wheeled walker. Post Doctorate fellow, James Tung, and his research team have developed a system that records patients' walking stance and the environment that the walker is being used in [7]. The entire system was loaded onto the walker, with a laptop computer controlling the operations. Although this system was portable and can be operated without direct supervision, it was difficult to transport, required a lot of power to operate and was not suited for daily continuous use. The data collected by the device, however, was extensive and the device could be used to study how patients use their assistive devices.

2.2.5 Limitations of existing technology

Although these systems work well in the environments that they were developed for, (i.e. in the lab); they often cannot be operated without a team of specialists set out specifically with the intention of collecting data. A patient must perform actions as per a routine laid out by researchers, while under their supervision via large equipment in a laboratory setting in order to gather data. Currently there are no devices that allow measurements on a long-term basis outside the lab.

3

Proposed solution: the Step Sense cane

A general purpose walking cane has been modified to construct the Step Sense device. Step Sense includes sensing apparatuses for applied force and the cane orientation. The sensor components do not protrude from the shaft of the cane, and are stored inside the device; however the user is still able to adjust the height of the cane.

3.1 What is Step Sense

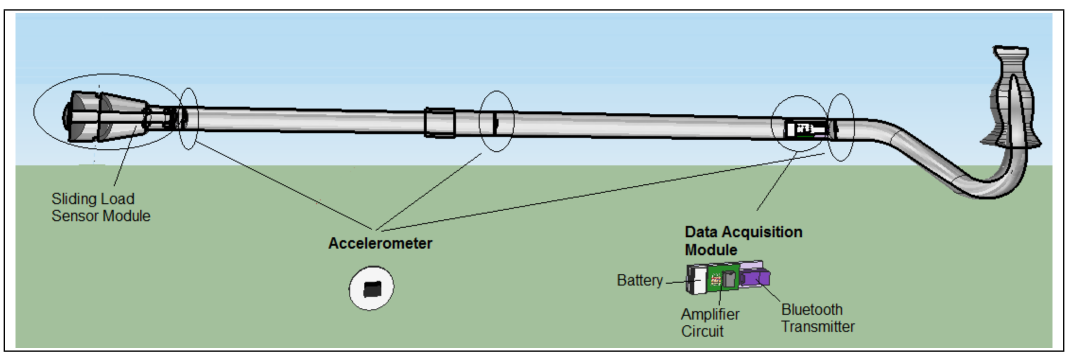


Figure 3.1: The complete Step Sense Cane

The Step Sense cane will measure the loading forces and orientation of the cane in use with mounted strain gauges and accelerometers. It will be able to transmit data wirelessly to a mobile device or a computer terminal or store the data for direct download onto a external storage device. Software will then collect and analyze the incoming data for the use of researchers or doctors. The Step Sense cane will operate with little input from the user, operating as a passive device that must merely be charged every one or two days. The sensing devices mounted onto the cane serve as non-intrusive add-ons to the cane and will not affect its normal functionality.

3.2 Uniqueness of Step Sense

The Step Sense device differentiates itself from existing gait measurement solutions by being able to collect data outside of the lab, and by being able to collect data over an extended period of time.

3.2.1 Long term collection of data outside of lab environments

Currently, existing diagnostic devices tend to be used for a short period of time, with extensive external peripherals that confine the testing inside a lab environment. There are currently no devices that can be taken outside of the laboratory to gather data over a long period of time. This feature allows researchers to study long-term loading patterns such as the amount of force applied to the cane at different intervals of the day in different terrains and challenging environments that the patient walks on. This data is crucial to get an accurate understanding of a patients' movement during their normal everyday activities [2]. Long term trends may also expose additional data, such as a change in the cane loading pattern when the patient is fatigued.

3.2.2 Compact and affordable solution for data collection

The Step Sense cane was designed to be a cheap and simple solution for researchers and clinics to be able to collect long term and accurate data from their patients. The components that make up the cane are relatively inexpensive compared to the other systems that measure gait trends which incorporate large machinery such as treadmills and video cameras. The low cost of the Step Sense cane will allow research facilities and clinics to purchase multiple canes at once and give it out to their patients to collect various data samples.

3.2.3 Non-invasive

In many of the current gait analysis systems, for example in the Outwalk system, sensors must be attached to the patients body in order to analyze their movements. The Step Sense cane takes all its measurements from the body of the cane and is a non-invasive method of collecting data; thus encouraging more patients to participate in the research and data collection process.

3.3 Benefits of the Step Sense cane

Many patients may abandon assistive devices if it is not suited to them; however, they may not tell their doctors about the abandonment of their assistive devices [7]. The ability for physicians to monitor the usage frequency of canes they give out will allow them to determine whether the device is actually useful for the patients or whether another solution is required to better suit the patients lifestyle. Enabling a cane to collect data in the daily life of a user will drastically increase personalization of the data gathered to help suit the individual needs of the patients.

Loading patterns placed upon the cane will serve as crucial information for analysis for patients and research. Firstly, the loading pattern can be assessed to see the weight distribution of the user. For example, a hemiparetic patient should attempt to use their affected limb as much as possible and the cane might inhibit the function of that limb [8]. Secondly, loading patterns can be analyzed over different terrains. The differentiation of the use between the beginning of the day versus the end of a day can be assess to see whether the user became worn or tired. The data from patients using the device at home on a continuous basis will also allow determination as to the patients' dependency on the cane and the effectiveness of its use.

The Step Sense cane not only has a tremendous impact on individual patients, but also has a tremendous benefit towards the population in general. The data collected on the cane of individual patients can be used to improve the design of canes in aspects such as grip design, loading angle, and can also be used to investigate means to promote healthy usage.

3.4 Target market

The Step Sense cane at its current stage is primarily addressed to researchers and physicians in clinics who require gait pattern data for their research or for monitoring patients. The intended direction of the production of the Step Sense cane is to have clinics or universities who are able to purchase a number of these canes at one time and give them out their patients or volunteers to collect data. These canes should also be affordable for university researchers so that they are able to distribute the canes widely and collect data from patients in their own homes without having to invest a great amount of money on a static lab-based gait analysis system.

In future iterations of the cane's design, the scope of the product can be expanded to the commercial sector. For example, the Step Sense cane would be useful for recovering athletes to help them monitor whether they are loading their leg the right amount to ensure the fastest recovery. It could also be used by insurance companies to detect false claimants who would fake disability to gain long-term disability insurance. Because the cane is able to process and send data wirelessly, the companies will be able to determine whether these claimants are actually using their canes and will be able to find the ones with false disabilities; of course, privacy concerns have not been analyzed yet for this application.

The device could also be used by companies designing assistive devices to use the data in order to collect detailed long-term analysis of usage patterns of their devices.

4

Requirements and constraints

The Step Sense cane will take long term measurements of orientation and the compressive load on the cane over time. In order to ensure that the cane is able to be used effectively by users of the cane, the design must meet the following requirements. Some of the requirements have been changed since the initial requirements document due to more research into the justification for the past requirement definition.

Strength Most offset canes have a weight limit of 250 lbs, however this refers to the weight of the person using the cane. Typical cane loading for a 200 lbs adult male with a limp induced by differential leg lengths was less than 50 lbs when walking on a flat plane without fatigue [1]. Assuming a safety factor of 2, the cane must be able to have a loading of 100 lbs without damage to the device or the cane, as well as not have damage to the cane or the device when a shock load of 150 lbs is applied to the cane.

Robustness The cane must be able to endure the wear and tear it will endure under a patients use. It is vital that if the device fails, it does not affect the strength of the cane.

Weight The device should not increase the weight of the cane in excess of 10% of a typical cane. Lightweight canes may be used to facilitate achieving this requirement.

[1] This refers to one of the group members taking off one shoe while using the cane to simulate proper limping.

Aesthetics The cane must not have obvious protrusions and the average elderly patient should be willing to use the device on a daily basis. Success will be measured based on how many people are accepting of the device's appearance.

Power The device be powered by a battery. It is required that the device is able to run for 2 days without charging while being used with a usage frequency typical of 95% of the potential market.

Signalling The device must send and/or save the data it collects during its use. Success will be measured by the device's ability to save the collected data correctly, and is able to be retrieved by an operator.

5

Design analysis

Components of the Step Sense cane were selected based on their cost, size, ease of use and overall fit and suitability to satisfy the design requirements. The following is the breakdown of the comparisons between the chosen concept or components versus the other alternatives.

5.1 Force measurement component selection

For the design of the project, many different components for measuring the force and angle were considered. For force measurements, strain gauges, load cells, and photoresistors and lasers were considered for the final solution for the design. The ideal solution would be one that is the most affordable, easy to manufacture, robust, with a large range of detectable compressions and be able to make precise and accurate measurements of the cane compression.

5.1.1 Strain gauge

A strain gauge is a variable resistor that changes its resistance when it undergoes deflections in its physical shape. Strain gauges are relatively cheap to buy and can generally be purchased for $20 for a pack of 5. The wholesale price from bulk suppliers would be even lower. Strain gauges also come in many variations that can hold various classes of force. An individual strain gauge is not as sensitive as a load cell; however, there are configurations of strain gauges, such as a Wheatstone bridge of 2 to 4 connected strain gauges where it then increases the sensitivity of the system dramatically. The drawbacks of strain gauges are that they are relatively fragile and integrating them into the device would be a complicated process. The strain gauges also need to be carefully calibrated and amplified in order to collect any useful data.

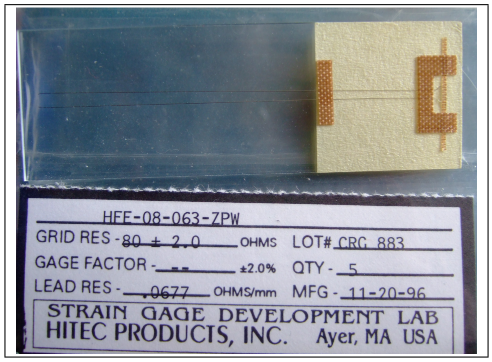


Figure 5.1: HFE-08-063-SPW. The group's selected strain gauge.

5.1.2 Load cells

Load cells are inherently a number of strain gauges packaged together to achieve high sensitivity and capacities to handle large loads. Load cells are very durable and can withstand tremendous amounts of pressure. Load cells are very sensitive and can be mounted into a device very easily just by putting it between where areas of pressure are assumed to be. The drawbacks of Load cells are that they are very expensive, usually costing around 400 to 500 dollars for one load cell. The signals from the load cell would also need to be amplified; however, unlike the strain gauge, it is precalibrated for general measurement purposes.

5.1.3 Photoresistors and lasers

The last concept for force measurements includes the combination of photoresistors and lasers. The photoresistors would be placed incrementally along the inside wall of the cane and there would be lasers parallel to each photoresistor that shines into the resistor. When the cane is depressed, a bar that sticks up from the bottom of the cane covers up the light from the lasers into the photoresistors. As more force is added, more of the lasers would be obscured by the bar. By using a spring to provided a resistance to the compression of the cane, and calibrating the bar movement corresponding to compressive force, the number of obscured photoresistors could be corresponded with the cane compression, without the need of a strain gauge of load cell. The advantages of this concept is that it would be very cheap to implement, as photoresistors can be bought for less than $1 per piece and small laser emitters can also be bought very cheaply. The drawbacks of this concept are that the sensitivity of the results will be very low, as we can only measure discrete values of force and each level of force would have to compromise a large range of force.

5.1.4 Summary of force measurement methods

In the final design, using strain gauges to measure load would be ideal. There are strain gauges in production that can measure very sensitive forces and they are relatively cheap and easy to implement compared to other alternatives. In the design of the prototype, strain gauges were initially experimented with; however, the group did not have the skills to properly set up the strain gauges so a load cell was replaced for the strain gauges in the prototype for easier building.

5.2 Angle measurement component selection

Angle measurement selection was based on price and the component's effectiveness in measuring the cane relative to the world angle.

5.2.1 Gyroscopes

While gyroscopes can be constructed very small and require little power, they are subject to following error. The gyroscope output value would need to be re-calibrated and reset to an external reference in order to avoid the following error and to obtain accurate values of tilt and roll.

5.2.2 Accelerometers

Accelerometers can be made very small an have low power consumption. However, filtering would need to be done on the sensor data output in order to isolate the acceleration from the linear acceleration of the cane.

5.2.3 Laser/ultrasonic rangers

Lasers and ultra sonic rangers would be able to determine the orientation of the cane by determining the distance various points on the cane are from the ground.Unfortunately, rangers are susceptible to noise produced from uneven surfaces. Rangers are also less effective when attempting to take a reading against a non-normal surface.

5.2.4 Local and global measurements

When measuring orientation of the cane, there are two different reference points that can be used, local and global coordinates. Local coordinates measure the orientation relative to the ground normal, while global coordinates are measured are measured relative to the gravity vector.

Processing the orientation data, access to both the local and global angle will allow researchers to determine on what type of terrain the device is being used on. As the local and global orientations measurements will differ if the patient is walking on an inclined plane, determining the type of terrain can allow the analyst to properly categorize heavy loading to to fatigue as opposed to heavy cane loading due to ascending/descending a steep incline.

5.2.5 Selection of angle measurement devices

Accelerometers were considered over gyroscopes in the construction of the prototype due to its easy to acquire part and preference in software coding. Local angle rangers were not purchased for use in the prototype due to the lack of available ports to send data to the wireless processing digital to analog converter. A final design uses three accelerometers to determine the loading angles of the patient on the cane.

5.3 Mechanical Design Concepts

Different concepts for the implementation of the strain gauges were explored to determine the best and easiest method of measuring load.

5.3.1 Ball and Pivot

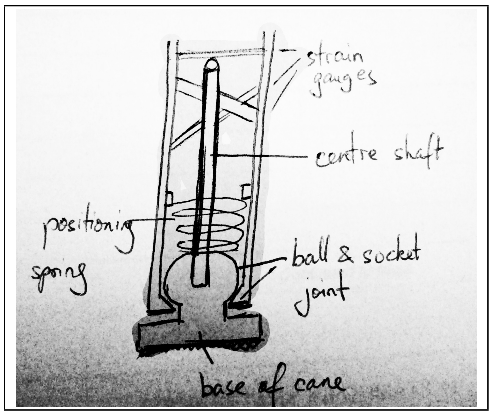


Figure 5.2: Ball at base of cane rolls and presses against strain gauges mounted across the diameter of the cane to measure force when cane is at an angle.

In this concept, the rod that is mounted on the ball would poke at the strain gauge mounted across the cross-section of the cane. the ball would have a weighted bottom so that it will be able to pivot inside the base of the cane and be able to take measurements of the force even when the cane is at an angle to the ground. This concept was not selected as the final design because it compromised the safety of the user. With a pivoting ball at the base of the cane, the risk of slipping would greatly increase and the well being of the user would be compromised.

5.3.2 Side-mounted strain gauge

In this concept, the strain gauge would be mounted on the side of the cane. The deflections on the side of the cane would be measured by the strain gauge. The advantages of this

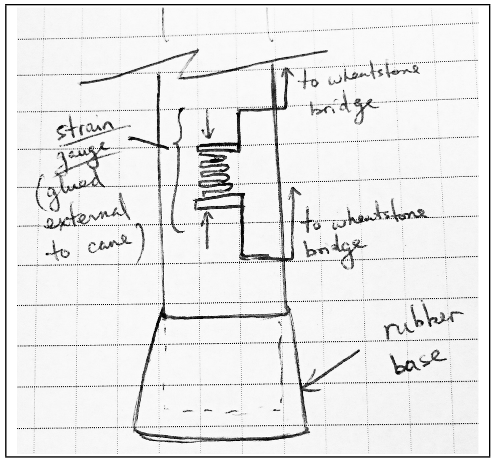


Figure 5.3: Strain gauge mounted on the side of the cane will sense the compression on the cane to measure loading force.

concept is that the structure of the cane would not be altered; the strain gauge can just be glued to the side of the cane whereas in the other concepts, the cane would have to be cut and inserted inside the diameter of the cane. However, it was found out through testing that the deflections on the side of the cane would not be enough to give an accurate measurement of the loading force; therefore, this concept was not selected in the final design.

5.3.3 Spring and Rod

In this concept, a sliding rod would be installed to press the strain gauge when the cane touches on the ground. A spring is also mounted to restore the position of the rod and depress the strain gauge when the cane is in the air. Two technical problems were associated with this design: firstly, it was hard to find a spring that has less than $\frac{3}{4}$ diameter to fit inside the cane shaft, while possessing sufficient stiffness to rapidly restore the rod to initial position; secondly, positioning the spring require a base on which the spring would press against. In this case, the only possible base would be the strain gauge mounting piece. If the piece was pressed by the spring in addition to the rod, it risks compromising the accuracy of the measured data from the strain gauge.

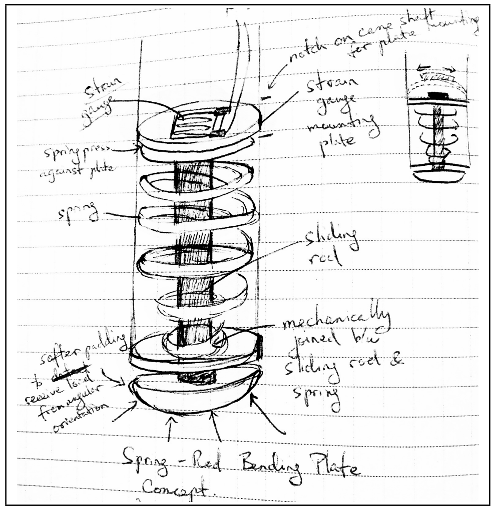


Figure 5.4: The spring inside the cane will reset the rod as it presses on the strain gauge mounted inside the cane.

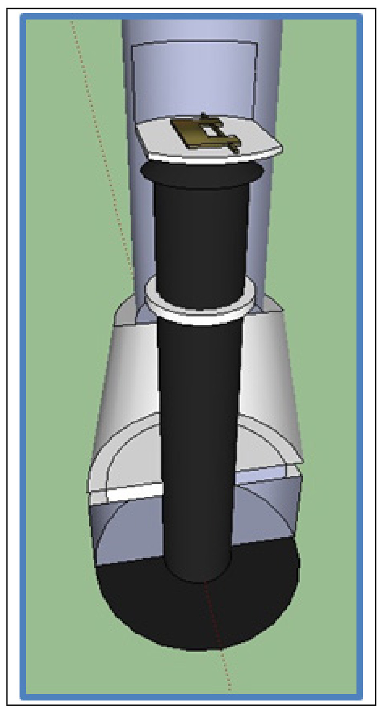


Figure 5.5: Instead of using a spring inside the cane, the rubber base is substituted for the spring. This makes the design easier to construct.

5.3.4 Modified spring and rod

A modified version of the previous concept was created during the construction of the prototype, primarily because a sufficiently stiff spring that could fit inside the cane shaft could not be found. Consequently, the rubber cover at the bottom of the cane was used to replace spring. The maximum deflection of the rubber was only 1-2 mm, which did not compromise the safety of the cane. The end of the protruding portion of the slider rod was covered by a curved soft rubber surface layer to enable the slider rod to depress the strain gauge while the cane is loaded at different angles.

5.3.5 Mechanical Design Concept Selection

The final mechanical design for the strain gauge mounting was the modified spring and rod concept. This concept was selected because it was easier to build and it required the least modifications to the body of the cane.

5.4 Hardware data acquisition

A instrumentation amplifier was connected to the outputs of the strain gauge to amplify the signal from the strain gauge. This amplified signal is connected to the Bluetooth analogue digital converter (AD converter) which encodes the incoming signals to the computer. The accelerometers were connected directly to the AD chip.

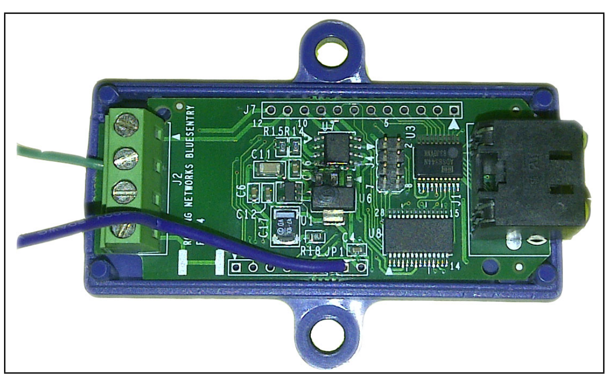


Figure 5.6: The BlueSentry Analogue to Digital converter wirelessly transmits the sensor data.

5.4.1 Sensor data collection

All sensor data outputs are collected by a Bluetooth AD converter that was made available by the project advisor. The AD converter is able to have a very high sampling rate (1kHz) and also is relatively high precision (16 bits). Bluetooth transmission simplifies communication with other data collecting devices because its embedded data acquisition module eliminated the need for any additional interfacing device; however, during transmission, the Bluetooth device is the largest power consumer in the cane.

5.4.2 Sensor pre-processing

The load cell requires a 9V excitation, and it outputs two 4.5 V signals. The load cell signal is encoded in the differential between the signals. An Instrumentation Amplifier (IA) is required to amplify the signal, since the output of the load cell has a very high common mode signal. The IA was set up with a gain of around 200 to achieve a signal output between 0 and 4.8 volts from the IA. This corresponds to approximately 1 to 160 pounds after calibration.

5.5 Software data acquisition

The Bluetooth device maps to a serial COM port on the device receiving the data. This data is read by a Python program which writes the data out to a file, as well as graphs the data in real-time, after applying the sensor calibration functions.

Python was used to decrease development time and to benefit from existing development libraries. It is likely that an additional component, perhaps written in a lower level language could be used in a producing model to increase the refresh rate of the real time graphs, currently limited to 3-5Hz while displaying 3 channels.

The real time graphs also lack any processing to reduce noise or to bridge missing data in the output, as this is difficult to do in real time. Non-real time graphs were smoothed with a low pass filter, and a simple hold of the last valid signal was used for missing data.

5.6 Power

Powered components in the prototype include the accelerometers, the strain gauge amplification circuit, and the Bluetooth AD module. The accelerometers operate under 5-10 VDC, while the Bluetooth AD module also shares the same voltage range. The instrumentation amplifier INA114 operates within 2.25-18V. For simplicity, a 9V power supply was used to power all of the above equipments in the prototype construction. In the final design, the board would be powered by a lithium ion cellular phone battery for longer battery life.

5.7 Calibration

In order to correspond the quantized digital output of the AD sensor values to the real world values that the sensors are measuring, calibration was performed in software.

5.7.1 Compression calibration

In order to calibrate the load cell output, various voltages were sampled when a compressive force is applied to the cane. The compressive force was measured by a scale and the sensor output voltage is measured by the Bluetooth AD converter.

After the initial calibration, it was apparent that the load cell mounting had established a 15 pound dead zone, where regardless of the compressive force applied between [0-15] lbs, the voltage output was the same. After this region, the relation between voltage and compressive force is linear.

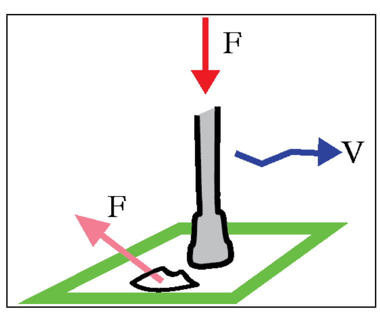


Figure 5.7: The sensor voltage-cane compression curve was derived with the aid of a scale

This "dead zone" was eliminated by biasing the sensor. The load cell mounting was modified so that it would be applying a 15 lb force to the load cell when no force was being applied to the cane.

5.7.2 Accelerometer calibration

The 2-axis accelerometers used to measure tilt and roll were unfortunately not mounted perfectly aligned with the cane tilt and roll axises. In order to be able to resolve a tilt or roll from the sensors, a calibration function with 4 inputs and 2 outputs needed to be derived.

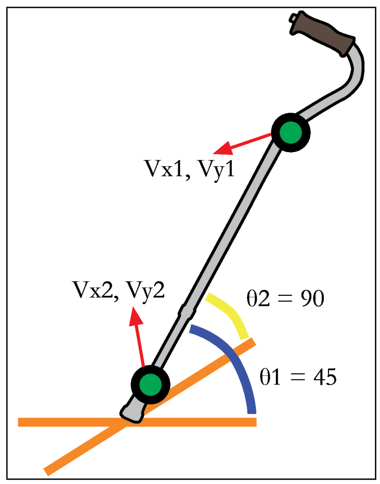


Figure 5.8: Sensor voltages were measured at different cane orientations in order to derive the calibration curve for orientation.

The calibration of the accelerometers was isolated from the removal of the cane acceleration relative to the orientation of the cane. In order to determine the calibration function, multiple data points were taken when statically orienting the cane in various positions. Finally, a linear calibration function was able to determine the orientation of the cane with a root-mean-square error of 3 degrees on the tilt axis and 5 degrees in the roll axis.

5.8 Prototype construction

Keeping in mind the limitations of the prototype compared to the final production model, the prototype will consist of the following:

- An Arduino micro-controller with at least 4 analogue inputs with a resolution of at least 1024 (8 bits)

- A single strain gauge/load cell that is able to determine the compressive stress in the cane

- Amplification circuitry for the strain gauge signal

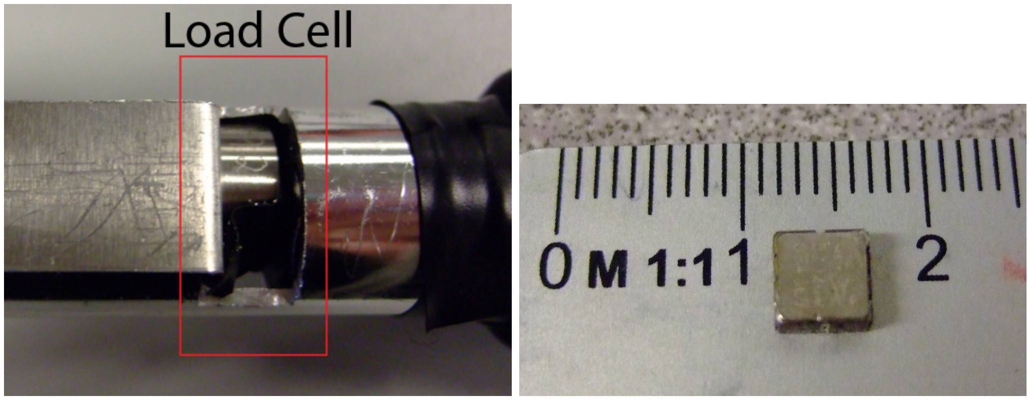
- A 2 dimensional accelerometer that is able to determine the orientation of the cane throughout the gait cycle

- An offset cane that will be used to integrate our measurement equipment

5.8.1 Construction Process

The first iteration of the prototype consisted of mounting the strain gauges onto the cane. First, a pair of slits were cut near the bottom of the cane so that the steel insertion piece could be placed across the shaft. A $\frac{1}{4}$ inch bolt was secured into the rubber end of the cane to serve as the sliding rod to deflect the strain gauge. Although the strain gauges were tested and worked prior to insertion into the cane, they failed to perform normally once they were actually mounted inside the cane. This could be due to a number of reasons, such as mechanical damage on the fine leads when inserting the mounting piece through the slit on the cane. After three consecutive strain gauges were broken during the mounting process, the group decided to use the load cell that was provided by the team's supervisor to speed up the construction process. The load cell was mounted the same way as the strain gauges and was able to provide the team with a good representation of the loading pattern on the cane. During the calibration stage, a slight toe region of around 10 pounds on the load cell was discovered. To correct for this toe region, stiff rubber bands were strapped on the bottom of the cane to pre-tension the load cell and eliminating the toe region.

The first set accelerometers that the team ordered had not arrived by the time the prototype was in construction; because of this, the team had to purchase another set of surface-mounted accelerometers that were not directly compatible with the breadboard circuitry nor the Arduino board. The group spent a great amount of time and effort soldering leads



(a) Load Cell (b) Accelerometer

Figure 5.9: Cane components

onto the minuscule accelerometer chips. One accelerometer was destroyed due to a permanent short-circuit during this initial soldering process. Two accelerometers were glued to mounting surfaces near the the top and bottom of the shaft. During testing, it was discovered that another accelerometer also failed due to faulty wire connections, leaving one working accelerometer and the working load cell remaining.

The circuitry to amplify the load cell output signal was done on a breadboard. Initially, a Wheatstone bridge-amplifier circuit was used for the strain gauges. After the load cell substituted the strain gauges, the external bridge was removed because the load cell has a bridge circuit built-in. The op-amp was also replaced by an instrumentation amplifier with a 250 ohm resistor for a gain of 200.

Initially, a Bluetooth AD device was used to wirelessly transmit the data going into the AD to a laptop for calibration and analysis; however, an accident occurred when during testing: the Bluetooth AD was overloaded and one of the embedded chips was destroyed. A wired connection to an Arduino data acquisition module was implemented instead.

Figure 5.10: Step Sense Cane Prototype

6

Testing and evaluation

6.1 Testing procedures

6.1.1 Strength Testing

Although the load cell used in the cane was only able to register compression less than 100 lbs, the cane can be loaded in excess of this amount without causing damage to the load cell. The load cell operation was also tested by several team members, with body weights ranging from 100 to 200 pounds, in an experiment to simulate the loading effects of a limping person. The test subject walked with only one shoe on, such that his/her two feet are of uneven length, and consequently more force is applied on one foot. It was observed that for even for a 200 lbs male, the average applied force on the cane during regular walking patterns was approximately 40 lbs. Therefore, the 100 lbs load cell offered a range that satisfied the measurement requirements of the prototype.

Static load

The cane was not damaged after subjecting to a static load of 100 lbs and held for 60 seconds. However, due to offset of the load cell to deal with the non-linear behaviour of the load cell mounting, the load cell zero point is changed after the force is applied, registering up to 8 pounds of compression under its own weight. The zero point gradually returns to the previously calibrated zero point over a period of 20 seconds or so, and this process can be accelerated by rapidly applying compression to the cane to allow the pre-tensioning device to return to its normal state.

Shock Load

The load sensor integrity was not affected when subject to an impulse load of over 200 lbs. The load was induced by a 200 lbs team member instantaneously pressed on the cane with his entire body weight. However, the cane demonstrated minor flexing through the offset section.

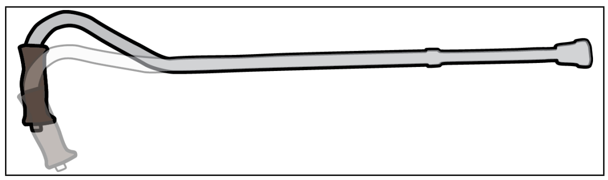


Figure 6.1: Large shock loads to the cane cause the cane to deflect, however the deflection is not due to modification to mount the device.

The load cell took approximately 0.5 seconds to re-zero after the shock load. The calibration of the sensors were not affected.

6.1.2 Robustness

The robustness of the prototype was limited by the incompatibilities of some components. For the production model, the robustness of the cane and the sensors could be tested by repeatedly dropping the cane to simulate the effects of the cane slipping out of the user's hands. The test could involve dropping the cane, with the foot of the cane placed one foot above the ground, and the cane positioned at a 30 degree angle to the ground. The cane is dropped, and it is ensured that the cane is not damaged in any method that could affect the structural integrity of the cane, or in a method that could affect the data output functionality; including calibration, of the cane.

The device will also tested against repeated impact. The device should be able to withstand 60-100 thousand impacts with the ground before recalibration or replacement of a component is required (assuming approximately 8-30 days of use, depending on activity level of patient).

The cane with the device installed will be placed under a fixed load of 50 lbs for 24 hours for creep analysis. Success will be determined by whether the sensor calibration is affected and the device is still able to maintain a similar level of accuracy as to the level before the creep loading was applied. After performing this testing, the shape and structure of the cane should not change. However, the zero point of the cane would likely shift, and it could be restored by palpitating the elastic elements at the foot of the cane in order to dissipate the friction between the elastic and the rubber foot plate.

6.1.3 Weight

The cane used for the project was an offset aluminium cane, aluminium canes typically weigh approximately 0.75 lbs. Typical wooden canes weigh approximately 3 lbs. The aluminium offset cane with the device attached weighed approximately 2 lbs, and weighed less than the average weight for a "typical" cane.

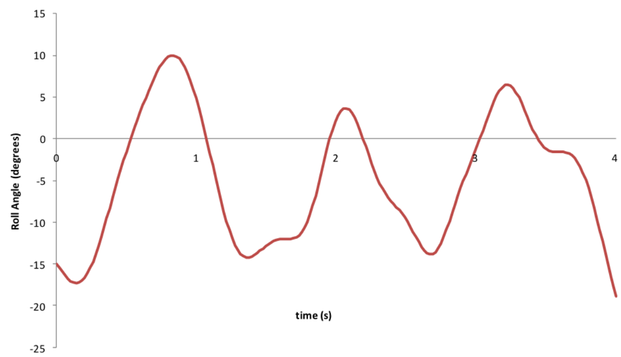
This design goal was accomplished for the prototype. However, it was unknown how patients currently using lightweight canes would react to the heavier cane for analysis. The production model would substantially reduce the weight via integrated components and compensate for the difference.

6.1.4 Data acquisition

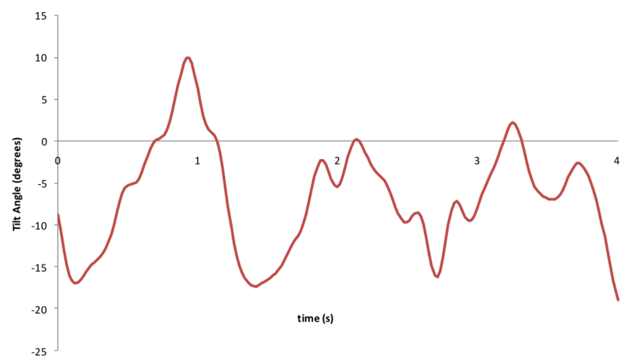
The data from all sensors was sent to a Bluetooth AD. The data is collected at 50 Hz, well in excess of the required 5 Hz required for pressure sensing, as well, 50 Hz delivers enough data to appropriately filter the accelerometer values and deliver more than 10 different orientation points of the two axes of the cane throughout the stride.

6.2 Functional prototype

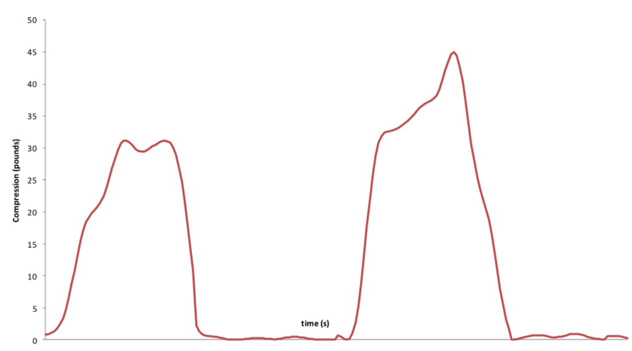
The key feature that the functional prototype demonstrated was its ability to collect data over an extended period of time, enabling the patient to take the device home.



(a) Roll



(b) Tilt



(c) Compression

Figure 6.2: Sensor data obtained from using the cane with a simulated limp. The sensor data has been low pass filtered to remove noise.

Step Sense also demonstrated that a functional gait diagnostic and analysis device could be constructed for under $1000. Presently, Step Sense requires a laptop to collect its output data. Future plans include using the Bluetooth module present on many Smartphones to collect data. The production model would also include a dedicated high-capacity battery with reduced power requirements from the components to lengthen the service period.

6.2.1 Evaluating prototype

The accuracy of the orientation sensor unit could not be evaluated due to the failure of two of the three available accelerometers. While some data was collected, at least 2 accelerometers were required to isolate the tilt of the cane shaft from acceleration.

Calibration of multiple accelerometers in static positions was accomplished by orienting the cane in a known orientation and comparing with the accelerometer readings. A 2-D calibration was required to match the accelerometer readings with the orthogonal axes.

The force sensor exhibited some problems with the pre-tensioning of the sensor to remove the non-linearities. Pre-tensioning was accomplished with an elastic band, and the friction of the elastic band against the bottom of the cane led to variability in the measurements of force during calibration. Calibration was accomplished by applying a compressive force to the cane, and measuring the corresponding output from the sensor and a measurement of the compression on a scale. A linear calibration curve was created, with a calibration root-mean-squared error of 5 lbs.

6.3 Economic analysis

To determine whether a device will have a large demand in the marketplace, an economic analysis was done to determine how much the cane would cost to manufacture, its retail and bulk prices, and the potential market size for the device. The cost of the components listed in Tables A.1 and A.2 are taken from the team's spending or sourced from the Internet when ordering lots of 1000 or greater. The potential market analysis is a rough estimate of the number potential customers that our product would be suited to.

6.3.1 Cost of the prototype

Due to the failure of some components during construction of the prototype, components inside the prototype differ from components that were selected for the final design. The cost of the prototype was therefore slightly greater than that of the final design. A detailed cost breakdown is available in Appendix A in Table A.1.

6.3.2 Cost of final design

The final design would use different components than the prototype, both to benefit from economies of scale, and also to ensure robustness in certain components. A detailed cost breakdown is available in Appendix A in Table A.2.

The construction of the prototype used commercial parts for all the components, which provided an estimate for the maximum construction cost; however, if the canes were manufactured in bulk, the cost of the final design would decrease dramatically. The sum of all components demonstrated that the final design would not cost more than $500 for parts. If done efficiently, the total labour required to put together one cane would be around 5 hours by hand. If labourers were paid $20 per hour, the total manufacturing cost would be around $100 per cane. This increases the total price of creating one cane up to $594.52.

At retail price, the cost would be multiplied by a factor of 2.5 or 3, creating a retail price of Bulk supplying of these canes would naturally reduce the cost per unit of these canes. The estimated price for shipments of over 50 or more canes could have a unit cost of $1486.3 to $1783.56. At the bulk price, the profit margin factor on each cane would only be 2, creating a bulk price of $1189.04 [9].

6.3.3 Market Size

According to a study done by the University of Toronto, Michigan, Hamilton, and the Toronto Rehabilitation Institute, the number of disabled elderly adults requiring the use of a cane was 35% in the year 2000. Because the percentage of the elderly requiring the use of canes increases over time (between the years 1980 to 1994, the increased use in canes was 37%), it can be estimated that currently, the number of disabled elderly over 65 years of age that requires the use of walking canes is around 48%. In October 2002, approximately 13% of people over 60 years of age not living in institutions have mobility impairments. This proportion increases to about 30% by the age of 80. [10]

In 2009, the entire population was around 33,894,000 people [11]; we can estimate that around 25% of these people are aged 65 years or older based on the lifespan of an average Canadian (80) [12]. From this information, it can be estimated that there over 500,000 Canadians over the age of 65 in need of canes for walking assistance in 2002. This number would have increased by the year 2010 as the population size increases and more people grow older; however, because. The number of people that can use this cane increases with further iterations of the design that will allow athletes and younger individuals to use.

Based on these statistics, if 1 out of 100 receive a cane from their clinics, a total of 5000 canes could be sold. With each cane giving around $600 of profit, which gives an expected revenue of around 3 million dollars, which would be enough to pay for any initial overhead costs such as marketing and manufacturing equipment. Also to be considered is the replacement of the diagnostic devices when they wear out. A lifetime for the device has not been analyzed, but it is likely that the mechanical parts comprising the load cell mounting would wear out first. The device would then require maintenance or replacement, both of which would help to maintain a market fr the devices.

6.3.4 Cost of competitor's systems

Competitor systems such as the Portable Lab system from medical motion includes many sensors and cameras with their package. From a recently acquired quote from the company, their entire portable lab system would cost around $4300 to $4400 for the basic one camera with laptop and software package. With additional upgrades, the entire portable package would cost around $5500 [13].

Another company [14] created an infrared system to conduct gait analysis. The estimated cost of their system was around $5000; however it can still only be used for one person at a time and must be connected in a static lab environment. With the $5000 needed to purchase this system, 4 Step Sense canes could purchased for usage by 4 different individuals, allowing researchers and doctors to collect significantly more data.

7

Summary

There is currently a lack of effective portable long-term measuring equipment for gait patterns. The Step Sense cane, proposed in this project, will enable researchers to measure the usage frequency, load patterns, and derive the effectiveness of the prescribed assistive device for individual patients.

For the purposes of demonstration, a functional prototype was constructed based off a standard aluminium offset cane. Accelerometers and a load cell were embedded into the cane in order to measure the orientation and compression of the cane. Sensor data collection was performed by a BlueSentry wireless AD converter. A production model of the device would demonstrate a system that measures and records load information and provides observers with gait pattern data. At the same time, the device will not interfere with the regular operations of the cane as it will not obstruct the comfort in its use, nor will it add significant weight nor hazards to its operations.

This device would fulfil the goal of supplying researchers with long-term gait pattern monitoring data that would not be otherwise available in lab environments, and assist in enhancing the applications of walking-aid devices.

8

Recommendations

Currently, the data sent from the Step Sense prototype device is processed by a laptop. In future iterations of the Step Sense device, the data would be streamed to a portable device, such as a Smart Phone.

The Step Sense produces an extraordinary amount of data by collecting gait pattern data for an entire day. An analyst examining the sensor data would be unable to study the long term trends in gait. It is likely that some pattern recognition and machine intelligence clustering techniques could be used to firstly categorize step cycles according to the terrain: stairs, ramp or flat ground; and secondly to determine whether the majority of steps corresponds to the ideal step for the patient on the given surface. These techniques can help to drastically improve the analysis of the long term collection of data. However, manual inspection of time-series data can still be performed by the analyst on short-term time windows.

When testing the prototype, determining the orientation of the cane from the filtered and processed accelerometer data was difficult. Accelerometer noise, as well as isolating the acceleration of the cane from gravity was difficult to deal with. A future iteration could use a low power MEMS gyroscope, while using the accelerometers on the device to reset the following error of the gyroscopes.

When presenting the device at the design symposium, the replacement AD controller board, (Arduino Uno) was unshielded, electrical noise may have contributed to the inability of the board to correctly detect the pulse-width-modulation of the accelerometer outputs.

Despite the fact that the original design called for accelerometers with analogue input, it is good practise to shield sensor leads and electrical components to avoid noise.

The sensor packages and data processing technologies comprising the Step Sense cane could also be expanded to other assistive devices such as four point canes, walkers and crutch to appeal to a wider range of people and to help researchers collect additional data from these other widely used assistive devices.

The final goal for future iterations of the Step Sense cane would be to expand the concept to broader areas in the marketplace such as providing the same technology to walkers and four point canes in order to benefit mobile aid users worldwide.

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Appendix A

Components Costs

Table A.1: Cost of Prototype

Component	**Cost**
Cane	$30.97
Load Cell	$395 [15]
Accelerometers	$72.60 for 3
Arduino Board	16.99 for serial kit [16]
Instrumentation Amplifier (INA114)	Around $4 per piece
Energizer Batteries	$11
Wires and Miscellaneous Equipment [1]	$20
Total	$550.56

Table A.2: Cost of Final Design

Component	**Cost**
Cane	$30.97
Strain gauges	$16.95 for 5
Accelerometers	$72.60 for 3
Bluetooth device	$299 [17]
Instrumentation Amplifier (INA114)	Around $4 per piece
Lithium Ion batteries	$25 [18]
Integrated PCB and wiring	estimated $50
Total	$ 494.52

[1] Includes bread board, resistors, capacitors, tape, and thick rubber bands

Appendix B

Weekly Summary

B.1 Group Summaries

Table B.1: Group Summary January

3	Design group formed. Topic idea focused on contemporary medical problems.
10	Topic ideas narrowed down to 3 potential design problems:muscle dystrophy, cane force measurement and insulin pump. There was a growing concern for how novel the patent and the confusion was resolved with professor Clausi.
17	Problem to solve was selected to be a cane for research purposes measuring applied force and angle. Approved James Tung, professor at the University of Waterloo, to be our workshop design supervisor. He has previous knowledge in gait analysis and constructed a sensory walker measuring the applied force of the patient.
24	Met with James and discussed the implementation of the cane. Deciding on the component of choice for each specific function was done using a comparison matrix. James provided a variety of documents to read over for the requirements.
31	Hannah gathers springs for one potential prototype. Schematics of the diagram from Ben were constructed. The remainder of the group were deciding on which components for applied force and angle measurements were to be.

Table B.2: Group Summary February

7	A cane was purchased. Strain gauges purchased . Wireless Bluetooth board was borrowed and Colin began software development to transfer the voltage data to his computer.
14	James was dissatisfied with the requirements section of the document. An approved revised version detailing the specifications was written.
21	Prototype construction started. Strain gauges arrived and testing began. Schematic diagrams adjusted to components used. BlueSentry board available for development by Colin.
28	Accelerometers purchased. Colin's software program works in almost real time. Working still on the code implementation to provide a quicker response from the wireless board to his computer. Hardware signal amplification system constructed.

Table B.3: Group Summary March

7	Strain gauges broke when mounting onto the cane. Load cell alternative is inserted at the bottom of the cane. Schematic diagram updated to reflect results. Instrumentation Amplifier circuit unable to accurately amplify the difference in strain. A consideration for a higher bridge is recommended.
14	Accelerometers for the cane from Dimensions Engineering in USA has not arrived yet. Instrumentation Amplifier and lower quality accelerometers purchased by Colin in Scarborough. Prototype construction completed. Colin's firmware debug began.
21	Presentation board completed. The wireless AC (Data Acquisition control module) board was fried. This weekend was spent reestablishing the connections of the accelerometers which had lost contact with new Arduino.
28	All group members present for symposium and writing of the report. James Tung was at the symposium and marked our presentation. One of the two attached accelerometers have their data recorded in graphs.

B.2 Group member Contribution

The group worked as a complete unit. Everyone was able to contribute and collaborate well together. The entire group brainstormed ideas equally and worked together by bouncing ideas off of each other. The breaking up of tasks was always seamless as everyone was eager to learn and attempt any research. Once construction was complete all the group members knew how to wire the devices together when the device was running. All group members wrote the final design report. Again, all members edited and gave constructive criticism when editing. Since the team had diverse and unique skills, certain tasks were divided and completed separately. More detailed personal contributions are shown below.

B.2.1 Martin Lui

Martin is the project manager of the design workshop. He scheduled the team meetings as well as with James Tung to discuss the current plan and issues to resolve. During times of making final decisions, Martin reviewed each option and made reasonable conclusions for each choice. This included the priority of applied force measurement options to test strain gauges and load cells first prior to using a spring system.

Martin edited the presentation board material and wrote the appendix of the report. He also contributed a small portion of text throughout the report to fill in missing gaps. Martin made purchases to accelerometers but they did not arrive in time for the display at the symposium.

B.2.2 Hannah Lindsey

Hannah provided majority of the prior art information in the lab report and greatly helped with the flow of the sections. She gathered springs that were to be used in a potential prototype. This prototype was not used in the end. She also wrote and assembled the display of the presentation board material. During critical times, she was able to keep the team motivated to work. Assisting, Yiling, Ben, and Colin: Hannah was a helping hand when it came to the calibration as well as device assembly (whether it may have been soldering or operating a glue gun). During the symposium, Hannah displayed detailed knowledge of the background information to show why this device was useful and needed to the public.

B.2.3 Benjamin Tan

Ben constructed majority of the prototype and wired the components together to work with assistance from Yiling. He constructed the strain gauge mounting mechanism using primarily scrap metals salvaged from the design workshop, and fabricated all necessary components. After observing the dissected cane, he also proposed the use of the existing rubber cover as a substitute for the spring to restore the shaft position, which was ultimately adopted in the prototype. After the load cell replacement was introduced, he made modifications to the cane and the mechanism components to adapt to the change. He also performed most of the soldering of the electrical components, ranging from attaching the fine wires onto the minute accelerometer terminals to extensive wiring and circuit troubleshooting. With a malfunction of the Digital to Analog Converter, an Arduino-based alternative to transfer data from the cane to the laptop was used.

B.2.4 Yiling Wang

Yiling assisted Ben in the fabrication of the components for the prototype. She made the executive decision on the choice and purchase of the strain gauges, for which she designed and implemented the corresponding amplification circuit. After the strain gauges were experimentally proved to be too fragile and difficult to work with, she then suggested implementing of the load cell as a replacement, and participated in the adjustment and reconstruction of the mechanical components to accommodate the load cell.

She was a key member in the iterative calibration and maintenance of the sensitive and fragile accelerometer installation. After all three accelerometers suffered from mechanical failures and poor connection the day before the symposium, Yiling and Ben managed to recover operations on one of the two accelerometers to perform consistently during the symposium.

B.2.5 Colin Heics

Colin handled the implementation of the firmware for both the original BlueSentry wireless AD board as well as the firmware on the replacement wired Arduino board. Colin also handled writing the software to display and store data coming from the sensors.

During component selection, Colin helped to guide component selection of accelerometers and investigated other options for sensing the orientation of the cane. Colin also did the last minute non-ideal component selection for accelerometers (ordered accelerometers caught in brokerage).

Colin also did a small amount of mechanical prototype assembly, as well as troubleshooting associated with the circuitry involved with the electrical part of the device. Colin also determined the method which the accelerometers and force sensor were calibrated, and collected and processed some test data points to derive the linear calibration of the sensors.

B.3 Evaluation from James Tung

(Attached)