Alternative Design 3 Report

Biomechanics Gait Analysis Lab

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Team 3

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1. Alternative Design Gait Analysis Lab 2

1.1 Introduction

The gait analysis laboratory design will incorporate a hands-on approach to gait analysis through the use of a pressure mat, digital cameras, National Instruments equipment, and an interactive National Instruments LabVIEW® software program. A drawing of the overall system design is shown in Fig. 1 and the laboratory set-up is shown in Fig. 2. The pressure mat will be designed with two thin layers of material with an array of pressure sensors that are imbedded between the material. Data acquisition will be accomplished using digital cameras, a pressure mat, and the National Instruments PXI-1031 and BNC-2120. The LabVIEW® program will be able to determine the acceleration, velocity, position, angles, and forces for one complete walking cycle.

Digital cameras will be used to record a full gait cycle, each providing 2-D data. External markers will be placed laterally on the hip, knee, and ankle of the right leg. In considering the use of multiple cameras, two cameras will provide the software with the data necessary to create 3-D analysis. The use of more than two cameras would aid in keeping the markers in view as they become obscured by arm swing or patient rotation, improving the tracking accuracy, but the markers could still be missed during parts of the gait cycle. Each camera records the gait cycle and the software determines the horizontal and vertical coordinates for each marker throughout the gait cycle, which is transformed into 3-D by the computer software. Tracking the markers provides the data needed to determine angles and distance over a gait cycle time period, which will further allow for determining velocity and acceleration. The images acquired will be received by the National Instruments PXI-1411 and sent to the LabVIEW® program.

The major advantage of a pressure mat is its portability. Pressure mats provide a plantar pressure picture, force and pressure measurements versus time, and gait lines. The pressure mat also allows for determining areas of high and low pressure, and the center of force and how it travels down the foot. As a person walks on the mat, the feet strike the sensors, which send signals to the computer. These signals will vary depending on the amount of force applied to each of the sensors. The sensors act as
variable resistors in a circuit with its resistance changing in inverse proportion to the applied force. In other words, as the force increases, the resistance decreases. These data are sent through the PXI-4220 for signal conditioning, then to the BNC-2120, followed by the PXI-6040E, located within the PXI-1031, and finally to the computer.

The LabVIEW® program, along with Vision Development Modules, will aggregate and synthesize the data received from the National Instruments PXI-1031 and display the angles, forces, and acceleration vs. time, velocity vs. time, and position vs. time graphs, as well as the average acceleration and velocity. This portion of the lab is unique in that, some components of this program will give the opportunity for students to build certain portions of the program, such as the force measurement function.

![Figure 1: Complete System Drawing](image)
Figure 2: Laboratory Layout
1.2 Subunits

1.2.1 Force Measuring Device – Pressure Mat

1.2.1.1 Background
For clinical gait analysis, measurements of plantar pressure provide an indication of both ankle and foot functioning during gait and other similar activities, since the ankle and foot provide: 1) the necessary support and 2) flexibility for weight bearing and weight shifting while performing these activities. Plantar pressure data has been recognized as an important element in the assessment of subjects with diabetes and peripheral neuropathy as well as in determining and managing the impairments associated with various musculoskeletal, integumentary, and neurological disorders. When evaluating patients, atypical amounts or patterns of loading may be reflective of a systemic pathology that acts as indicators or risk factors for further or worsening pathology. Also, plantar pressure measurement systems offer the clinician a high degree of portability, allowing operation among several clinical sites.

Pressure mats provide a quick and easy way of obtaining plantar pressure pictures as a subject walks across it during gait. Currently, there are two basic types of transducers used in a pressure mat system, compression transducers and force sensitive resistor (FSR) transducers. Since the area of the transducer is known, the applied force can be calculated by adding up the force computed from each active sensor at a given point in time. These systems are valuable because they provide an immediate method for determining the areas of high pressure on the plantar surface of the foot, which may have resulted from tissue breakdown.

1.2.1.2 Force Sensitive Resistors
For this design, we will use FSR transducers to construct the pressure mat. FSR transducers consist of two thin layers of flexible plastic which have electrically conductive electrodes deposited in varying patterns (Figure 1). In Figure 2 below, the inside surface of one sheet forms a row pattern, while the inner surface of the other employs a column pattern. The spacing between the rows and columns varies according to sensor application and can be as small as ~0.5 millimeters. Prior to assembly, a thin semi-conductive coating is applied as an intermediate
layer between the electrical contacts (rows and columns) and provides an electrical resistance change at each of the intersecting points. By measuring the changes in current flow at each intersection point, the applied force distribution pattern can be measured and displayed on a computer screen. The force measurements can be made either statically or dynamically and the information can be seen graphically in 2-D or 3-D displays. The 2-D and 3-D displays show the location and magnitude of the forces exerted on the surface of the sensor at each sensing location. Force and pressure changes can be observed, measured, recorded, and analyzed throughout the test, providing a powerful engineering tool.

**Figure 1:** Physical Structure of a Basic FSR

**Figure 2:** FSR Transducer Surface Structure
Over a wide range of forces, one can determine that the conductivity is approximately a linear function of force \( F \propto C, F \propto 1/R \). Figure 3 shows the resistance of the sensor as a function of force. Also, it is important to note the three regions of operation of the sensor. The first is the abrupt transition which occurs somewhere in the vicinity of 10 grams (g) of force, in this region the resistance changes very rapidly. The second region is above the first region where the force is directly proportional to \( 1/R \) until the third region where saturation is reached. When forces reach this magnitude, additional forces do not decrease the resistance substantially.

Figure 3: Resistance as a function of force for a typical force sensitive resistor

Figure 4 on the top of the next page shows a plot of conductance versus force for a typical FSR sensor. Notice that the x-axis is now a linear axis, and that above the break-point, conductance is approximately linear with force.
1.2.1.3 Pressure Mat
The pressure mat for this design will provide static and dynamic barefoot pressure and force measurements over several steps during gait. The mat dimensions for this design are 1468 mm x 442 mm x 5 mm (57.8 in x 17.4 in x 0.2 in). It is comprised of 25,056 sensing elements and it has a spatial resolution of 4 Sensels/cm$^2$. Some applications of the pressure mat include:

- Capture multiple foot strikes on walkway
- Quantify continuous gait patterns over many strides
- Identify pressure profile discrepancies between left and right feet
- Observe gait abnormalities
- Identify asymmetries during stance phase
- Assist in writing orthotic prescriptions
- Monitor improvements in balance & sway, strength & weight bearing
- Monitor degenerative foot disorders
- Assess high pressures and deviated Center of Force trajectories due to pronation, supination, or other foot and/or gait related disorders

Figure 4: Conductance as a function of force for a typical force sensitive resistor$^4$
The Schematics of the pressure mat for the gait analysis laboratory are shown below in Figures 5, 6, and 7.

**Figure 5:** Top View of Pressure Mat

**Figure 6:** Side View of Pressure Mat

**Figure 7:** Front View of Pressure Mat
For the pressure mat, an 8-bit electronics system is used to scan the intersecting points of the sensor’s rows and columns as well as to measure the resistance at each contact point. The points are read in the presence of multiple contacts, while simultaneously limiting the possible current flow through the device. Figure 8 below illustrates the sensing system where each contact location is represented by a variable resistor whose value is high when no force is applied to it. 

Figure 5: 8-Bit Electronics Sensing System Schematics
1.2.2 The Optical System

Two digital cameras, Sony Handycam DCR-TRV27 shown in Figs. 1-2, will be used in this design. The digital cameras are used to record the instantaneous position of each marker in order to analyze the movement of the body in a 3-D system.

![Sony Handycam DCR-TRV27](image)

**Figure 1:** Sony Handycam DCR-TRV27

The cameras provide the following performance abilities:

- An advanced hole accumulation diode imager with 690k pixels, which will provide highly detailed images with great clarity.
- MiniDV digital recording format that delivers 3 times the color bandwidth of VHS and lower signal-to-noise ratio compared to analog formats, which will provide stunning video performances comparable to DVD.
- A clear color view of video subjects, which makes spotting or following subjects easier.
- A high speed bi-directional digital video and audio communication between two compatible devices equipped with an IEEE-1394 interface, including camcorders, digital VTRs, capture cards, and PCs.
- Converts and records any analog NTSC video source to digital video via the analog inputs.
- A digital still memory mode captures high quality Megapixel still images at 1152 * 864 or 640 * 480 resolution directly to memory stick media.
- Playback zoom: during video playback, pause mode or while viewing still images stored on memory stick media, it can zoom up to 5x closer.
- An MPEG movie EX mode, which will allow the recording to be uninterrupted to the full capacity of the memory stick.
media. For example a 128MB memory stick will record up to 85 minutes of non-stop MPEG1 video.

- **10X Optical/120X Precision digital zoom**: the optical zoom brings the action close up from far away.
- **Precision digital zoom interpolation technology** means that extreme digital zooming is clearer, with less distortion than previous types of digital zoom.

![Figure 2: Sony Handycam DCR-TRV27](image1)

The cameras will be connected directly to the National Instruments PXI-1031, each to its own dedicated PXI-1411 card. The National Instruments PXI-1031 contains the National Instruments PXI-1411 data acquisition device that is responsible of transforming the digital input from the camera that will be sent to the computer to be analyzed using the National Instruments LabVIEW® program.

Three Styrofoam balls, shown in Fig. 3, will be used as motion markers. The markers are used so that the images from the cameras can be used to detect the motion of the different segments of the body, which can be tracked by the program. In capturing the 3-D coordinates, these markers will be placed on the ankle, knee, and the hip of each body segment.

![Figure 3: Styrofoam balls used as motion markers](image2)
The cameras will record a complete gait cycle of the subject, as depicted in Fig. 4. The gait cycle may also be referred to as a walking cycle. A complete gait cycle includes the heel-strike-to-heel-strike of a single leg, but also involves the person’s stance and swing phases for each leg. In the complete gait cycle, movements can be divided into the instances when a foot strikes the ground, also referred to as the stance phase and makes up about 62% of a gait cycle, and when the foot is not on the ground, also referred to as the swing phase and makes up the remaining portion of the gait cycle. The stance phase of a gait cycle can be separated into the initial foot strike (shown as HS for ‘heel strike’ in Fig. 4), the instance that the entire foot is on the ground (shown as MidStance in Fig. 4) and the instance where the phase ends (shown as TO for ‘toe off’ in Fig. 4). Figure 4 is further divided into ‘single support,’ which indicates that the body is supported by only one foot during this time interval, and ‘double support,’ which indicates that the body is supported by both feet. The green shaded areas indicate the left foot and the yellow shaded areas indicate the right foot.

Figure 4: Complete Gait Cycle
In order to achieve a high-quality recording that will lead to optimal results; the digital cameras will be spaced as shown in Fig. 5 (on the top of the next page), which is a snap shot of the laboratory set-up in section 1.1.

**Figure 5:** Camera Spacing Diagram
1.2.3 National Instrument Devices

Figure 1: National Instruments PXI-1031

The PXI-1031, as shown in Figs. 1-3, combines 4-slots PXI backplane with a structural design that gives it the ability to be used in a wide range of applications. The key features include the following:

- Accepts 3U PXI and Compact PCI (PICMG 2.0 R 3.0) modules
- 4-slot chassis with universal AC input, and automatic voltage/frequency ranging
- DC power input (PXI-1031DC only)
- On/Off (Standby) power switch on the front panel for easy access
- AUTO/HIGH temperature-controlled fan speed based on air-intake temperature to minimize audible noise
- Optional) Carrying handle for portability
- Rack mountable

Figure 2: National Instruments PXI-1031 Front View
Figures 2-3 show the rear and front view of the PXI-1031. As mentioned before, this device contains 4 different slots. One of these slots contains the NI-1411, shown in Fig. 4, which consists of a PXI plug-in image acquisition device that accepts digital video input from standard color or monochrome cameras. It also includes image acquisition driver software. The PXI-1411 Series includes features that improve overall image acquisition and image processing speed, using the onboard programmable ROI feature, only a portion of the image would be acquired. The National Instruments PXI-1411 can be used with several different software programs include LabVIEW®, Measurement Studio, and C/C++.
The National Instruments PXI-1411 will receive images from only one camera and send it to the computer. Since the PXI-1031 contains only one PXI-1411, and because two digital cameras will be used, a second PXI-1411 will need to be added to the PXI-1031 so the results from both cameras can be sent to the computer.

This National Instruments BNC-2120, shown in fig. 5, is generally used to connect analog input, analog output, digital I/O and counter/timer signal. The National Instruments BNC-2120 also provides a function generator, quadrature encoder, temperature reference, thermocouple connector, and LED so the functionality of the hardware can be tested. The pressure mat will be connected to the BNC-2120, as well as the National Instruments PXI-1031, so the data will be received from the pressure mat through the BNC-2120 to the PXI-6040E, fig. 6, in the PXI-1031, where the data will be read and converted to digital data that the computer will be able to read.

Figure 5: National Instruments BNC-2120
1.2.4 Computer Program

The LabVIEW® program used for this design will be able to receive the digital signal, or bytes of data, from the digital camera and the pressure mat. The products and specifications required to accomplish the necessary data acquisition to produce the desired results, are listed as follows in Fig. 1.

<table>
<thead>
<tr>
<th>Operating System</th>
<th>Windows XP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardware</td>
<td>Pentium(R)4 CPU 1700 MHz Celeron</td>
</tr>
<tr>
<td></td>
<td>Microsoft Internet Explorer 6.0</td>
</tr>
<tr>
<td></td>
<td>256 MB of RAM</td>
</tr>
<tr>
<td>Software Applications</td>
<td>National Instruments LabVIEW® 7.1</td>
</tr>
<tr>
<td></td>
<td>National Instruments Vision Development Module</td>
</tr>
<tr>
<td></td>
<td>- IMAQ Vision 8.0</td>
</tr>
<tr>
<td></td>
<td>- Vision Builder for Automated Inspection (AI)</td>
</tr>
</tbody>
</table>

**Figure 1:** Operating System, Hardware and Software Application Requirements
All software applications are produced by National Instruments and will be referred to by the application name, through the remainder of section 1.2.4.

1.2.4.1 Digital Image Acquisition and Displays
The digital data or bytes of data, from the cameras are received from the National Instruments PXI-1031 by the Vision Development Module, IMAQ software, serving as the interface path between the LabVIEW® program and the PXI-1411, to deal with any issues such as programming interrupts, and performs the functions that acquire and saves the images. IMAQ Vision performs functions such as image analysis, interpretation, manipulation, processing, storage and display. IMAQ Vision Builder for Automated Inspection has many abilities, which include setting up coordinate systems, performing pattern matching, geometric analysis, and measurements. Examples of the IMAQ Vision Builder for Automated Inspection are shown in Figs. 2-3. The program will be able to match a shape of a defined size, which will be based on the markers used, and follow the markers on the person recorded to measure the location change in the recorded frames. By determining the location changes in the frames, data will be acquired that is required for producing the position, velocity, acceleration, and angles over the recorded timeframe.

Figure 2: IMAQ Vision Builder for Automated Inspection
The Vision Builder for Automated Inspection generates LabVIEW® code that allows for custom and optimal inspection algorithms that, used in conjunction with the LabVIEW® software, will meet our application and display requirements.

1.2.4.2 Pressure Mat Signal Processing

The signals from the pressure mat will need to go through the National Instruments PXI-4220 and then, the BNC-2120 to the PXI-6040E to produce data that may be used by the LabVIEW® program. Once the signals from the pressure mat are received by the computer, the LabVIEW® program will translate this data into a displayable measurement in engineering units. An example of a displayable measurement is a graph, such as the graphs shown in Figs. 4-5.
**Figure 4:** Digital Waveform Graph (graphical indicator from LabVIEW® 7.1)

**Figure 5:** Waveform Graph (graphical indicator from LabVIEW® 7.1)
2. Realistic Constraints

Engineering standards are very important when designing a biomedical device. For this design project, we are using the International System of Units (SI units) in order to keep with engineering standards around the world. Also, we are utilizing basic static laws of applied loads, moments, and points of application in order to analyze the raw data that is output from the pressure mat.

Some economic considerations for this design project include the proposed budget (although not yet specified) and the longevity of the device itself. Although currently we do not have a limited budget, our design needs to be within a reasonable cost, ranging from approximately $450 to $1,500. The gait analysis laboratory that is being designed will need to be used in the University of Connecticut’s biomechanics laboratory which is presently offered in the Fall semesters. Therefore, our device should be able to last at least five years of operation.

A major environmental consideration for this design project is the weather conditions and temperature ranges in Connecticut. The gait analysis laboratory will need to be stored in a closet that may or may not have a good source of heat and will hence need to survive the relatively harsh temperatures of Connecticut winters.

Two very important ethical constraints for this design project come from the Code of Ethics for Engineers. The first ethical constraint is the statement “Strive to prevent a person from being placed at risk due to the use of technology”. This constraint demands that the gait analysis laboratory be set-up in such a way that will keep the subjects and testers’ safe at all times of operation and assembly. The second ethical constraint is the statement “Work toward the containment of costs by the better management and utilization of technology”. This constraint asks that we utilize existing materials that are on hand or that are cheaper than others on the market as well as to make things ourselves which is more cost-effective than purchasing from suppliers.
3. Safety Issues

Safety consideration is one of the most important issues in any project, especially when dealing with electricity. In general, any equipment or device uses electricity and when it is in contact with people, it must be electrically isolated from the power main or battery supply. Even if the instrument is not in direct contact with the person, it must be grounded.

In our design for the gait analysis lab, the students will only be in contact with the pressure mat which is electrically wired. Besides walking on the pressure mat, students will have to run the National Instruments PXI-1031 and BNC-2120 equipment. The safety of these devices was already taken into consideration by the company prior to distribution.

All of the wires that are connecting the pressure mat, National Instruments equipment, cameras, and the computer, will be placed in a cable tunnel or conduits, as shown in Fig. 1, so that wires are not hazardously placed in such a way that somebody may trip on them. This will also reduce the chances of somebody receiving an electrical shock. Also, the correct size electrical cables will be used to ensure the power voltage is not too high and cause the cables to heat up and potentially produce a fire.

Another safety issue to take into consideration is the material that will be used for the pressure mat and the connection circuitry of the force sensitive resistor sensors. The FSRs are connected through the mat which is made-up of safe/non-conducting material which ensures safety to the subject and prevents the electrical voltages and currents from entering the subject’s body.

By using conduits to arrange the wires and the right voltage source, the lab will be safe for students to use. Overall, our main safety concern in building the design is the electrical components that include cables, circuitry, and voltage source.
4. Impact of Engineering Solutions

Designing a gait analysis program can have many impacts that are global, societal, economic, and environmental. Learning about gait analysis and its applications will provide a better understanding of the impact of biomedical engineering solutions for students and, hopefully, the students will be able to discover some of the global, societal, economic, and environmental impacts in the gait analysis lab. Some of those impacts will be discussed next.

Globally, in researching applications of gait analysis, these types of programs were found in countries such as Australia, the United Kingdom, China, and all across the United States. The Hugh Williamson Gait Analysis Laboratory, as part of the Royal Children’s Hospital in Melbourne, Australia, uses their laboratory to perform research and to develop ways of providing useful information to surgeons and therapists, primarily for children with Cerebral Palsy and also Spina Bifida. The Derby Gait and Motion Laboratory, in the United Kingdom, evaluate adults and children with Cerebral Palsy, stroke, and amputated limbs. The Institute of Biomedical Engineering, Tsinghua University, in Beijing, China has been involved in the use of gait analysis for analyzing Cerebral Palsy. Clinical gait analysis is also used at the Gait Analysis Laboratory at the Connecticut Children's Medical Center.

The use of gait analysis to treat diseases and disabilities has a positive impact on society. By discovering ways to treat physical conditions, people with disabilities may be able to receive better medical treatment or therapy, and
assistive devices. These treatments could help patients become more productive and independent. Research and use of gait analysis for patients with Cerebral Palsy has been performed on a global scale, at all of the institutes mentioned previously. Cerebral Palsy is an incurable disorder that hinders the control of muscle movement and can affect the use of one or any combination of limbs. The lack of motor control makes walking very difficult, for which gait analysis could be a great tool in determining proper treatment, allowing patients to participate more easily in society.

The economic impact can affect consumers, both patients and providers. The cost of building a gait analysis laboratory is extremely expensive. The patients that use the facilities that use “state-of-the-art” equipment often have higher fees, which may exceed insurance coverage or may not be covered at all. The benefit to the patient, and the usefulness in determining proper treatment by the health professional, must outweigh the cost. The growing expectation for a quality life, demands tools to better serve the recovery or treatment process and gait analysis is one of those tools. A patient may require treatment in order to regain the ability to work, which could provide a better income than disability compensation, thereby improving the individual’s economic situation.

Environmentally, the impact can be found in the creation of materials and electronics that must eventually be thrown out. As materials and electronics age, they must be replaced to ensure operational safety and quality results. While some materials can be recycled, this is not true for all materials and, unless the user is environmentally conscious, all of the materials could conceivably be thrown away. Recycling is very expensive, but the cost to the environment may be irreversible and every effort should be made to recycle as much of the used materials as possible.

Depending on how one views the definition of ‘environment,’ the patient’s environment could be impacted as well. The environment in which the patient lives could improve and expand greatly. This may mean the patient becomes mobile, or more easily mobile, and is able to gain access to areas of their environment that were previously restricted by their condition. The recommended treatment from gait analysis may allow the patient to re-enter the workforce and regain involvement in the environment of society.
Designing a gait analysis program has already greatly impacted the world in a global, societal, economic, and environmental sense and shows how engineering solutions can make a positive difference in the world, if put to good use.

5. Life-Long Learning

In the Biomechanics gait analysis lab, we learned about gait analysis processes in general, including ‘what is gait analysis?’ and ‘what is it used for in the medical field?’ We also learned about the gait cycle and how it is divided into different parts. We have increased our understanding of this process and will highlight some of the knowledge gained with comparisons to what we had previously learned.

During the biomechanics lab, we built a simple LabVIEW® program to process the information recorded from the digital camera. In this design, by building the gait analysis program, we acquire more details and learn more about the different parts of the program and how each part functions and communicates to produce the desired, complex results.

By building the program, we will learn more modules in LabVIEW® and gain more in-depth knowledge of the data the program receives and how it is used. The difference between creating this program and the one used in the biomechanics class is that we are building the program and not simply using it. The students using the new design will be given portions of the program to get started and will be expected to build a portion of it. Due to time constraints, were students only have one lab section, building the entire program and finishing the entire lab would be impossible.

For the optical devices, we learned the differences between using one or two cameras, and which one is the better option. We have also learned how the cameras should be placed, to include how far apart the two cameras should be placed in order to give an accurate motion recording. Also getting to know the quality of the cameras and how the quality affects the results has been a learning experience.

Concerning the markers used in gait analysis lab, we have found that, in order to detect 3-D motion properly using
the cameras, three markers should be placed on each body segment instead of one, as was done in the previous Biomechanics gait analysis lab.

The PXI-1031 and BNC-2120 national instrument equipments are being used for the first time in this lab, meaning that we had no prior knowledge about these devices. After creating the first alternative design for the new lab, we have gained more knowledge about how these instruments functions to transform the data from the cameras and the pressure mat, so that the collected data can be analyzed.

Adding to all of this new information that we gain in designing the gait lab, we also learned about pressure mats and what kind of material is best to use, how many sensors are used, and how the sensors connect and send data through the system.
References for Section 1.2.1

1.  www.ptjournal.org/April00/public/ad040000399p

References for Section 1.2.2

2.  www.bjcraftsupplies.com

References for Section 1.2.3


References for Section 1.2.4