PORTABLE INSTRUMENTATION TO DETECT GAIT INSTABILITIES

FINAL DESIGN REPORT

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1. ABSTRACT

The project seeks to measure spatio-temporal parameters suitable for accurately detecting gait instability in elderly individuals. Using one tri-axial accelerometer located on the S2 vertebra and two dual-axis accelerometers on the heel columns, the data obtained can be used to make accurate conclusions on the gait instability of the subject. With a focus on trunk acceleration to maximize accomplishments, the team purchased a commercial logging device with customized accelerometers. To venture into the possibility of simplifying the commercial product, a circuit was designed and constructed to accommodate further adjustments and reductions in size in accordance with the client's needs and possible variability among subjects. An attachment device was also made to fix the tri-axial accelerometer and data logger securely to the subject.

2. MOTIVATION & PROBLEM STATEMENT

Walking is an action that most people take for granted, but as age progresses, walking may bring a sense of fear − with each step, there is a chance of falling. Not only does falling lead to embarrassment and injury, falling accounts for 70% of accidental deaths in people over the age of 75[1]. Because of the detrimental effects of falling, it is imperative to identify patients that are at high risk of falling, so that preventive measures can be set in place before accidents occur. Current methods of predicting falling in patients depend on subjective evidence such as interviews by the clinician, or the patient's medical history. Clearly, a more objective method is needed for accurate prediction.

Using accelerometry, various spatio-temporal parameters can be measured to indicate gait instability. Two results from recent studies are crucial for this approach: trunk acceleration, and stride/step parameters. Trunk acceleration was seen to be accurate in the detection of imbalance during normal walking habits, being a precise measure of the degree of sway[2,3]. On the other hand, stride/step length and duration were found to positively correlate with the risk of falling[4,5]. Combining these two techniques of analysis provides sufficient information to detect gait instability and hence predict the risk of falling.

Focusing on trunk acceleration, the team seeks to develop an accelerometry device that can be securely attached to the subject's center of mass. The device should consist of a data logger, an accelerometer, and a means of attachment that does not impede the patient's normal gait. At this stage, a commercially available data logger may be used to collect preliminary data, but the accelerometer and attachment device have to be customized to the client's needs.

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[1] "Advanced trauma life support for doctors" published by Weigelt JA, in "Chicago: American College of Surgeons" 6th edition, 1997

[2] "Assessment of Spatio-Temporal Gait Parameters from Trunk Accelerations during Human Walking" published by Zijlstra W and Hof Al, on October 18, 2003

[3] "Detecting Balance Deficits in Frequent Fallers Using Clinical and Quantitative Evaluation Tools" published by Chiung-Yu Cho and Gary Kamen, in "JAGS" Volume 46, Number 4, April 1998

[4] "Gait Variability: Methods, Modeling and Meaning" published by Jeffrey M Hausdorff, on July 20, 2005

[5] "Footswitch System for Measurement of the Temporal Parameters of Gait" published by Jeffrey M Hausdorff, Zvi Ladin and Jeanne Y Wei, in "J Biomechanics" Volume 28, Number 3, 1995

3. BACKGROUND INFORMATION

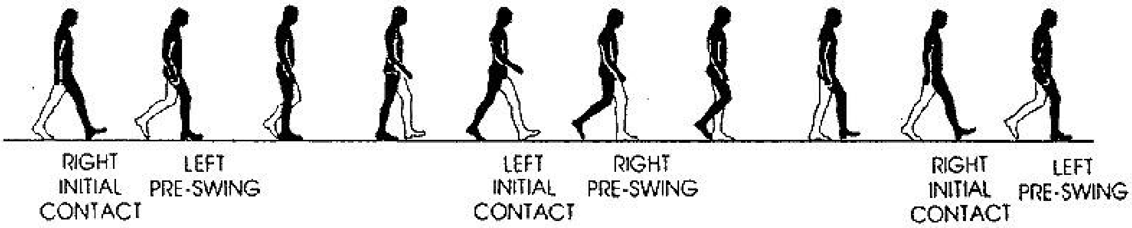

Figure 1: The gait cycle of an average human being

Figure 1 shows the gait cycle of an average human being. One stride is defined as the heel-strike from one foot to the next heel-strike of the same foot, whereas one step is defined as the heel-strike of one foot to the heel-strike of the other foot.

Gait instability is indicated by the degree of sway of the body's center of mass during a stride or a step. By anatomical definition, the body's center of mass is located at the second sacral vertebra (commonly abbreviated as the "S2 level") which is about 4 cm along the spine inferior to the iliac crest. As mentioned in the problem statement, the body's degree of sway can be determined using trunk acceleration. Therefore, by securing a tri-axial accelerometer at the S2 level, the degree of sway and hence the degree of gait instability can be derived.

4. CLIENT'S NEEDS & DESIGN SPECIFICATIONS

The client has several requirements for the design. The main considerations were portability, accuracy, and safety. In addition, the device must include a data logger with internal data processing capabilities and enough memory space to complete a sampling duration of two minutes, as well as a tri-axial accelerometer.

The design specifications need to incorporate strict size and weight limits, so as not to inhibit any normal motor activities. Inhibitions of movement will reduce the accuracy of the data and thus introduce undesirable noise into the data. Consequently, the data logger needs to be small and lightweight (preferably less than 500g). The logging system should not be connected to a computer or other processing machine via wires to ensure free motion. It should also have a minimum sampling rate of 60 Hz so that an accurate plot of the subject's acceleration can be obtained. The memory function of the logger must meet the requirements stated above. Data should either be stored in a removable memory chip, or be hardwired into the logger.

The tri-axial accelerometer must have low g-range and high sensitivity to optimize resolution. If the g-range is too low, too much interference will be picked up simply from moving the leg. Conversely, if the g-range is too high, the impact from the heel will not be large enough register a prominent spike in the plot.

In the future, this device is likely to be worn by the subject while engaging in daily activities, which include motor activities ranging from standing to bending over to walking, as the client plans to collect long-term data to assess its feasibility for detecting gait instability for the population at large. This is an additional factor that could affect the choice of design.

More details can be found at Appendix I.

5. CURRENT PRODUCTS

The current market does not have a device specifically designed to detect gait instabilities. However, a company in the United Kingdom, MIE Medical Research Limited[6] (hereinafter referred to as MIE), offers data loggers together with custom-made acceleration transducers, which utilizes accelerometers from Analog Devices[7]. The logger also uses LEMO[8] wire connectors, which supply power to the accelerometers and allow transfer of data to the logger. Figures 2 and 3 shows images of the products offered by MIE.

Figure 2: A sample data logger provided by MIE

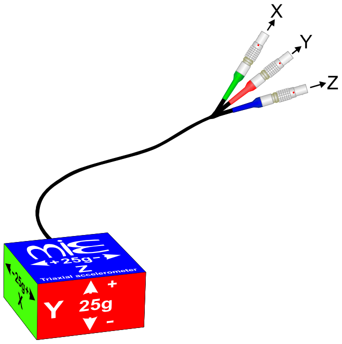

Figure 3: Custom-made acceleration transducer accompanying the data logger

6. BRAINSTORMING

Four main areas are of primary concern: type of data logger, sensor signals, memory storage, and attachments to the body. The data logger can either be custom-built from scratch, or bought from the market. Communication between the data logger and the accelerometer can happen in a variety of ways: for instance, hardwiring them directly to the memory, or using wireless transmission (eg. Bluetooth technology). The means of data storage was another area with several options. The possibilities were narrowed down to either using internal memory available in the data logger, or using a removable memory device such as a thumb drive or a Secure Digital (SD) card. The final point of focus was on how to attach the accelerometers and data logger to the subject. The attachments would have to allow maximum mobility yet strong enough to keep the device from slipping. Based on the design specifications agreed between the client and the team, three potential models of the device were considered:

Model 1 – Commercial Product & Self-Made Attachments

The data logger can be purchased directly from MIE. It weighs approximately 90g and has a programmable sampling rate between 10 Hz to 4000 Hz for 8 channels. It uses SD cards or MultiMediaCards (MMCs) for data storage, and is able to acquire data continuously for 2 hours at 4000 Hz on a 512 MB SD card. However, despite fulfilling many desired specifications, this model has limited ability to adapt to a home environment where data acquisition will be executed for longer periods of time. Thought the project's focus does not concern the long-term use of the device, it is prudent to take note of this in the interest of the client.

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[6] Reference website: www.mie-uk.com

[7] Reference website: www.analog.com

[8] Reference website: www.lemo.com

Apart from the data logger, MIE also provides customized tri-axial accelerometers, implying a need to design a support system to carry both the data logger and the accelerometer. This configuration might hinder the patient, though not enough to impede movement.

Model 2 – Entirely Self-Built Device

A self-built microcomputer can be fully customized according to design specifications for the data logger. The memory storage would be a removable SD card, which can be plugged into a desktop or laptop computer for data analysis. As long as the data remains intact during transition, this model reasonably fulfils the design specifications for the logger.

Ideally, the sensors can be constructed using wireless components so that hindrance to movement can be minimized. Better still, the sensor can be attached to the body using strong surgical tape and/or adhesive patches, allowing almost total freedom of movement. Nevertheless, the need to have a separate power supply for each component may prove to cause excessive weight on the subject.

The feasibility of this model will depend largely on the team's ability to design the circuitry and procure all the necessary components. It would be considerably difficult, and much assistance must be sought from commendable resources and mentors. Moreover, this approach has a heightened margin of error.

Model 3 – NIKE/iPod Configuration

One commercial product that does not directly involve gait analysis but involve some accelerometry is the NIKE/iPod configuration[9]. NIKE and iPod collaborated to measure distance and stride information by placing accelerometers in a cavity inside NIKE running shoes. Data is wirelessly transmitted via radio-frequency identification (RFID) to a memory card inserted into the iPod which the subject carries while exercising. The card can then be inserted into a computer system for data retrieval and analysis. Unfortunately, the memory capacity heavily relies on the type of iPod device purchased.

To use this model, every subject has to purchase his/her own NIKE shoes and iPod device at commercial prices – an aspect that compromises long-term economic benefits. Moreover, the necessity for the subject to wear NIKE shoes may subtly influence his/her normal gait and affect the validity of the data. Nevertheless, this wireless system permits total freedom of movement.

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[9] "Devices that tell on you: the NIKE + iPod Sport Kit" published by T. Scott Saponas et al, on November 30, 2006

7. MODEL ANALYSIS & DESIGN MATRIX

To assess their relative strengths and weaknesses, the three models were ranked according to weighted criteria as follows:

Cost Efficiency (5%) – The device cannot be too expensive, though our budget allows freedom to create an efficient and reliable system.

Portability (20%) – An incredibly important factor because the subjects need complete freedom to walk with ease in order to simulate their normal gait. Any alteration in the normal gait of the patient due to the device is unacceptable.

Ease of Analysis (15%) – The clinician must be able to work with the system we create and assemble it repetitively across different situations.

Data Storage/Transmission (15%) – Data has to be efficiently, safely, and accurately transported from the collection system into a visualization computer program.

Numerical Accuracy (20%) – The data collected results from the voltage output from the accelerometers. It must be quantified and calibrated in an efficient and reliable way to ensure consistency and accuracy.

Adaptability (5%) – In the interest of the client's long-term goals, the device must remain efficient in various settings.

Safety (20%) – The device must not put the subject at risk.

With these in mind, a design matrix (Figure 4) was created. Results reveal that Model 1 fits our design specifications the best.

CRITERIA	WEIGHT	MODEL 1	MODEL 2	MODEL 3
Cost Efficiency	5%	30	80	50
Portability	20%	70	50	90
Ease of Analysis	15%	90	40	30
Data Storage/Transmission	15%	90	70	90
Numerical Accuracy	15%	90	60	30
Adaptability	5%	90	90	30
Safety	20%	90	60	90
TOTAL	**100%**	**83**	**59**	**64**

Figure 4: Design matrix

8. DESIGNING THE ATTACHMENT

An attachment device was designed to secure the tri-axial accelerometer and data logger firmly to the subject. It consists of a belt made from elastic straps, one polymer buckle, adjustment clips, a swatch of material, leather stabilizer, and an elastic strip, as shown in Figure 5.

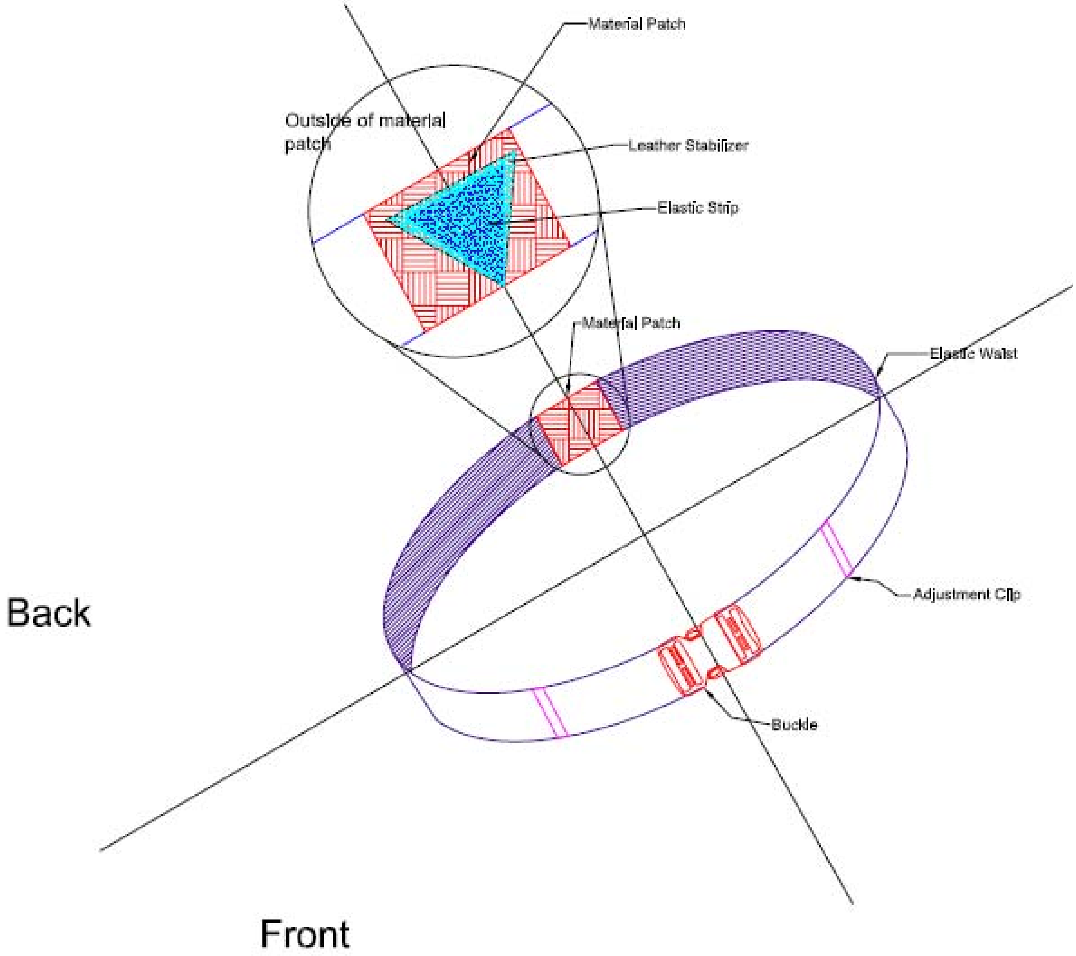

Figure 5: The attachment device

The attachment device must be adjustable to accommodate waistlines ranging from 20 inches to 60 inches. Hence, two belts were made: one that covers 20 inches to 40 inches, and another that covers 30 inches to 60 inches.

To attach the data logger to the belt, a pouch was made to the dimensions of the data logger (72 mm × 55 mm × 18 mm) and a cell phone clip was sewn to it. This enables the data logger to be clipped at any position on the belt, addressing any unforeseen problem with the placement of the logger. For instance, should the subject have a medical condition like scoliosis, this design presents an immediate solution, that is, allowing the logger to be moved to a more comfortable position on the belt.

9. DESIGNING THE LOGGER-SENSOR SYSTEM

The logger-sensor system essentially entails 2 major functions: data storage and data acquisition. Data storage is primarily accomplished by the MIE data logger, whereas data acquisition requires the use of tri-axial accelerometers with some accessory components to refine the output signals. Indeed, MIE provides custom-made acceleration transducers in addition to the data logger, but the price of the data logger is high − USD$8900, with an additional USD$495 per transducer. This greatly justifies the need to duplicate a simplified sensor model instead of purchasing the MIE transducers.

The Data Logger

The specifications of the commercial data logger from MIE are tabulated in Figure 6.

Resolution	12-bit
Sampling Frequency	10 to 4000 Hz (programmable)
Input Channels	8
Physical Dimensions	72 mm × 55 mm × 18 mm
Mass	90g (including memory card and battery)

Figure 6: Relevant specifications of data logger

Using only one 1.5-V AA battery, the MIE data logger does not require any external power supply. In addition, it stores data on SD cards MMCs, which are non-volatile storage devices that do not require electrical power for data retention. The data logger is thus truly portable.

Moreover, the 8 channels are scaled down to 4 ports with the use of 4-pin LEMO wire connectors. More details on the connectors can be found at Appendix II.

The Tri-Axial Accelerometer

To accurately assess the variability in trunk acceleration, measurements must be taken in 3 dimensions. As trunk accelerations of an elderly typically fall in the ±2.5g range, a relatively high sensitivity is warranted. The accelerometer should also operate at low power to maximize the period of data collection.

The MMA7261QT tri-axial accelerometer from Freescale Semiconductors[10] was hence chosen. The company also provides an evaluation board (KIT3109MMA7261QE) customized to relay the signals from the accelerometer. The combined technical specifications are listed in Figure 7. It is evident that the accelerometer and its evaluation board are reasonably compatible with the data logger.

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[10] Reference website: www.freescale.com

Voltage Supply	2.2 V to 3.6 V *(3.3 V recommended)*
Current Consumption	500 μA to 800 μA *(normal operation)* 3 μA to 10 μA *(sleep mode)*
Sensitivity	2.5g/3.3g/6.7g/10g
Internal Sampling Frequency	11000 Hz
Operating Temperature	−20°C to +85°C

Figure 7: Relevant specifications of tri-axial accelerometer

The Circuit Design

Supplying Power to the Accelerometer

As mentioned in Appendix II, each LEMO connector contains 2 branches (carrying +5 V and 0 V respectively) to power up the accessory devices, and 2 other branches to receive signals between 0 V and +5 V. The data logger can hence be used to supply power to the evaluation board. To step down the 5-V supply of the logger to within the input voltage range of the evaluation board, a 3.3-V Zener diode (1N5226B) is connected in parallel with the evaluation board to maintain a maximum of 3.3 V across the evaluation board. A resistor is also connected in series with the data logger and the Zener diode or evaluation board to limit the current supply into the latter components. The calculations below show the type of resistor to be used:

Maximum current consumption of Zener diode = 20 mA

Maximum current consumption of evaluation board = 0.8 mA

Maximum current flowing across resistor = 20.8 mA (by Kirchoff's Current Law)

Voltage drop across resistor in direction of current = +3.3 V

Minimum resistance of resistor = 159 Ω (by Ohm's Law, assuming linearity)

For a factor of safety of at least 5, a 1-kΩ resistor should be used. A better alternative is to utilize a 1-kΩ variable resistor to optimize the performance of the Zener diode by trial and error. The maximum current supply from the data logger is 50 mA, way beyond what is required.

Sending Signals to the Data Logger

The range of output signals from the evaluation board is provided in Figure 8. Given that the input voltage range of the data logger is between 0 V and 5 V, the output signals of the accelerometer should be amplified to obtain a good resolution. Moreover, it is very likely that different axes will produce different ranges of acceleration, let alone the variation among different subjects. For example, if the subject is walking normally along the x-direction, one would expect more abrupt changes in acceleration along the y- and z-axes relative to the x-axis. This implies that the output signals have to undergo variable pre-amplification before being sent to the data logger.

g-Range	Minimum Sensitivity	Maximum Sensitivity	Output Range
0g	–	–	1.4850 V to 1.8150 V
±2.5g	444 mV/g	516 mV/g	0.1950 V to 3.1050 V
±3.3g	333 mV/g	387 mV/g	0.2079 V to 3.0920 V
±6.7g	167 mV/g	193 mV/g	0.1919 V to 3.1081 V
±10g	111 mV/g	129 mV/g	0.1950 V to 3.1050 V

Figure 8: Output ranges of tri-axial accelerometer

A good way to execute pre-amplification is the use of operational amplifiers (op-amps). One common function of an op-amp is the non-inverting amplifier, whose behavior is dictated by the equation below:

$$V_{\text{out}} = \begin{cases} \left(1 + \frac{R_f}{R_1}\right) V_{in} & \text{for } R_1 > 0 \\ A(V_{in}) & \text{for } R_1 = 0 \end{cases}$$

where V_{out} = the voltage at the output terminal of the op-amp
V_{in} = the voltage at the non-inverting terminal of the op-amp
R_f = the resistance of the feedback resistor linking the output terminal and the inverting terminals
R_1 = the resistance of the resistor connected between the inverting terminal and virtual ground
A = the open-loop gain of the op-amp

A negative feedback approach is adopted in order to maintain stability of the circuit. The user should be warned not to set R_1 to zero to prevent the functionality of the op-amp from becoming a comparator, which essentially drives the output voltages of the op-amp to saturation.

The dual op-amp model provided by Parallax, Inc[11] was chosen for the project. Its specifications are tabulated in Figure 9.

Voltage Supply	3 V to 30 V
Current Drain	0.7 mA
Open Loop Differential Voltage Gain	100 V/mV

Figure 9: Relevant specifications of dual op-amp

The dual op-amp can hence share the same power supply as the evaluation board, that is, the data logger. To attain variable gains, a 2-kΩ variable resistor and a 1-kΩ variable resistor are used for R_f and R_1 respectively. Their combined effects are tabulated in Figure 10.

Range of R_f	Range of R_1	Gain
$0 \leq R_f \leq 2000\ \Omega$	0	× 0
0	$0 < R_1 \leq 1000\ \Omega$	× 1
2000 Ω	1000 Ω	× 3

Figure 10: Effect of various combinations of R_f and R_1

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[11] Reference website: www.parallax.com

Connecting All Components

The entire circuitry is shown in Figure 11.

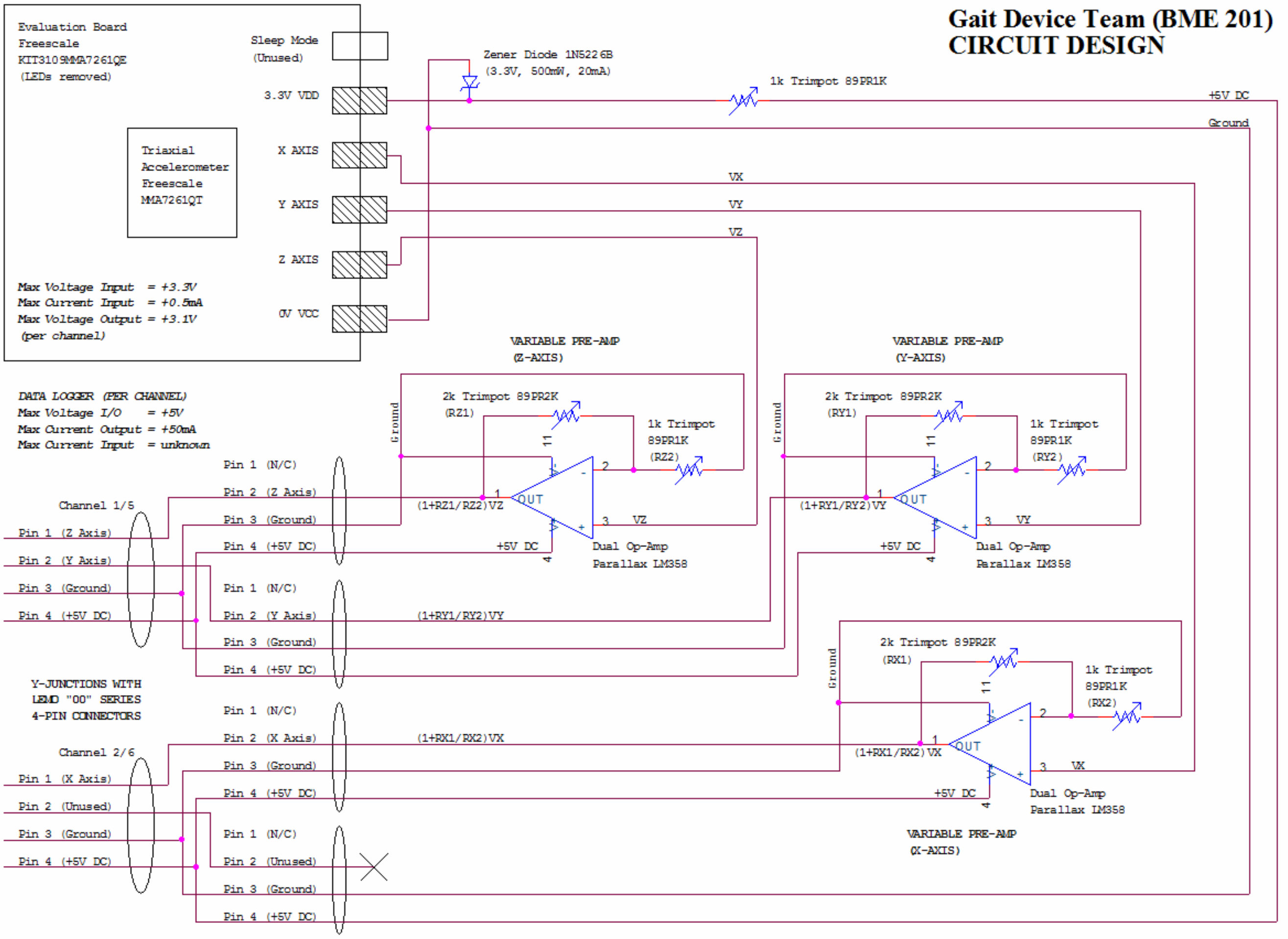

Figure 11: Circuitry of logger-sensor system

10. VALIDATION

Once the circuit was constructed, it was important to confirm that the correct voltage and current were passing through the circuit, as the tri-axial accelerometer had specific voltage and current limits that cannot be surpassed. It was also important to check the output voltages of the three different axes to ensure that they were being amplified correctly and that the variable resistors were functioning properly. All these were confirmed using a digital multi-meter.

Initial tests with the multi-meter revealed that the current supplied to the Zener diode was insufficient, hence the voltage supplying the evaluation board was not enough power. This problem was solved by setting a lower resistance at the variable resistor connected to the Zener diode. Thereafter, the output signals from the evaluation board showed significant responses when the accelerometer was moved in different directions. More tests were performed on various parts of the circuit, before it was attached to an oscilloscope to track real-time responses.

BNC cables were used to attach the circuit to the oscilloscope. Only two axes could be observed at once, as the oscilloscope had only two input channels. Some positive results are listed below, indicating that the accelerometer and pre-amplifiers were working properly.

- Periodic movements along a specific axis corresponded to periodic responses from that particular axis, with little to no response from other axes.
- When the accelerometer was tapped sharply in one direction, a large spike was observed on the oscilloscope screen.
- These results confirmed that the tri-axial accelerometer and pre-amplifiers were working correctly.

The next step was to use LabView to write a program that recorded the voltage change over time and export the data into a Microsoft Excel Worksheet so that the data could be converted into a graph (see Figure 12). The accelerometer was placed on the lower back of a team member, who then walked to and fro along a straight line. The results simulated something similar to what the client will be using the device for, and also represented how the data will be interpreted by the MIE data logger. This preliminary test was done to observe if data could be recorded from the accelerometer and how it looked when it was graphed.

LabView will not be used by our client, however, since the data logger will come with its own software. The testing done on the accelerometer to this point was mainly used to confirm that the circuit design worked correctly. Further testing is necessary to show that it can collect data that is reproducible and reliable enough to draw conclusions from.

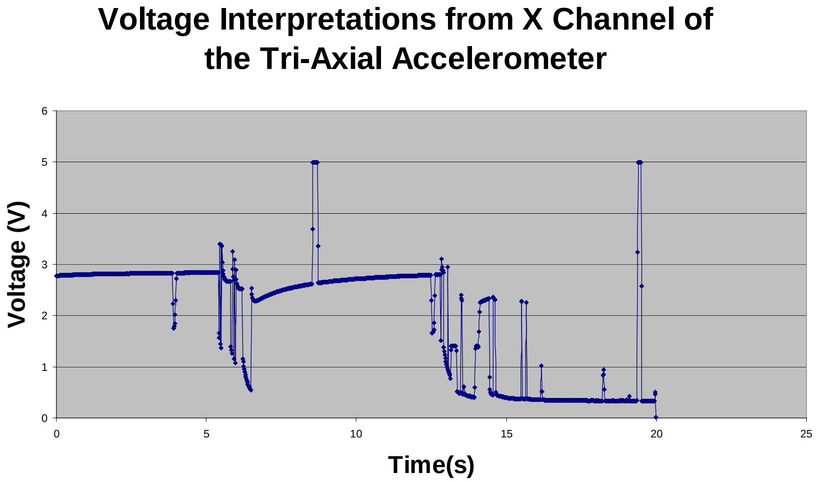

Figure 12: Preliminary data showing accelerometer responses

11. Future Work

Once the data logger arrives, the circuit design can be customized to the data logger's specifications. This entails tailoring the output signals from the pre-amps so that the data logger can accurately interpret the signals. Because the data logger uses LEMO connectors, the accelerometer must be fitted with male LEMO connectors so that it can transmit signals to the logger. Once the data logger and the tri-axial accelerometer are fully compatible, more extensive testing is necessary on human subjects. This means that the logger-sensor system must be reduced to a more manageable and compact size, so that it does not hinder the gait of the patient or cause discomfort. Finally, testing human subjects will show if reproducible data can be collected.

***** END OF REPORT *****

APPENDIX I: PRODUCT DESIGN SPECIFICATIONS

Project Title:

Portable instrumentation to detect gait instabilities

Statement of Purpose and Function:

The project seeks to measure various spatio-temporal parameters suitable for accurately detecting gait instability in elderly individuals. Two important results from recent studies are crucial: trunk acceleration and stride/step parameters. Trunk acceleration has been proven to be accurate in the detection of imbalance normal walking habits[12, 13], while stride/step length and duration were found to positively correlate with the risk of falling[14,15]. Focusing on trunk acceleration, an instrumentation depending on solely three-dimensional accelerometry is to be designed. The device must be interfaced to a data logger that is user-friendly and suitable to be worn over clothing to ensure accurate and precise data collection.

Client Requirements:

- light weight, preferably below 500g
- reproducible
- durable over multiple use
- remote recording for at least 2 minutes
- placement of tri-axial accelerometer on second sacral (S2) vertebra
- sampling rate of 60 Hz
- minimum resolution of ±10g
- data processing at hardware level
- adaptable for clinical and home settings
- no movement constraints

Design Requirements:

1. Physical and Operational Characteristics:
    a. **Performance Requirements**: This device needs to sustain multiple uses and multiple patient models of varying body types. One tri-axial accelerometer must be placed at the S2 level. The attachment of this device must be adaptable to multiple patient body types.
    b. **Safety**: This device must be user compatible and have no loose wires, radiation, or sharp edges.
    c. **Accuracy & Reliability**: A sampling rate of 60 Hz minimum must be maintained.
    d. **Life in Service**: Recording time must be at least 2 minutes. The device must also sustain multiple uses (as long as possible with changeable battery lifetimes). In the future, the device may have to maintain optimal performance over long periods of time under home settings.

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[12] "Assessment of Spatio-Temporal Gait Parameters from Trunk Accelerations during Human Walking" published by Zijlstra W and Hof Al, on October 18, 2003

[13] "Detecting Balance Deficits in Frequent Fallers Using Clinical and Quantitative Evaluation Tools" published by Chiung-Yu Cho and Gary Kamen, in "JAGS" Volume 46, Number 4, April 1998

[14] "Gait Variability: Methods, Modeling and Meaning" published by Jeffrey M Hausdorff, on July 20, 2005

[15] "Footswitch System for Measurement of the Temporal Parameters of Gait" published by Jeffrey M Hausdorff, Zvi Ladin and Jeanne Y Wei, in "J Biomechanics" Volume 28, Number 3, 1995

e. **Shelf Life**: Normal AA alkaline batteries to be used as power source for data logger, with a shelf life of at least 10 years.

f. **Operating Environment**: Room temperature (25°C), low humidity, at clinical or home setting.

g. **Ergonomics**: Interaction with elderly people must be considered. This device must also cling to the clothing of the patient, and must withstand the walking process of 2 minutes and the jostling that is associated with such motion.

h. **Size**: This device must be as small as possible to ensure minimal interference with standard walking motion.

i. **Weight**: This device must be lightweight, preferably below 500g, as it has to easily be carried to assess normal walking conditions.

j. **Materials**: Heavy materials should not be used. Some possible materials include LEMO wire connectors, copper wires, breadboards, attaching belt, adhesives.

k. **Aesthetics, Appearance & Finish**: Appearance should exhibit smooth surface and edges. Ideally, it should be sleek and discrete while patient is using it.

2. Production Characteristics:

   a. **Quantity**: One unit will be made as a prototype. It must be easily reproducible so contact with the manufacturer must be maintained.

   b. **Target Product Cost**: $5000 for the initial customization and purchase of the data logger, and an additional $1000 for other miscellaneous materials.

3. Miscellaneous:

   a. **Standards and Specifications**: International and/or national FDA standards must be abided by for patient safety and patent purposes.

   b. **Customer**: Specific information on customer likes, dislikes, preferences, and prejudices should be understood and written down.

   c. **Patient-related Concerns**: The device should adapt to any physical disabilities which the patient might have, and not cause any discomfort while it is in use.

   d. **Competition**: Equivalent devices utilizing accelerometers are available with prices ranging from $20 to $5000.

APPENDIX II: DATA LOGGER CONNECTORS

Data Logger – Analogue Input Pinouts

Transducers can be connected directly to the DataLogger or via 'Y Connectors'. With direct connection, the transducer will be assigned to channels 1-4 depending on the socket you choose. Connection via the 'Y Connectors' allows access to the entire channel range (channels 1-8). Obviously, you need only use the 'Y Connectors' when using more than 4 channels simultaneously. Alternatively, for bespoke transducers you could pair transducers into a single plug, utilising both channels directly without need for 'Y Connectors'.

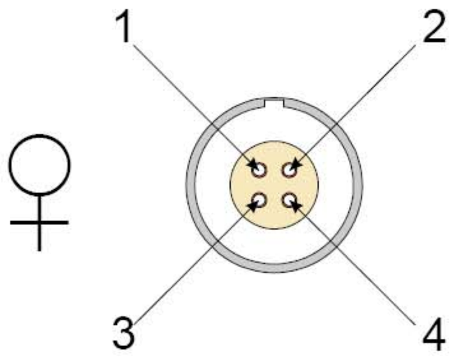
Please refer to the appropriate section of this documentation for the method of connection you intend to use.

Direct Connection Pinouts

The DataLogger DL8 utilises 4 four pin LEMO input sockets, each providing 2 single ended analogue signal inputs together with a common supply and ground.

The first socket provides inputs for channels 1 and 5
The second socket provides inputs for channels 2 and 6
The third socket provides inputs for channels 3 and 7
The fourth socket provides inputs for channels 4 and 8

DL8 – Analogue Input Socket



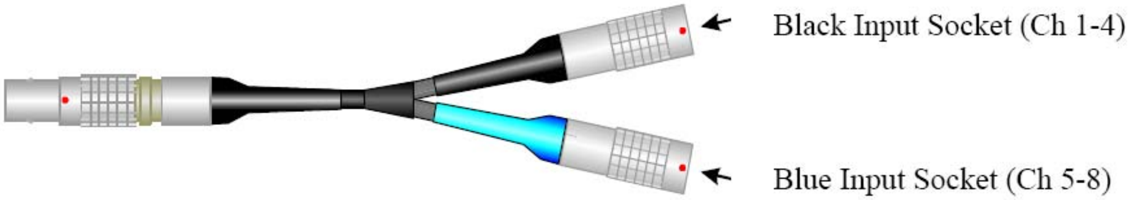
DataLogger DL8
Direct Connection Pinouts

Recommended Wire Colour	Pin	Description
Yellow	1	Signal 5,6,7,8
Green	2	Signal 1,2,3,4
Blue	3	GND
Red	4	+5V Power

Supply: Nominal 50mA at 5V per channel pair maximum (use absolute minimum required to conserve limited battery capacity)
Signal: Single-ended 0 to 5V. Exceeding this range may damage the DataLogger.
Plugs: The corresponding plug is a male LEMO plug. Part code: FGG 00 304 GLAD35Z.
http://www.lemo.com/display_product_detail.do?partNum=FGG00304CLAD35Z
Note: The last four figures of this code vary depending upon your cable thickness. We also recommend that you order an appropriate strain relief with the plug.

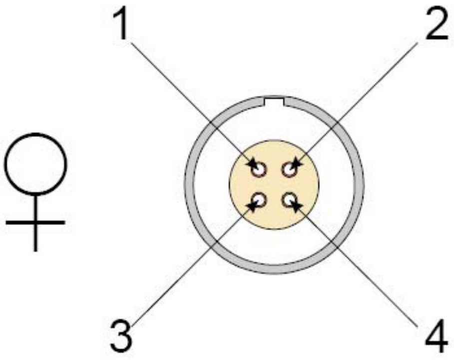
'Y Connector' Pinouts

Special 'Y Connectors' can be used with the DataLogger. These allow access to the entire channel range by effectively splitting each dual channel input socket into two separate single channel input sockets. Obviously, you need only use the 'Y Connectors' when using more than 4 channels simultaneously.



The black input socket of the Y-Connector is connected to the lower channel (Ch 1-4), whilst the blue input socket is connected to the upper channel (Ch 5-8). The pinouts of both the black and blue input sockets are identical.

DL8 – Analogue Y-Connector Input Socket



DataLogger DL8 Y-Connector Pinouts		
Recommended Wire Colour	**Pin**	**Description**
Yellow	1	Not Used
Green	2	Signal
Blue	3	GND
Red	4	+5V Power

Supply: Nominal 50mA at 5V per channel pair maximum (use absolute minimum required to conserve limited battery capacity)

Signal: Single-ended 0 to 5V. Exceeding this range may damage the DataLogger.

Plugs: The corresponding plug is a male LEMO plug. Part code: FGG 00 304 GLAD35Z.
http://www.lemo.com/display_product_detail.do?partNum=FGG00304CLAD35Z
Note: The last four figures of this code vary depending upon your cable thickness.
We also recommend that you order an appropriate strain relief with the plug.

APPENDIX III: COST BREAKDOWN

S/N	ITEM	QUANTITY	TOTAL COST (USD)
1	2-inch elastic belt	1	$3.78
2	2-inch coarse material	1	$1.69
3	Freescale KIT3109MMA7261QE evaluation board with postage (Distributor: DigiKey)	1	$50.02
4	Parallax dual op-amps	10	$5.10
5	Attachment clips	2	$1.98
6	Utility suspender	1	$17.99
7	Belt clip	1	$9.99
8	Package of battery clips and alligator clips	1	$5.68
9	Circuit components (breadboard, braided wires, 9-V batteries, Zener diode, variable resistors)	1	$17.36
		TOTAL:	**$113.59**

APPENDIX IV: WORKING HOURS OF TEAM MEMBERS

WEEK	ANN	KARISSA	TIM	KELVIN
1	3.50	3.00	1.00	2.50
2	3.00	3.25	4.00	8.50
3	6.50	5.75	7.00	6.00
4	3.00	3.50	7.00	2.50
5	6.00	5.00	4.00	4.50
6	7.00	7.00	5.00	8.50
7	7.00	6.50	4.00	3.50
8	4.50	4.50	3.50	5.00
9	3.00	2.25	3.00	2.00
10	10.00	6.25	8.00	7.00
11	8.00	5.50	5.00	4.00
12	5.50	5.50	5.00	6.50
13	19.00	18.00	15.50	15.50
TOTAL:	**86.00**	**76.00**	**72.00**	**76.00**