UNIVERSITY OF REYKJAVIK

HÖNNUN X

Project Lucy

Authors:
Aníta Björk Hlynsdóttir
Árni Þorvaldsson
Bjarni Kristjánsson
Björgvin Rúnar Þórhallsson
Bogi Brimir Árnason
Einar Bjarni Pedersen
Einar Snorrason
Hannes Rúnar Herbertsson
Kristján Oddsson
Magnús Freyr Smárason
Sæþór Ólafur Pétursson
Viktoria Alexeeva

If this was printed by the team:
- Check spelling!
- Check errors + missing graphics
- check citations ~~printed~~ not [?]
  (which were fixed in SVN)
  Make sure citation list is
  included (it is not)
- in text "Figure 1" to be consistent
- Use present/past tense!

Teachers:
Baldur Þorgilsson
JTF Joseph Timothy Foley

Turn on section numbering!
It is too easy to get lost.

May 18, 2012

Project description

This projects goal is to make a gait simulator, in cooperation with Össur hf., that can test lower body- prosthetics. The robot should be able to simulate a walking person, especially an amputee. The robot should be able to read data and simulate the gait cycle desired to test the product. Diversity in gait cycles makes it complicated to design a robot that can change it's walking behaviour. For example, a woman has broader hips and an obese person has ~~much more~~ a larger load applied to ~~the~~ each joints. The software also needs to be sufficiently modular to allow development with many possible configurations of hardware and sensors.

The need for this robot originates from the difficulty of locating good product testers, few amputees are willing to travel and walk on a treadmill for hours. (there is more....)

There is an aggressive schedule for making this robot a reality. The goal is to have a running prototype with two motors, for hip and knee, moving in the sagittal plane before the 3 week period (23.04.2012) begins. In the 3 week period the plan is to build the next prototype which will have a mechanically designed hip and pelvis with added degrees of freedom.

(need to explain)

Clear and measur goals

TOC?

Background?

Citations?

Initial research

link/citations

At the beginning of the course, the group was split into sub-groups for each joint to do initial research on required movements, torques and design elements. The groups had internet meetings with specialists from MIT Biomimetic robotics lab and Ekso Bionics, which gave the group an idea how to approach the problem at hand. Pétur Sigurðsson in the department of sport science also gave valuable input on the gait cycle.

missing general requirement specification

Pelvis

(exactly - how big?, how heavy?, how strong/fast?)

The pelvis group had the objective to research and design a mechanical pelvis that cooperates with the hip, knee and ankle.

Requirements and ideas

- The width of the pelvis has to be adjustable for different sizes. For example switch between the size of a female pelvis and a male pelvis. (dimensions?)
- The required movements are lateral tilt and side rotation. (diagram?)
- Implementing forward and backwards motion is not feasible for the given time frame.

Our idea of a solution is:

- To use a ball joint in the middle of the pelvis.
- Use wires to control all needed movements (lateral tilt and side rotation).
- To find the relative positions of the rotational axes for the pelvis and hip.
- The initial mechanism to control the width of the pelvis should ~~at the early stage of development~~ be manual, easily ~~augmented~~ modified to be controlled electronically.
- The tolerances for the tracks and adjustments need to be further researched. ??
- Needs to be able to handle the forces that act upon the pelvic region and the ones that translate into the support mechanism.
- The support mechanism needs to be relatively light and portable. It should be easily set up as well. The ~~stability~~ rigidity of it is very important to minimize the error, especially when the foot pushes down.
- Requirements for the motor: Small Small working angle, high torque, high speed, accurate and high repeatability. (estimated quantities?)
- Sketches are in Appendix - C.

Hip

The hip group had the objective to research and design a hip joint that could get the degrees of freedom needed to approximate human gait.

Research

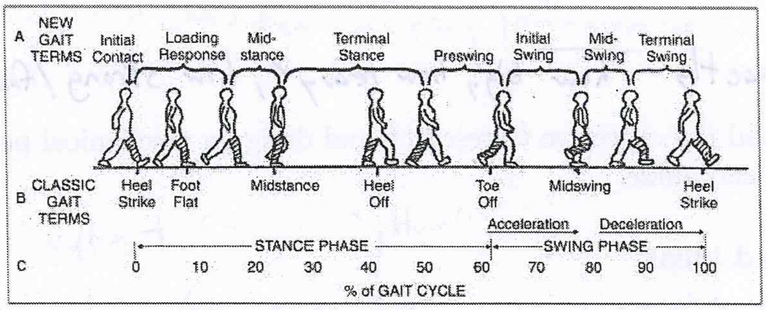


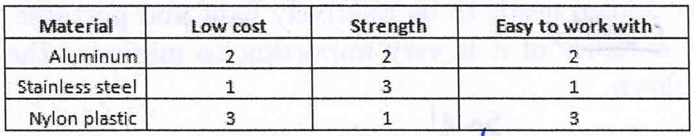
Figure 1: Diagram of a human gait cycle and classic gait terms. [?]

- Initial contact - Flexion (30 degree thigh forward).
- Loading response - Function (maintain hip stability).
- Mid stance - Extension (30 degree flexion to full extension).
- Terminal stance - Hyperextension (3 degrees).
- Pre-swing - Flexion.

Need a sketch to clarify more than

Requirements and ideas

- The hip joint has three degrees of freedom, therefore it needs three motors to move in three different planes.
- Has to be strong enough to handle the load of 120kg.



Material	Low cost	Strength	Easy to work with
Aluminum	2	2	2
Stainless steel	1	3	1
Nylon plastic	3	1	3

Figure 2: material of choice

ratings for hip.

By comparing the materials together where 1 is the worst and 3 the best. Cost has lower significance than strength and workability and that is why aluminum is the best choice for building the hip joint. Stainless steel is also a possibility but it is more expensive and harder to work with.

(Ratings good, but need explanation / quantities or it does not make any sense.)

In figure 3 there are three motors ~~that each~~ which each control~~s~~ one degree of freedom. The universal joint, idea 1 from figure 3 has a flaw where there is not enough space for the motors and therefore does not fulfill the projects requirements. Figure 4 shows the idea for the Agile eye [?]. The concept for the Agile eye is better explained in the Agile eye section. The Idea shown in figure 5 also requires three motors, one for rotation, one for movement front and back and one for side to side. The one for the rotation is intended to be on the pipe close to the joint. The other two are intended to be normal spur gears. (Need annotation on the figures to explain movement)

how?
how is that different from fig 3?

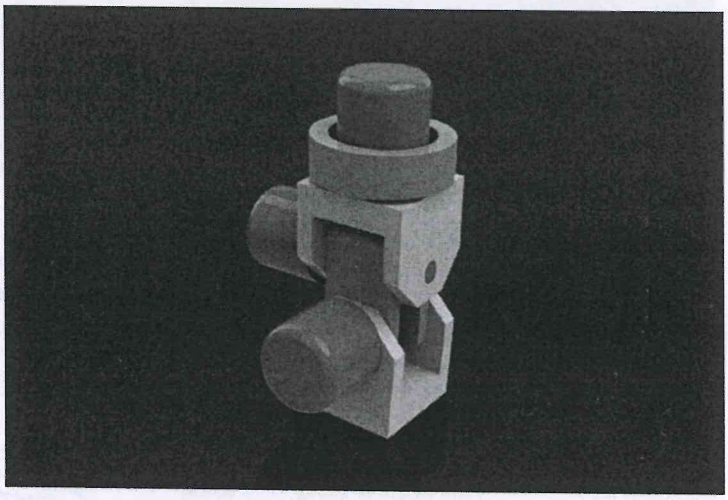


Figure 3: ~~Idea~~ 1, universal joint concept for hip

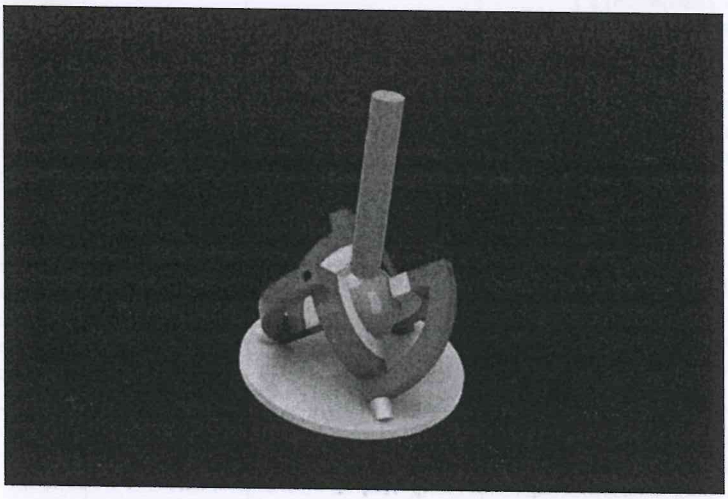
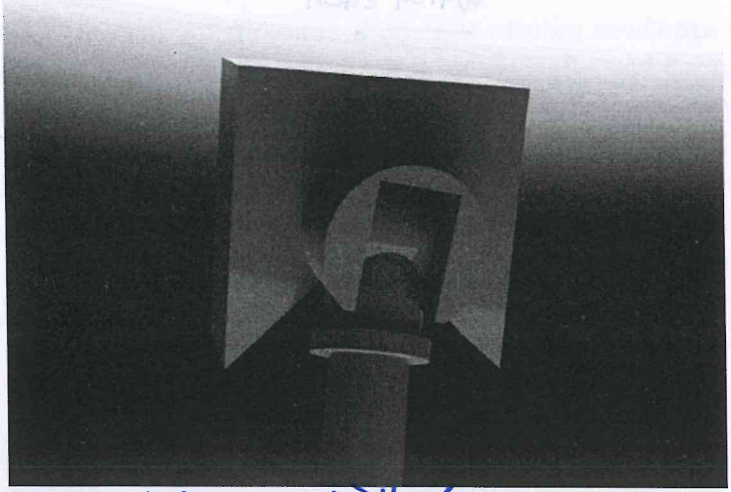


Figure 4: ~~Idea 2~~, the Agile eye concept for hip

Confusing



Re-read the FRDPRC Chapter 2 in Fundamentals of Design by Slocum

Figure 5: Idea 3

"What" "How" (these are the same!)

what would break? identify most likely.

	Functional Requirements	Design Parameters	Risk	Counter-measures
1	Needs to be able to carry weight of 120 kg.	The load bearing capacity needs to be able to carry the weight of 120 kg.	Something could break or go wrong	Static analysis, ~~good choice of materials and good design~~
2	**Needs to be able to move;** **2.1** Flexion (60° thigh forward). Extension (from 60° flexion to full extension) **2.2** Abduction (5°) adduction (30°) **2.3** Rotation (90°)	3 motors or 2 motors + dual air jacks	Lack of velocity or torque	carefully study the torque required for the motors and choose motors accordingly
3	**Power supply for motors:** **3.1** Electricity **3.2** Air	Cables (how long?)	Not flexible enough to with stand the movement	Make sure cables have enough slack to withstand the movement of the leg
4	(This is DP) Size of the hip joint should be no larger than a sphere diameter of 200 mm	~~Geometric design~~	Can't withstand the Weight	Do good static analysis on the design to make sure it does not break
5	**5.1** The swing motion for the gait cycle is 0.4 sec. **5.2** The stance motion for the gait cycle is 0.6 sec.	Max? Min?		

(this is always assumed.)

good!

FR?

Figure 6: The FRDPARRC for the hip joint.

period? (or some other word)

The swing motion for the gait cycle ~~is~~ lasts 0.4 sec.
(is it ok to be above or below?)

(Countermeasures are about how to deal with when the risk happens, not just how to prevent it.

Knee

The knee group had the objective to research and design a knee joint that could simulate the movement of a human knee.

Research

- Stance phase - Flexion, Extension, Flexion.
- Swing phase - Extension.
- Initial contact - Extension (-2 to 5 degree flexion).

Need sketch of these

Good ~~go~~ quantitative start

- Loading response - The knee can be hyperextended to -2 degrees. This means that the knee has to have a convertible knee joint which can vary from 4 to -2 degrees.
- Mid stance - 5 degree increased flexion, then extends to 12 degree flexion, to keep stability.
- Terminal stance - Completion of extension, then flexion starts again at the end.
- Pre-swing - Flexion(up to 40 degree) to prepare for the swing.

Citations?

Requirements and ideas

Requirements? moment? size? range of movement? Accuracy?

- A simple motorized hinge joint.
- Four bar linkage mechanism.
- Hall effect sensors position sensor.

Figures?

yes, next step is needed also.

- Accelerometers and angular position sensors to determine position and movement.

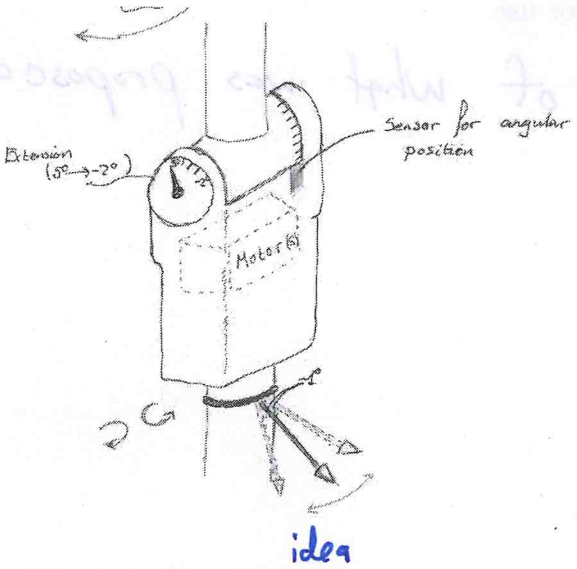


Figure 7: The first ~~Idea~~ idea for the knee

This design and the construction of this joint was halted due to Össur hf. providing a complete Power Knee for use. Still need to include what you learned!

Ankle

Research

- Initial contact - Neutral (90 degree), slight dorsiflexion. Preparing for response.
- Loading response - Plantar flexion (10 degrees). Function: Shock response.
- Mid stance - Dorsiflexion (from 8 degrees plantarflex to 5 degrees dorsiflex). Function: Allow forward progression of tibia.
- Terminal stance - Heel rise (doriflexion up to 10 degrees)
- Pre-swing - Plantar-flexion (20 degrees). Function: Initiate knee flexion for swing. Slight dorsiflexion in the ankle to prepare for ground contact.

Requirements and ideas

Requirements?
L moment?
L range of movement?
L size?
L accuracy?

- Electrical motor for flexion.
- Angular position sensor.
- Pressure sensor to determine when ground contact is established.
- Flexible sole
- Double hinge joint to replicate human ankle.
- Springs or elastic for shock absorption
- Motorized for natural push off and natural ankle flexion.

This design and the construction of this joint was halted due to Össur hf. providing a complete Proprio ankle for use.

Sketches of what was proposed?

Gait analysis

A ~~group~~ team went to Össur hf and recorded data in their gait-lab. They recorded approximately 60 seconds worth of angular positions, accelerations and velocities at a sampling rate of 120 Hz. When the data was analysed it was verified that the data points would serve well as input data for our robot. what kind of analysis? Why is it good input data?

Accuracy of recording

resolution?

[can't figure out repeatability]

This should be referred to in the text.

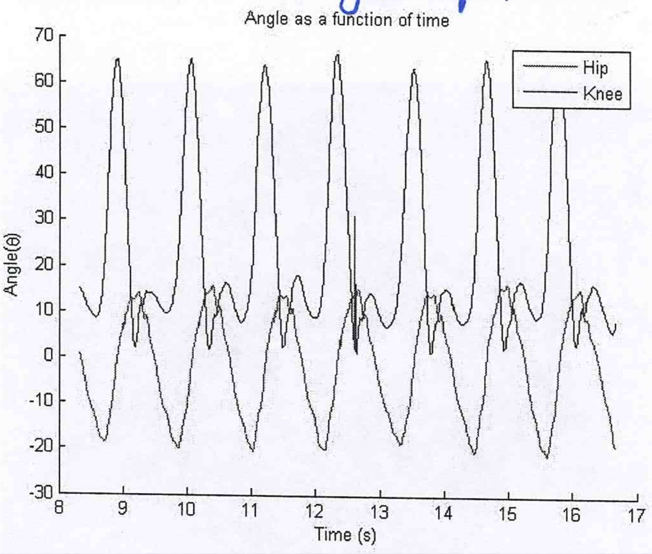


Figure 8: 9 second part of the recorded gait data, i.e. flexion and extension of the right hip and knee in the sagittal plane. Positive and negative values indicate extension and flexion respectively.

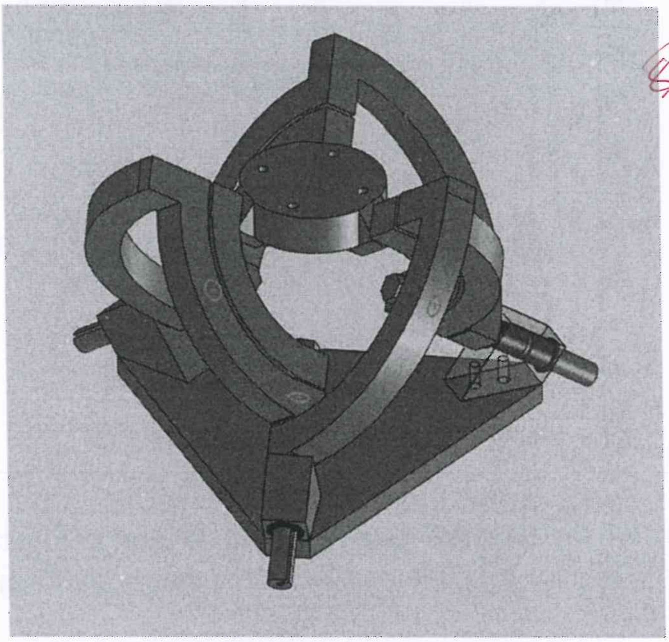
Financial research

Initial research was made to estimate funding needed for the project. It was done with a three point analysis with 95% confidence level, ~~tables were made in Excel~~. Estimated cost was about 1.3 million ISK. Risk analyses were made and the pessimistic scenario could see the cost rise to two million. While the optimistic case estimated the cost to be around 1.2 million ISK. In the worst case scenario the cost could rise above two million ISK. This was presented to Össur hf, the conclusion of that meeting was that ~~they~~ össur would ~~rather~~ provide the project with the material and components needed rather then giving the project a budget.
We ~~To~~ ~~have a~~ needed an overview of all material received from Össur hf, Reykjavík University and items brought by students. ~~Therefore~~ An inventory list was created in Google docs~~. All~~ and these tables are in the Appendix B finances. for the status as of May 10, 2012.

? bought

Agile eye

~~The idea with the~~ The Agile eye ~~is to use it to~~ seemed promising for implement ing the hip movement s. The idea for using this mechanism came from our initial research, where a similar device had been used in Lisa the robot which was built in Hannover University [?]. The agile eye has movement with three rotational degrees of freedom which we need for the hip joint. The design of the eye can be seen in figure 9. This design was sent to Össur where a prototype was printed with their 3D printer, it can be seen in figure 10.



~~Size?~~ Size? Material?

Figure 9: Drawing of the Agile eye

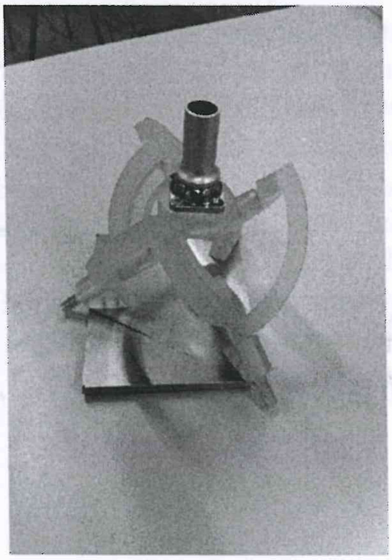


Figure 10: Printed prototype of the Agile eye

Kinematics (of Agile eye)

A solution for the direct kinematic problem of a spherical three-degree of freedom manipulators like the Agile eye leads to a polynomial of degree 8 which results in maximum 8 solutions. A ~~simple~~ closed form solution for these manipulators can be found in [?]. This closed form solution can be used for the Agile eye, but has to be altered so that the data obtained from the gait analysis can be used directly to solve for the movement of the actuators. In [?], the movement of the actuators is solved using the relationship between the actuator angles and the Euler angles from the reference frame of the platform and the frame of the rotated platform. The hip data acquired from the gait analysis represents the movement with Euler angles involving successive rotations about the Z, Y and X axis. To use the solution in [?] the data needs to be converted to Euler angles with rotation about the reference frame of the platform, that is done using Rodrigues‘ rotation formula. (citation!)

$$\vec{v}_{\text{rot}} = \vec{v}\cos\theta(\vec{k}\times\vec{v})\sin\theta\vec{k}(\vec{k}\cdot\vec{v})(1-\cos\theta)$$

When this transformation has been done the actuator angles can be found according to [?]. The

(→ What are is the experiment verification data? Examples of input and output?)

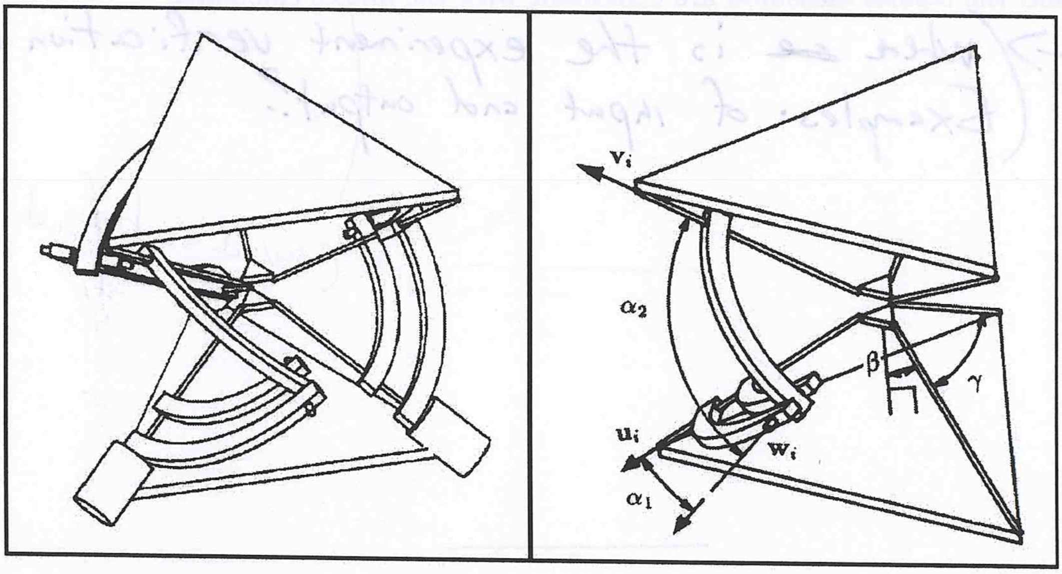


Figure 11: General architecture of a spherical three-degree of freedom parallel manipulator with revolute actuators [?]

u_i ,i=1,2,3 are orthonormal unit vectors that describe a frame on the base along the actuators and have the vectors

$$u_1 = [100]^T \ , \ u_2 = [001]^T \ , \ u_3 = [010]^T$$

According to figure 11 the vectors on the platform can be described as

$$v_{10} = [0-10]^T \ , \ v_{20} = [-100]^T \ , v_{30} = [00-1]^T.$$

By rotating the u_i vectors using rotation matrices X,Y,Z describing the data plane can be obtained. Using Rodrigues' rotation formula the rotation of the reference frame v_{i0} can be calculated from rotation of X,Y,Z. The rotated reference frame is noted as v_i ,i=1,2,3. According to figure 11 the link angle α_1 is equal to $\pi/2$ and intermediate joints can be described as.

$$\vec{w}_1 = \begin{pmatrix} 0 \\ -sin\theta_1 \\ cost\theta_1 \end{pmatrix} \vec{w}_2 = \begin{pmatrix} -sin\theta_2 \\ cos\theta_2 \\ 0 \end{pmatrix} \vec{w}_3 = \begin{pmatrix} cos\theta_3 \\ 0 \\ -sin\theta_3 \end{pmatrix}$$

Nice.

since link angle α_2 is also equal to $\pi/2$ the dot product of w_i and v_i is equal to zero. From that condition the actuator angles can be calculated.

$$tan\theta_1 = (v_{1z}/v_{1y})\ tan\theta_2 = (v_{2y}/v_{2x})\ tan\theta_3 = (v_{3x}/v_{3z})$$

Testing the solution

what is it called?
where is it in subversion?

~~Testing the calculations~~ A Matlab function for the kinematic solution shown above was constructed, the functions input arguments are the Euler angles that the data contains and the output is the actuator angles, the function can be seen in [appendix a]. To test if the calculations were right a set of angles representing the data was put into the function. The actuator angles were then manually fixed according to the output of the function. To check if the resulting Euler angles for rotations about the original X, Y, Z axis match with the input set, These angles were measured using an accelerometer placed on the platform, and positioned so it could measure the rotation of X and Y. A circle marked with degrees was placed on the bottom plate of the device and used to measure the rotation around Z. This was tested for a few sets of angles and the results measured are consistent with the angles calculated.

(where ~~are~~ is the experiment verification data? Examples of input and output?)

could not find it

(Need to define some where)

Prototype 1.0

This design is a full size leg with an active knee and hip movement in sagittal plane. A complete Power knee from Össur hf. is used for the knee and an additional ~~a~~ motor from a Power knee is used for the hip.

Power knee ® or ™

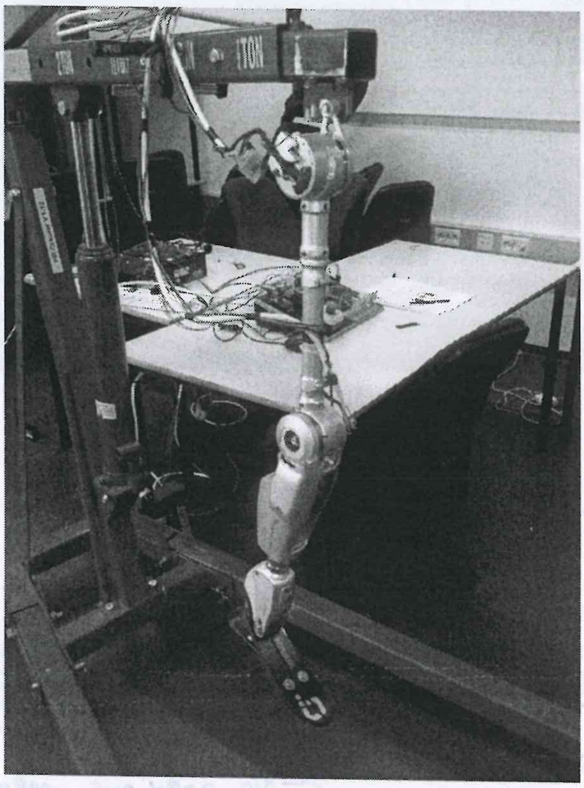


Figure 12: Prototype with knee and hip movement in the sagittal plane.

Electronics

The Power knee motor is a three phase brushless DC motor (BLDC). It has a gearbox with ratio 80:1 and a hall effect angle sensor. The motor controllers(MC) are from Elmo motion control and were purchased from Össur hf. The motors have three internal ~~built in~~ Hall effect sensors for the MC to determine the current in the coils. Necessary wiring for the MC are:

Type nr ?

- Hall effect sensors from the motor to MC.
- Power supply to MC (50 VDC)
- Three phases from the motor to MC
- Enable voltage from micro controller to MC (4 V)
- Signal from micro controller to MC (-3,75 V to +3,75 V)

Wiring diagram?

Manufacturer + ~~Type~~ Model?

The motors and the MC are rated 50 VDC @ 25 A continuous ~~continues~~ maximum. Our power supplies only support 50 VDC at 3 A. We got one power supply from Össur hf. with one in reserve. ~~and there is another one available for us~~. They can support 47 VDC @ 13 A. A specialist from Össur hf. said that we could drive 2 or probably 3 motors on these ~~their~~ power supplys. ~~That means we should not have any issues with power supplies.~~ We will monitor the performance to verify this.

Need to explain the Arduino earlier!

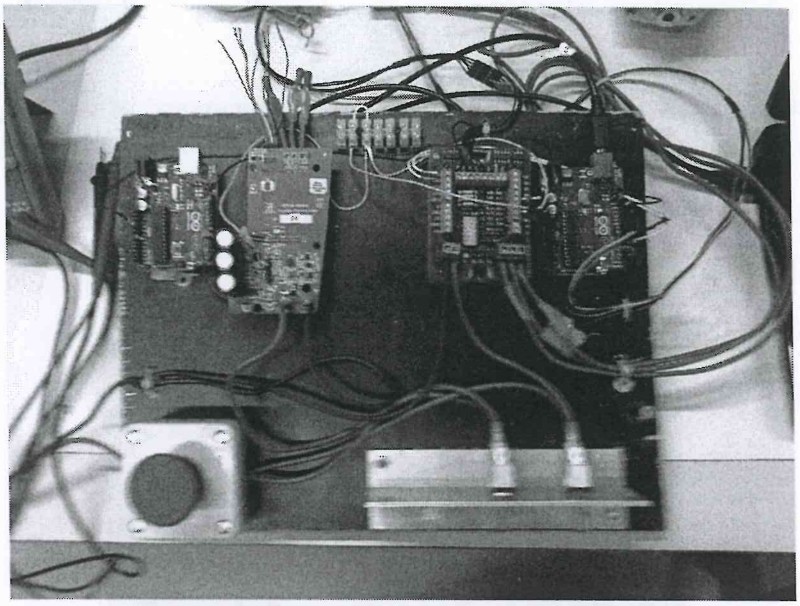


Figure 13: Control board for two motors

Software

typeno

reference? URL. Also where is the source code in SVN?

I don't understand the problem

- Angle sensor: The sensor is a magnetic rotary encoder and uses synchronous serial interface (SSI). We found a code on the Internet that reads the sensor but the plan is to make it more efficient. There was an issue with the sensor since it gave the angle periodically which was very bad for control. To fix that we made another variable that has continuous scale but uses the periodic angle to update.

No previous mention of Arduino.

What did you do?

- Generating a signal to the MC: The signal to the MC has to vary from -3,75 V forward to +3,75 V backward rotation. Arduino can neither generate a negative voltage or analog voltage. This was solved by using two digital ports that could generate Pulse-with modulation (PWM) signal. By default the frequency of PWM is 1 kHz. By changing the clock speed in Arduino the frequency is increased to 62,5 kHz. This is to eliminate the low pass filter that is necessary to smooth out the signal if the frequency is ~~too low~~ lower. By using two digital ports and always pull one to 0 V while generating PWM on the other its no problem reversing them and generating relative negative voltage .

mention bandwidth of controller

- Communication of Data: In order to be able to set two or more Arduinos to share information with each other ~~we are thinking of using~~ considered I2C, a serial bus interface. In this configuration one Arduino will be the master and the rest of Arduinos will be his slaves. This simplifies the communication between PC and Arduinos since instead of communication with all of them, we only need to communicate with one Master Arduino. The Master Arduino, is programmed to request, and then read, 6 bytes of data sent from the uniquely addressed Slave Arduinos. However this configuration has a possible flaw: The Arduinos are connected together in series and if one Arduino gets high voltage trough it, all the Arduinos will be affected. We are considering optical isolators to prevent this from happening.

↳ the data flows the other directi ?

full citation URL, not just arduino.cc

- Regulation: We are using the PID library from www.arduino.cc to regulate the angle. The idea is that the regulation system on each joint is independent. The only input variable is the setpoint. By using the data from the gait analysis to update the setpoint at the right rate we should by able to simulate the movements.

PID constants?

Mechanical

The decision was made to use the RU crane which was already in the energy lab ~~to begin with~~. The bracket for the crane is used to hold up the leg. Further in the project we ~~will~~ determine d what kind of bracket ~~is~~ was needed to hold the leg or if the leg will be attached to a wall. The crane that we are ~~going to~~ use d for the prototype 1.0 with the two power knee motors, 60x60mm square tube and a ~~plat~~ plate 60x50x8 with a hole to bolt the power knee motor.

CAD drawing?

Figure 14: Bracket for the crane

I'm missing the voting of the way to go (a class when Joe was traveling) no figures of a pelvis of any kind so far ??

Final design

Pelvis design

Össur hf requested that the pelvis would be more human-like. So we had to re-evaluate our pelvis design. Össur hf. offered us their facilities to make a carbon fiber pelvis, which changed a lot for us in options in our design. The decision was made to make a carbon fiber pelvis in „heart shape“ form which would replicate a real pelvis. There were a few ideas for the new shape

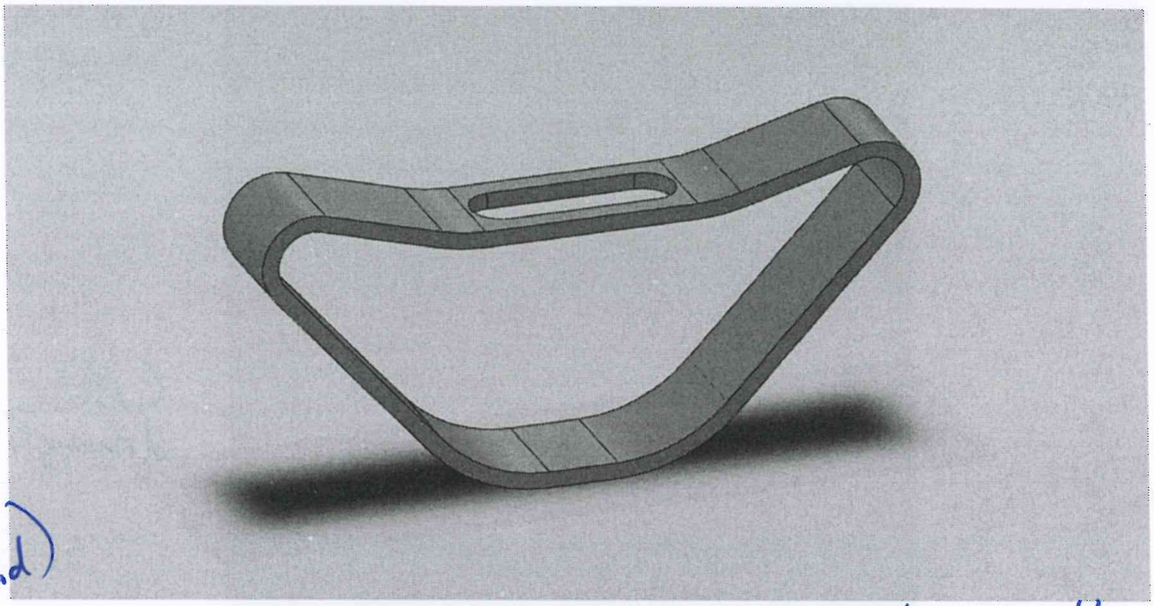


Figure 15: The final pelvis design

How did this affect the requirements? FR-DP

(I don't understand)

of the carbon fiber pelvis. Some of our pelvis designs were not suited for the building process so to solve the problem the edges were made more curvy so that the load would distribute equally over the carbon. The harness which connects the pelvis to the axle was based on a flat surface at the bottom. There was also a few ideas how to attach the hip to the pelvis frame. The idea chosen had a straight surface to attach the hip, and flexibility in the upper corners which would ease the impulse strain on the frame ~~if~~ as needed. All the ideas can be seen in the appendix. The decision was made to skip the lateral movement because of time constrains. There are two motors attached to the pelvis. One on top which implements the side rotation of the pelvis and one inside the pelvis frame which implements the lateral pelvis tilt.

(Where? Need exactly where to look.)

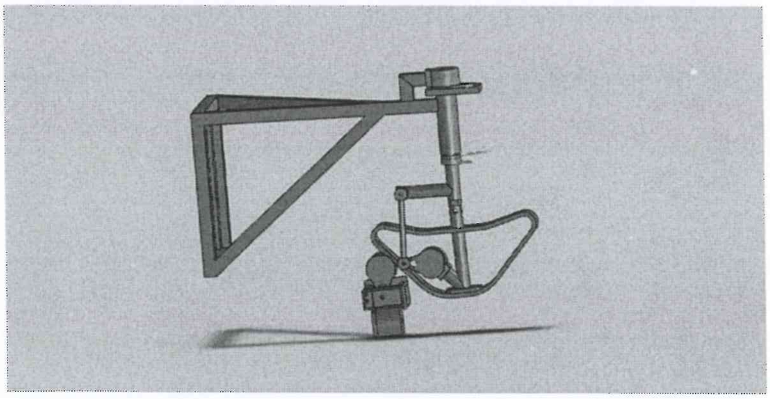


Figure 16: The pelvis with all the motors and small frame.

(how small?)

units?

(Need to speify default units or always specify)

The reason why it was decided to not implement the lateral movement is because it is the smallest movement of the three in the pelvis, and less important than the others to replicate human gait. The lateral movement can be implemented in the future, it can be with a sled on the pelvis frame where the hip joint is attached, to move the hip joint sideways. The bar connected to the top motor has two ball bearings (42*30*7) and two axial thrust bearings (47*30*11). The reason for the ball bearings inside the outer bar, is that the inner bar needs to rotate in the outer bar. The axial thrust bearings takes the pressure from each side. The axial thrust bearings can take dynamic load up to 19 KN and static load up to 43 KN.
A stress test (von Mises test) was done in SolidWorks, it showed a maximum stress around 200 MPa. Young modulus for steel is 200 GPa, so the device is in no danger of breaking as the Young modulus is 1000 times bigger than the maximum stress.

Good.

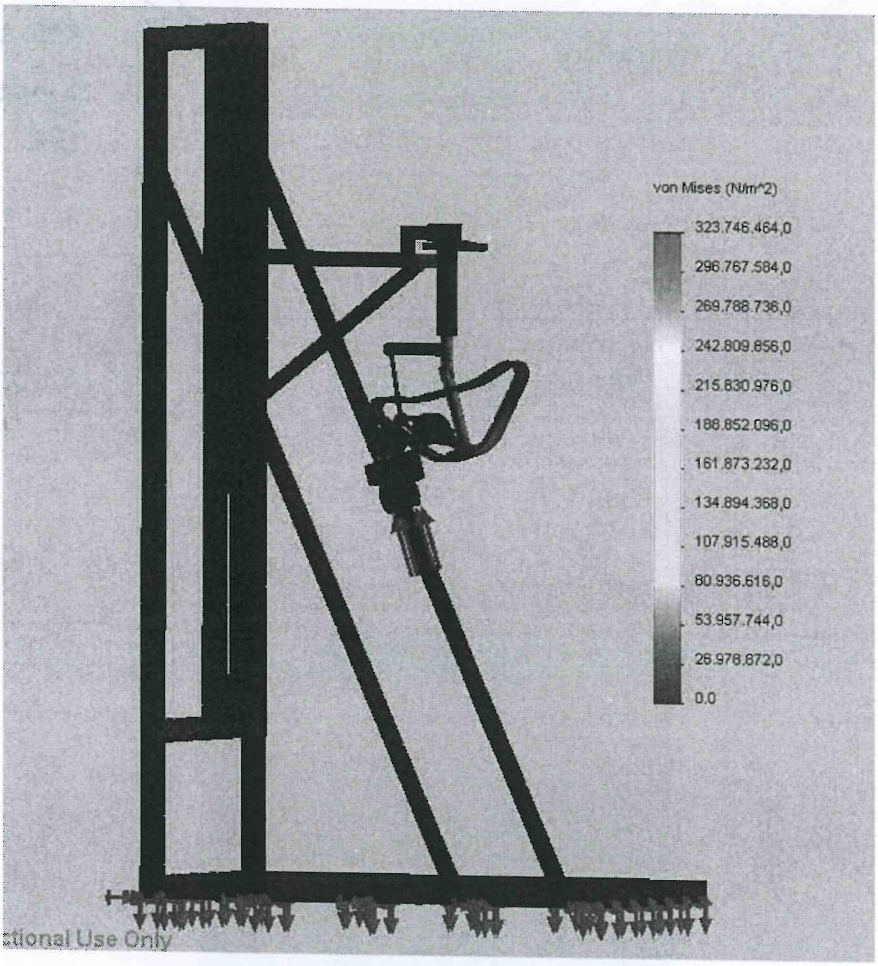


Figure 17: Stress (von Mises) test on the final design

Hip design

why this configuration (and not Agile eye)?

The final design for the hip joint is based on the movements of a universal joint. There is an aluminum piece connecting together two Power Knee motors from Össur hf. that gives us movement in two dimensions, one motor for each degree of freedom. The assembly in figure 20 gives us the means to replicate the movement in coronal and sagittal plane as we can see in human gait. The rotation in the axial plane which is needed to correct the pelvis rotation is ignored. The motors are linear to each other in the coronal and sagittal planes. The top motor controls the movement for the coronal plane with a range of motion of 15 degrees. The lower motor is situated about 145 millimeters beneath the top motor and it controls the movement in the sagittal plane with the range of motion at around 60 degrees. ~~To this design it~~ It is ~~quite easy~~ possible to incorporate rotation in the axial plane. at a later date.

this should be very early since you use the terminology.

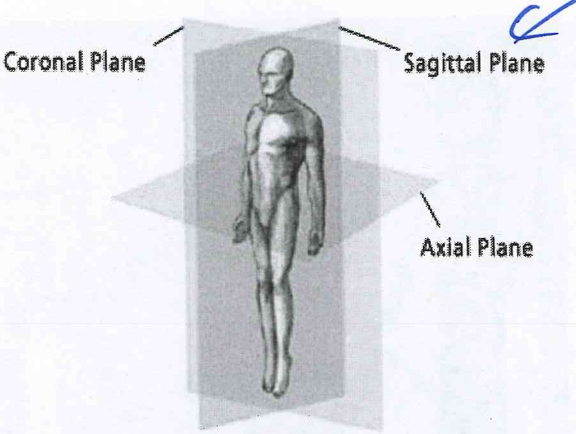


Figure 18: Anatomic planes [?]

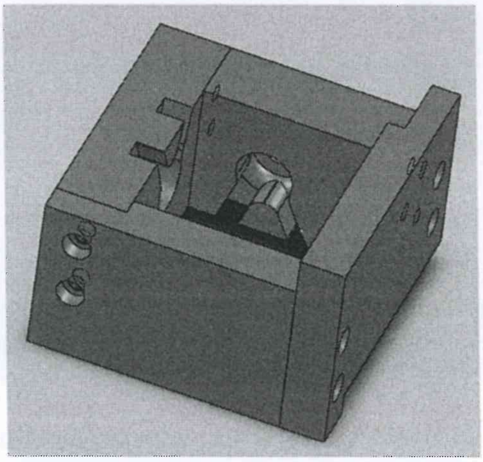
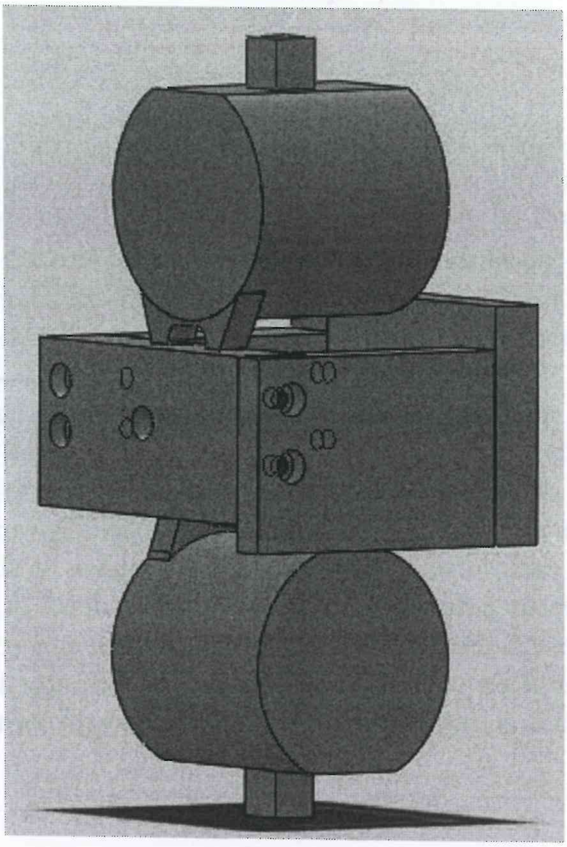


Figure 19: Final design for the hip joint



Good. Dimensions?

Figure 20: Final design for the hip joint with motors

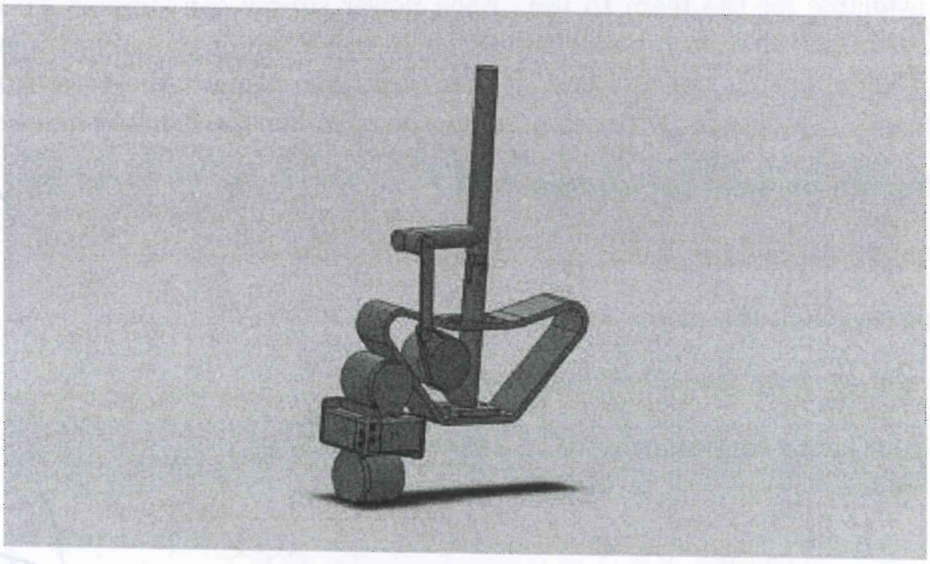


Figure 21: Hip joint attached to the pelvis

Produced by Össur

Electronics

The motor

This sounds as if it is from somewhere. Source?

The type of actuator that was used to produce mechanical movement in the robot leg was a three-phase brushless dc motor (BLDC). A DC Brushless Motor uses a permanent magnet external rotor, three phases of driving coils and one Hall effect device to sense the position of the rotor, and the associated drive electronics. The coils are activated, one phase after the other, by the drive electronics as cued by the signals from the Hall effect sensors, they act as three-phase synchronous motors containing their own variable frequency drive electronics. The gear ratio of the motor is 80:1, meaning that then the motor shaft had made five rotations, in the same time the output shaft had made three. The motor can generate enough force to lift 100 N. This is the same type of actuator which is used in the power knee from Össur. It is very important to connect the phases of the actuator correct. There are three wires coming out of the hub motor, they all have markings on them. The markings are in forms of stickers with letter A, B and C, where each letter represent different phase of the actuator. On the motor controller there are connector housing for the wires which have A, B and C labels on them. Connecting the phase wires on the actuator incorrect will prevent the motion of the motor and it is likely it will cause vibration with it in the actuator. Actuator has five Hall Effects Sensor wires coming out of it's hub it is important to connect them right for the motor to work properly.

10kg?

Motor generates torque. NOT Force!

full name

Motorcontroller

The motors and the MC are rated 50 VDC @ 25 A continues maximum. The power supplies only support 50 VDC at 3 A. One power supply was provided to us by Össur and there is another one available for the team to use. Each power supply can support 47 VDC @ 13 A. David from Össur said that each power supply could drive two or probably three motor. That means that power supply is not an issue. It is necessary to connect the wires from the MC to Hall effect sensors. The proper wiring for the motorcontroller the is listed below:

- Hall effect sensors from the motor to MC.
- Power supply to MC (50 VDC)
- Three phases from the motor to MC
- Enable voltage from micro controller to MC (4 V)
- Signal from micro controller to MC (-3,75 V to +3,75 V)

The chapter name is motor contoller but I think the content is more about the power supply

This is identical to the previous Controller subsection. If so, you just need to reference not repeat.

Software

Angle sensor

Where?

The sensor is a magnetic rotary encoder and uses synchronous serial interface (SSI). Code that was used to read the sensor was found on the Internet, the plan for the future is to make it more efficient. There was an issue with the sensor since it gave the angle periodically which was very bad for control. To fix that there was made another variable that has continuous scale but uses the periodic angle to update. → so ~~what~~ was the problem sw rather than h

Repeated! Not needed.

Generating a signal to the MC

The signal to MC has to vary from -3,75 V forward to +3,75 V backward rotation. Arduino can neither generate a negative voltage or analog voltage. This was solved by using two digital ports that could generate Pulse-with modulation (PWM) signal. By default the frequency of PWM is 1 kHz. By changing the clock speed in Arduino the frequency is increased to 62,5 kHz. This is to eliminate the low pass filter that is necessary to smooth out the signal if the frequency is too low. By using two digital ports and always pull one to 0 V while generating PWM on the other its no problem reversing them and generating relative negative voltage.

Identical to a previous chapter

Communication of Data

This is out of date!

~~In order to be able to set two or more Arduinos to share information with each other the plan is to use I2C, a serial bus interface. In this configuration one Arduino will be the master and the rest of Arduinos will be his slaves. This simplifies the communication between PC and Arduinos since instead of communication with all of them, one only needs to communicate with one Master Arduino. The Master Arduino, is programmed to request, and then read, 6 bytes of data sent from the uniquely addressed Slave Arduinos. However this configuration has a possible flaw: The Arduinos are connected together in series and if one Arduino gets high voltage trough it, all the Arduinos will be affected. The solution could be to use optical isolators to prevent this from happening.~~

PID control

reference ?

PID stands for Proportional, Integral, Derivative. The "textbook" version of the PID algorithm is described by:

why is this not in previous PID?

$$u(t) = K(e(t) + \overset{?}{\boxed{\frac{1}{T_i}}} + \int_0^t e(\tau)\, d\tau + T_d \frac{de(t)}{dt} \tag{1}$$

? y r

where y is the measured process variable, r the reference variable, u is the control signal and e is the control error. The reference variable is often called the set point. The control signal is thus a sum of three terms: the P-term (which is proportional to the error), the I-term (which is proportional to the integral of the error), and the D-term (which is proportional to the derivative of the error). The controller parameters are proportional gain K, integral time T_i , and derivative time T_d . The integral, proportional and derivative part can be interpreted as control actions based on the past, the present and the future. In process control today, more than 95% of the control loops are of PID type, most loops are actually PI control. PID controllers are today found in all areas where control is used. For the regulation of the robotic leg PID library from www.arduino.cc was used. When using PID library one should be clear on what the desirable setpoint should be. The idea is that the regulation system on each joint is independent. The only variable is the setpoint. In our case the setpoint were the angle values

contr
s

Variables for math in text need $ around them

becomes
u → u

from the excel sheet from Ossur. Using the data from the gait analysis to update the setpoint at the right rate could able on to simulate the movements.

PID measures the input and then adjusts the output trying to make the input equal to the setpoint. When starting regulate the system one should first determine the value of the appropriate value for Proportional part, highest value until the system begins to oscillate and then introduce the Integral part so to minimize the error. Usually the Derivative part of the PID control is not used.

Source? which textbook? Citation needed!

Use the variable names also.

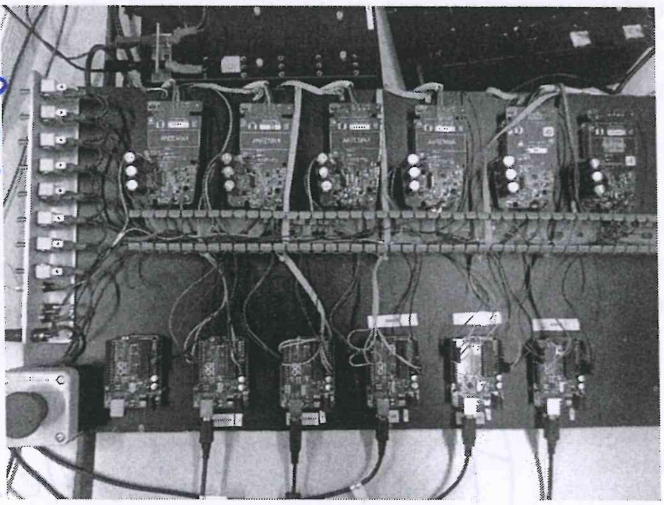


Figure 22: The final control board. Capable of controlling eight motors.

Circuit diagram?

Variables for math in text need $ around them

u becomes → u

Programming

The software element of Project Lucy consists of two different elements. ~~On one hand~~ We have code that runs on each of the Arduino Uno microcontrollers, ~~and on the other hand~~ There is also the python script that runs on the controller computer. This section will discuss Project Lucys software elements as they were when the project was handed in and at the end of the section we will discuss future plans and unimplemented ideas.

The elements need names:
1. Joint controllers (arduino)
2. Supervisor (python)

Architecture

One of the main functionalities that the team wanted to implement was usability for future use of Lucy. Since the project is to be handed off to either Össur hf. or a new team, the process of executing gait data should be as simple as possible. Since the Xsens MVN BIOMECH [?] that Össur hf. uses to record gait analysis outputs an Excel spreadsheet (among other formats, but the spreadsheet was the only format handed to the team) the controller computer ~~should~~ needs to be able to read and parse data from it faster than it occurs in real-time.

Controller computer

(No, it is not. It is compatible.)

~~Starting with~~ Python 2.7 was chosen for its readable code, rapid prototyping capabilities and cross operating system support. ~~there were several different options available~~. For the controller computer, the Excel spreadsheet is a Office Open XML [?] format and can be easily parsed in most programming languages. Using OpenPyXL's optimized reader [?] we can read, parse, format, send and receive over 7000 data points via serial communication in just over 10 seconds via a simple Arduino echo program. This time would of course diminish as more data would be sent but seeing that 7576 rows were iterated over, one cell in each row sent over serial at the baud rate 115.200 and read again in 10,483 seconds we are sending 7576 / 10.483 = 722,694 data points every seconds which is quite higher than the required 120 data points per second for each joint and is even within the range of five joints or 120*5 = 600 data points.

? ?

(which is what bandwidth? points/second? Data from your test?) Hard to understand.

Arduino

PID controller When the angle value is read from the controller computer it is set as the setpoint for the PID controller. The PID controller then utilizes the setpoint as well as the angle sensor value to tune the output so that the corresponding motor will move to the setpoint value position at a acceptable speed and minimal overshoot. The Arduino PID controller library is not included in the bundled Arduino compiler but can be downloaded from the Arduino website [?]. There also exists a autotune PID library for the Arduino but there was not time to implement it in this version of project Lucy. Citation?

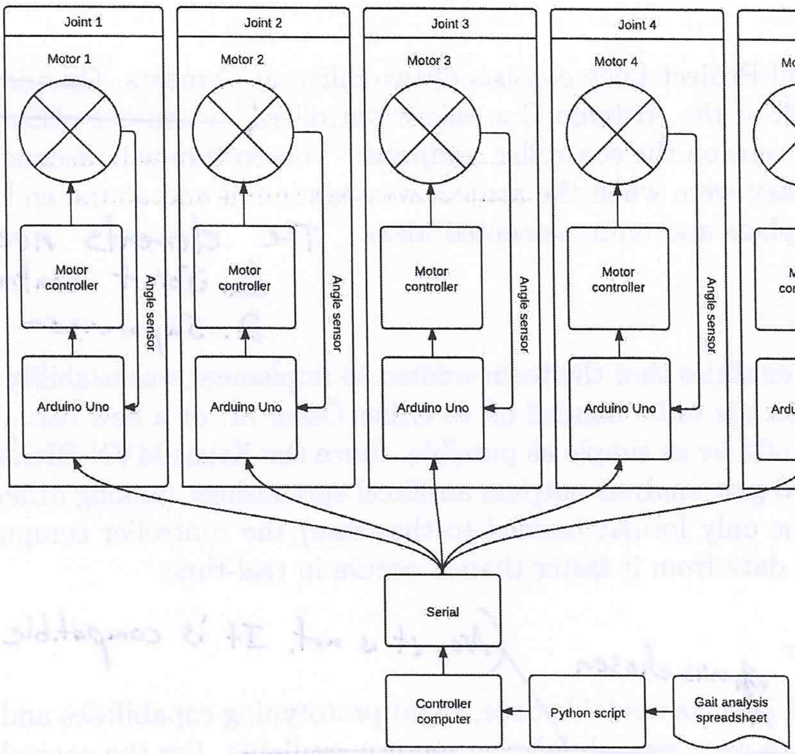


Figure 23: The system main architecture overview.

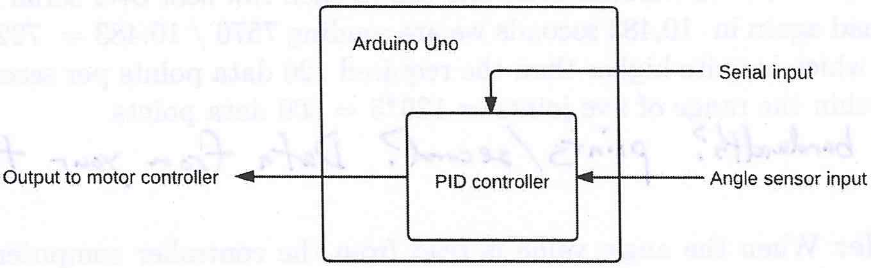


Figure 24: Regulation system.

Packed protocol To save bandwidth when sending data to the microcontroller we utilized the very nature of the eight bit bytes that the Arduino serial manager supports. Usually it used represent ASCII characters where each byte represents one character. The way that Lucy uses the remaining two bytes is to read the angle value sensor from the spreadsheet and split that value in two. Each integer is looked up in a ASCII table and the corresponding character is sent via serial. On the receiving end each Arduino Uno listens continuously for 3 or more bytes to be available. As soon as they are available the first byte is set as the sign byte and the following two bytes are read as integers and summed up. If the sign byte was the minus sign the summed up value is multiplied by -1. Then the setpoint is set at that value and the PID controller handles the regulation of the motor movement.

Unclear

Huh? You need a sketch explaining how the bits are encoded / decoded. This is very confusing.

Future work and unimplemented ideas

In this section we will go over the future software possibilities and ideas for Lucy.

Better PID tuning: All current PID tuning was done manually and/or by eye. To receive better accuracy there is the need to try some other PID tuning method such as the autotune PID library [?]. How would that help?

Optimized byte bandwidth: The current packet protocol could be shortened to two or one byte. For example, the current protocol uses two bytes to transfer the angle value which adds up to a max value of 765 or 65535 if the two bytes are concatenated into a 16 bit binary number. These numbers are quite higher than the required 360 value.

Live feed: Although there may be no need for this feature, during one brainstorming session the idea arose that there might be some benefit in linking the Xsens MVN BIOMECH suit to Lucy using a live link so that Lucy could live emulate the movements of the subject in real-time. If there is interest from Össur this could be a possibility for future implementation.

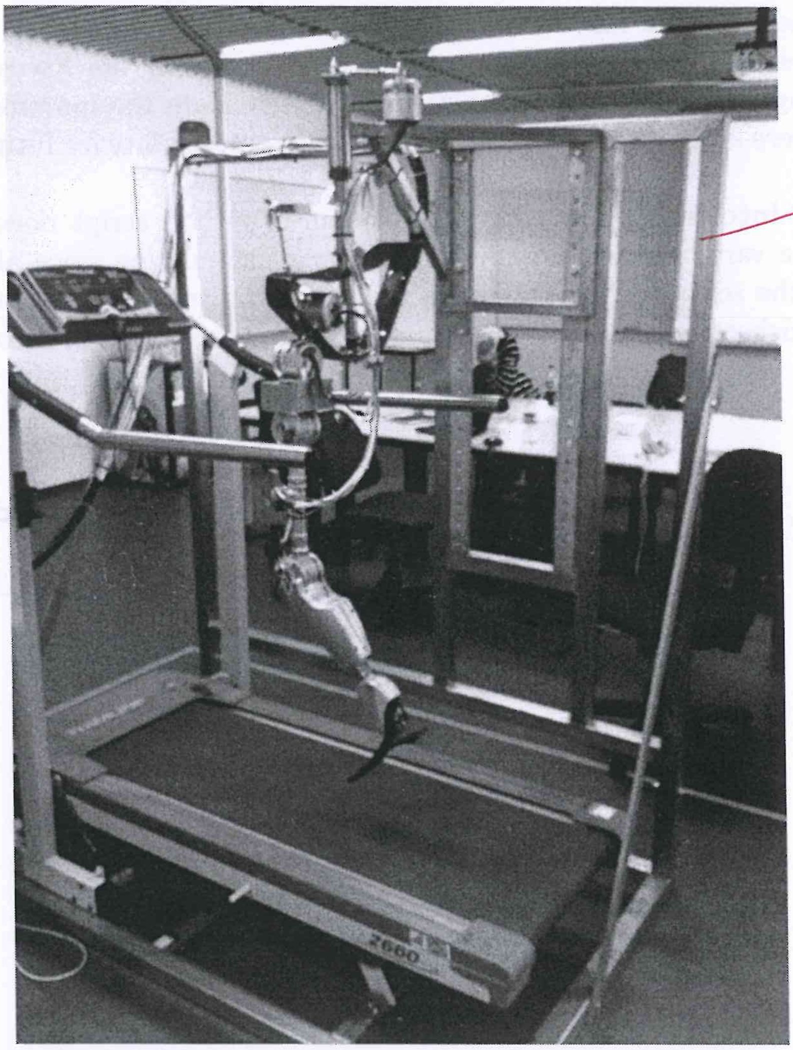
Improved user interface: The controller computer python script does not currently accept any run-time variables to customize the following simulation since all the variables are hard-coded into the script. The parameters that could be turned into run-time variables include what spreadsheet column represent what joint, baud rate, delay, zero positions for each joint and more.

Kinetics?

also need good directions
how to setup software + electronics.

Results

The group set out to build a robotic leg which could simulate human gait. At the beginning of the project some of the design ideas ~~may not have been~~ were not reasonable to implement ~~for the experience of the group or the~~ time frame we had to work with. During the development of the product the team ~~realized some of its limitations and~~ focused on designing simple and effective parts so we could ~~at the very least~~ implement the necessary movements. Some complex ideas were not ruled out entirely until late in the process, the most notable one being the Agile Eye ? 10. Other designs, for the pelvis, were discarded after discussions with the client, based either on design flaws or lack of aesthetics. In the end, the group delivered a working prototype of a human gait simulating robot, capable of replaying recorded data in a realistic way. This prototype can be seen in figure 27.



nothing about this frame?

Figure 25: The finished product

In order to deliver the finished product on time the group made a few sacrifices in terms of movements. For example, lateral movements of the pelvis and the rotation of the femur in the axial plane were not implemented. Despite the lack of these movements, the gait of the robot ~~seemed~~ appears quite natural. ~~This is something that seems an acceptable product for the given time frame but of course~~ There is a lot of work left to perfect the robot.

indent?

The missing movements can easily be implemented by other interested parties. How? In addition, more work needs to be done to make the software more user friendly, i.e. by building a user-interface. The robot also lacks the capability to walk on a treadmill and in order to do that it

is quite necessary to implement some kind of force sensor into the robot. It's also possible to finish work on the Agile Eye, something that the team would have liked to see done.
Overall, the results are good. With excellent support from our sponsor/client Össur hf., the team members came through and built a robot in 15 weeks.

How well did you reach your goals

Never end with the things that were unfinished. It looks bad. All of this should be in the middle or "Future work" section

Where are the quantitative performance measures? How fast / strong can it move? What is the accuracy, repeatibilty, resolution? This is incomplete otherwise.

Appendix A

why is this separate from ~~sep~~ "Final Prototype"

Prototype 2.0

This design takes the prototype 1.0 and adds the hip movement in the coronal plane using more Power Knee motors from Össur hf. It ~~will also~~ includes a basic pelvis that will simulate the pelvis movement by using three motors to implement the 3D movement needed.

Electronics

The electronic system in prototype 2.0 is nearly identical to the system in prototype 1.0 apart from the number of motors used.

Controlling multiple ~~Controling multible~~ motors

Ref to the picture

To control the prototype 2.0 a new control board was made. The board was designed with maximum eight Power Knee motors in mind, but only five motors are used. The board receive its motor controllers power throw a main emergency switch. In addition there is one switch per motor controller for the user to choose which motor he wants to drive. The enable pin from each motor controller a connected parallel and when in series with a connector on the control panel of the board. That is for optional mechanical fuse.

Connectors

An extension cable~~s~~ Was ~~were~~ ~~where~~ needed for ~~on every cable to~~ each motor. For the motor sensors, ~~the group got an~~ extra connectors identical to those how are used in the Power Knee were provided by Össur so the original connectors on the motors and the motor controllers are used with the new extension cables. For the motor faces a multi-core three ~~tree~~ wire cable is used as an extension cable. The connectors for the motor faces are traditional motor connectors. For the angle sensor it was necessary to make an custom PCB board for the connector from the sensor, figure 26.

Need to know the model and vendor for connectors.

no figure

Figure 26: The custom PCB board

Missing from SVN also.

Mechanical

The leg will be connected to the pelvis with a universal joint that will be controlled using two Power Knee motors from Össur. The joint that connects both motors together to simulate motion in two dimensions can be seen in figure 6.

Electrical Wiring diagram?

Pelvis design

No. How many?

The pelvis design has been designed ~~more than ones~~ in many different ways. From the information at hand the pelvis was created to get as much degrees of freedom as possible.
The pelvis will be connected to a rectangular frame ~~by three harnesses (red circles)~~ which will have a Power knee motor attached. The frame will be fastened to a wall or a crane. The pelvis itself will be a board which the foot will be connected to the three motors as well via connecting bars. One bar will be fixed to the pelvis to keep the pelvis stable, the other two will be connected to the bar with a small universal joint and one half universal joint to make the bar half fixed.

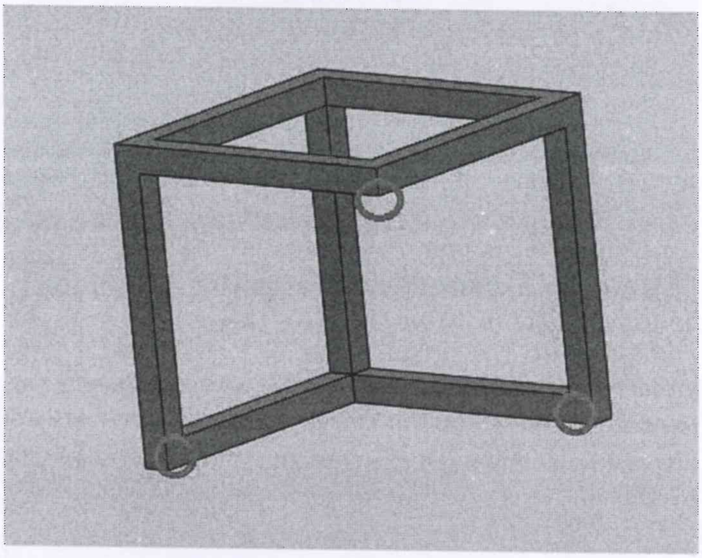


Figure 27: Frame for the whole component.

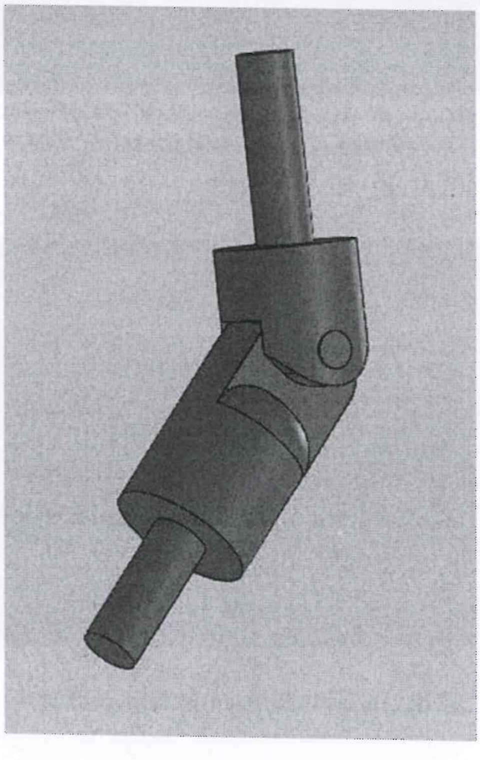


Figure 28: Half universal joint.

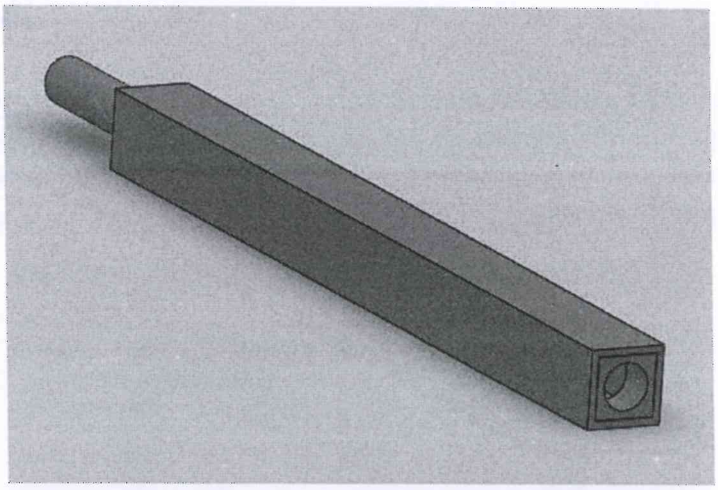


Figure 29: Connection bar with slot for uni-joint

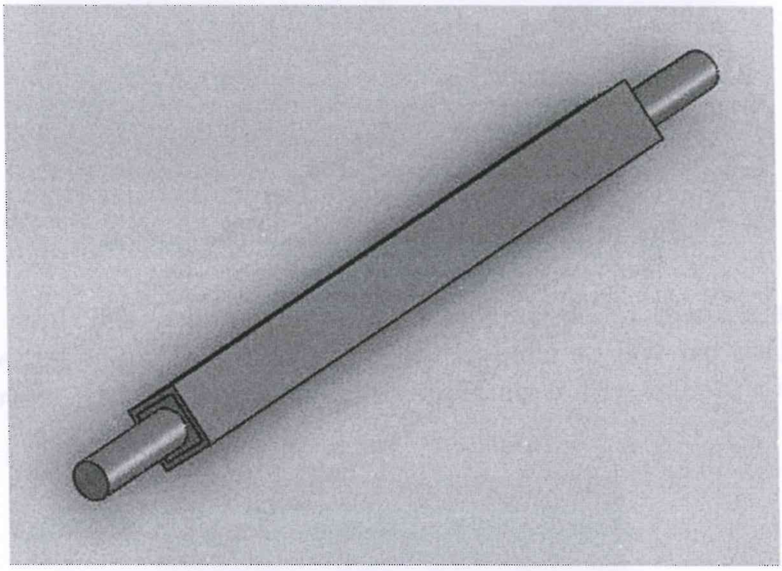


Figure 30: Fixed bar.

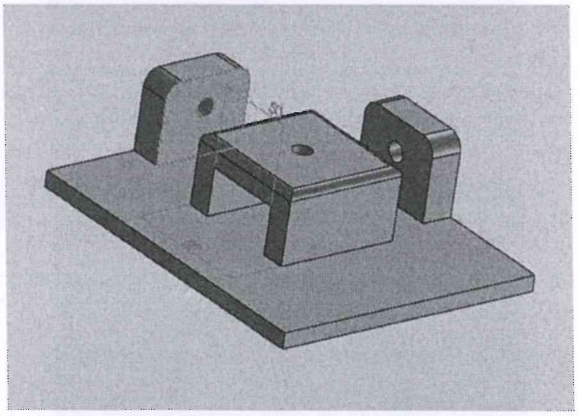


Figure 31: Plate for the pelvis.

The Power Knee motors that ~~will~~ serve as the actuators for the pelvic movement have a radius of 67mm from the ear of the motor. So the max movement from the motors are about 134mm without any changes to the length from the center of the motor. ~~Which~~ This fits the requirements for the movement for all the three axes (vantar kannski heimild fyrir þessarri staðfestingu). Holes will be put on the side of the frame so we can adjust the height of the leg and change the leg for a variaty of gait analysis data. The movement of the mechanism is not linear. So we made an approximation program in ~~m~~Matlab to so how the movement of the pelvis

(explain the calculation)

(Um! This is not good)

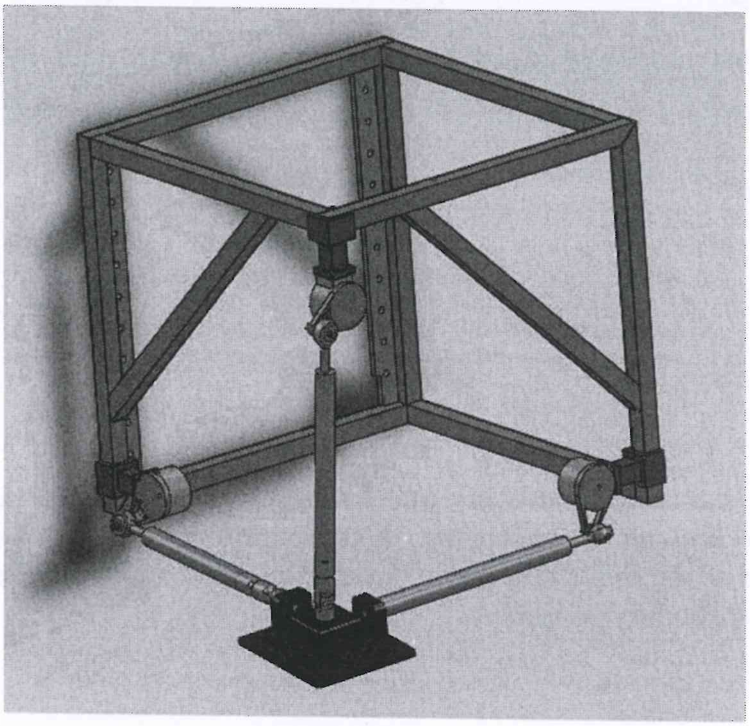
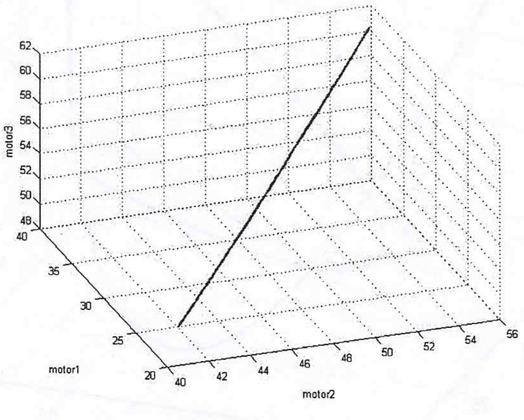


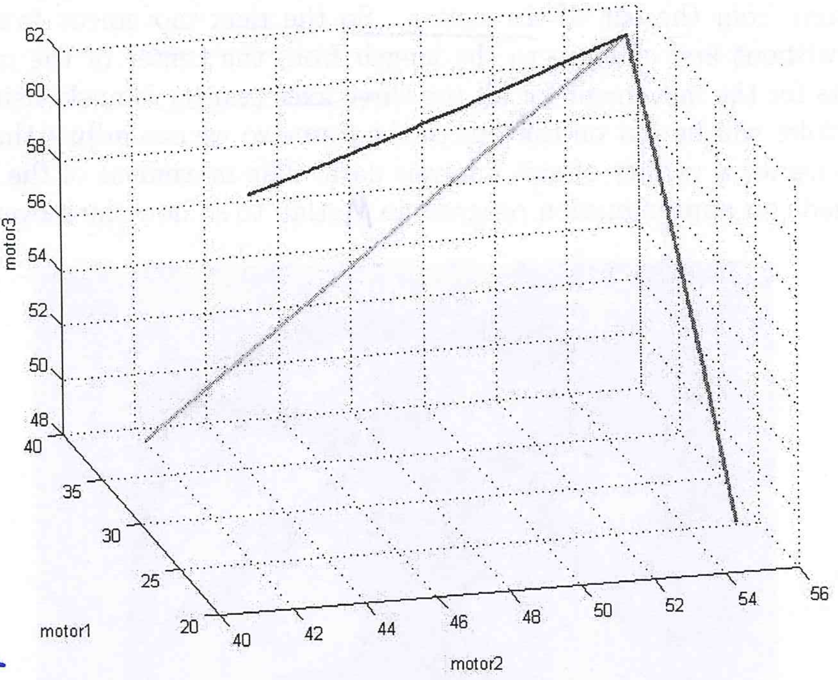
Figure 32: The pelvis.

behaves for each of the motor movements.



(This should go in supporting text, not a caption)

Figure 33: This is the movement of the center of the plate in third dimension. When the motors ~~ar~~ are all syncronized to move at the same time to the same degrees. Results are a linear line from the starting point to the end point. The motors go from 0 – 360 degrees so it goes back and forth.



Text not figure caption

Figure 34: Making one motor stationary and two run. Blue line: motors 1 and 2 move from 0-360 degrees while keeping the motor nr. 3 stationary at zero. We get a line which goes through the middle of the other two lines. Green line: Motor nr.2 is stationary at zero. Red line motor nr. 1 is stationary at zero.

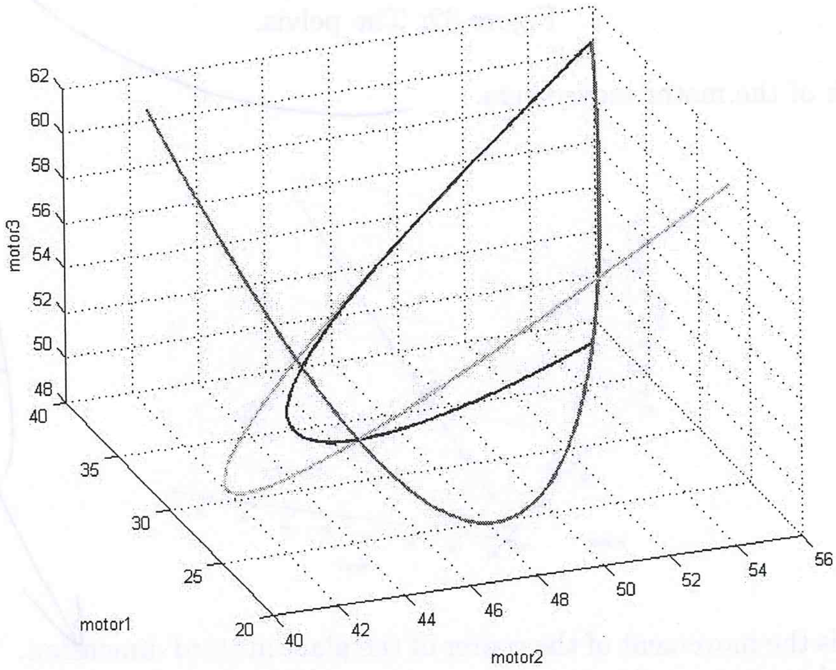
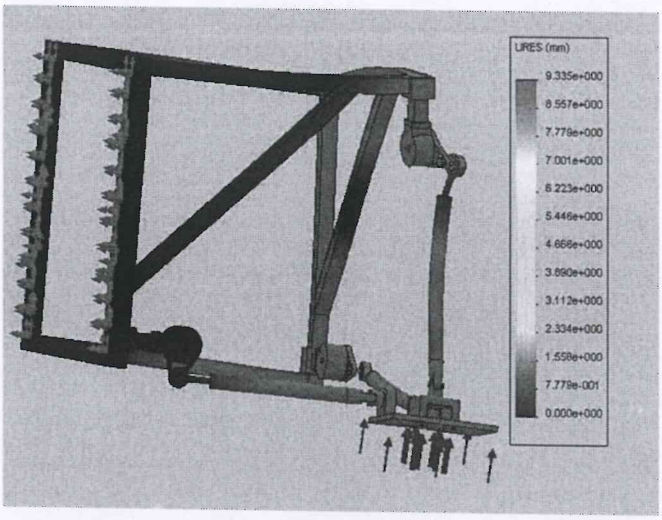


Figure 35: Making one motor slower by making it go from 0-180 degrees. Blue line: Making motor nr.3 go slower while the others go from 0-360 degrees in the same time frame. Green line: making motor nr. 2 slower. Blue line: making motor nr. 1 slower.



Put in text not caption!

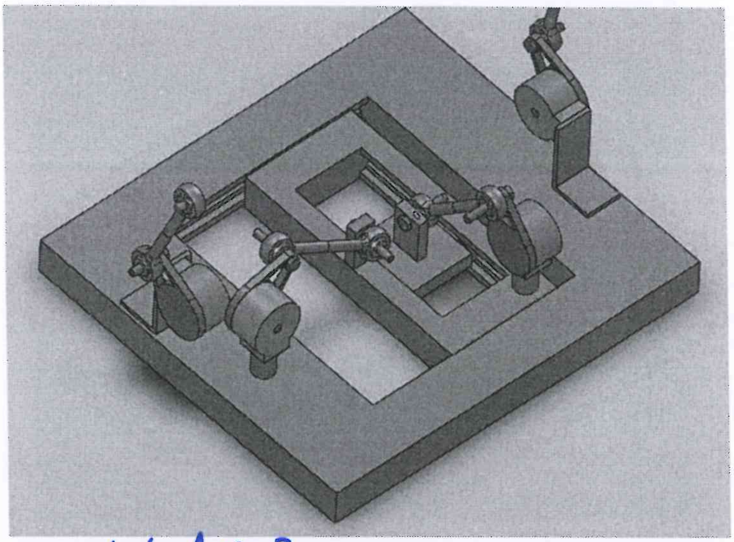
Figure 36: Buckling test using SolidWorks. Using force equal to 1.2KN upwards on the pelvis platter we can see the predicted buckling. The most buckling is 1cm in the worst case scenario, it us highly unlikely that this will happen because for now we will not be using this much load.

No. That is 120kg!

This pelvic design was ruled not constrained enough, because when the motors are moving the pelvic plate tilts at an angle which will create an unwanted bending moment and an error in the movement.
~~So the goal was to~~ we then create a new design which would be more stable and better constrained, but had one less degree of freedom, ~~which is~~ the axial rotation of the leg, ~~and making~~ we chose to make the movement more linear. ~~Decision was made to make~~ via a railsystem powered by PK-motors ~~so the rotation of the motors would convert to a pure linear movement~~.

need sketch or 3d model.

railsystem? You mean linkage?



which design?

Figure 37: Schematic of the design. Consists of four motors. One for side to side movement, one for front and back and two for up and down.

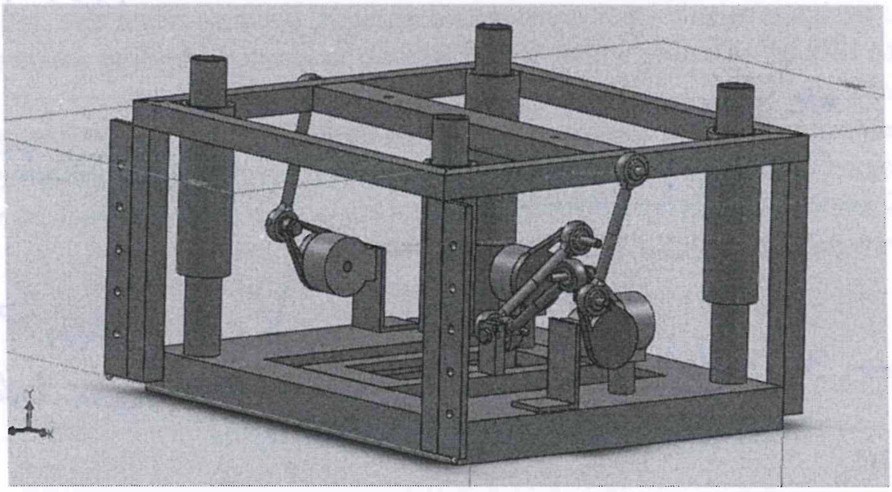


Figure 38: The pelvis was connected to the frame by flat iron with holes 5cm apart from each other to adjust the height of the leg.

This design was taken ~~of~~ off the table because it did not satisfy our clients expectation as they had an similar machine. Tests ~~where~~ were made in Solidworks, strain, displacement and buckling.

(uh, they don't.)

where? No data or ~~diagra~~ figures

Hip design

Text?

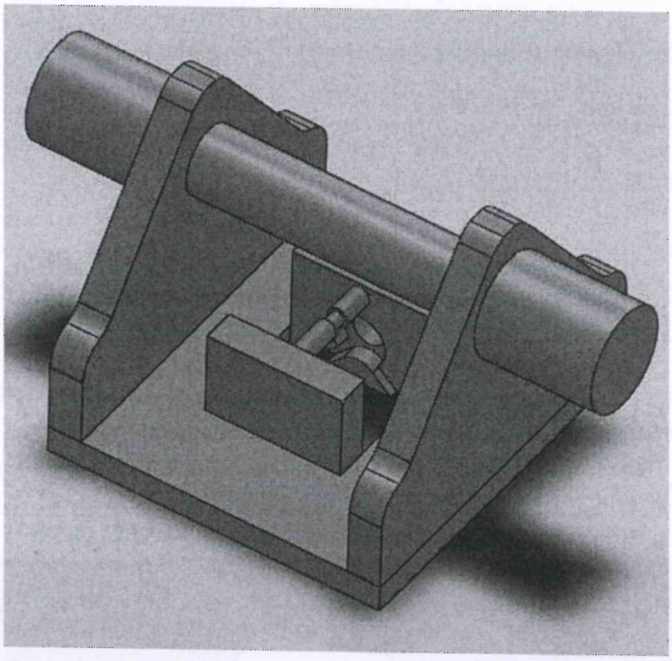


Figure 39: Universal joint with one or two stepper motors and the power knee motor.

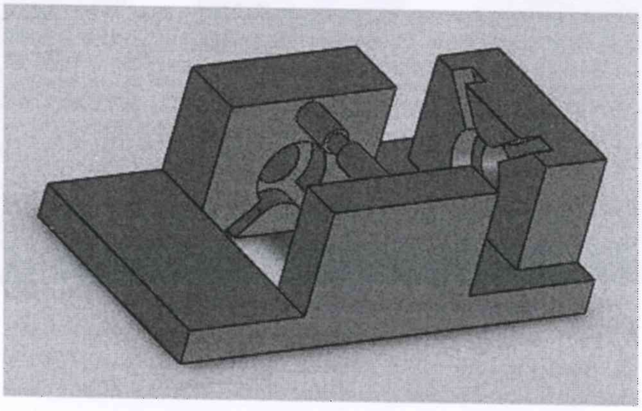


Figure 40: Universal joint movement in two dimension with two power knee motors.

Construction group

Devices ~~Devises~~ and other parts: Modules + assemblies?

- Motor box for the Power Knee Motor
- Testing device for motors
- Testing device for a motor and a potential meter
- Bracket for crane

Motor box for the Power Knee Motor

Motor box was designed with Occam's Razor principle in mind. Material was found in the energy lab and from looking into similar mechanisms, this motor box was designed and constructed. From figure 17 we can see 3D sketch of the part holding the motor. From Figure 18 we can see 3D sketch of the motor box. From figure 3 we can see the finished part.

Huh? I don't see it These references are probably wrong.

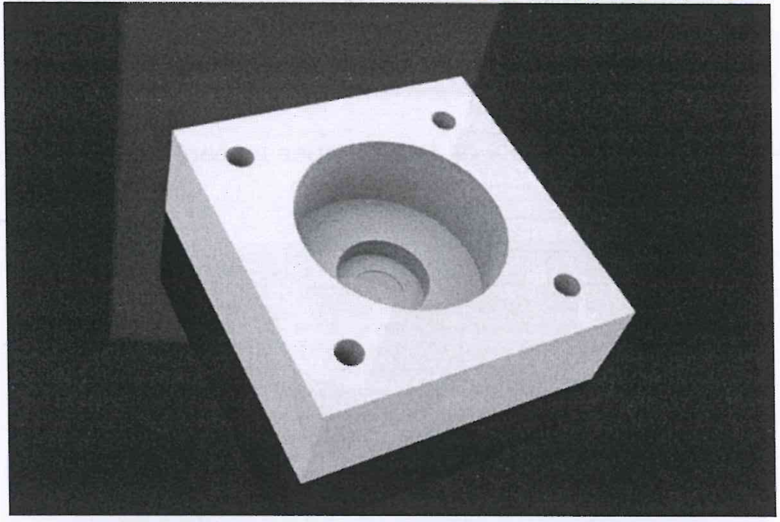


Figure 41: Motor box design

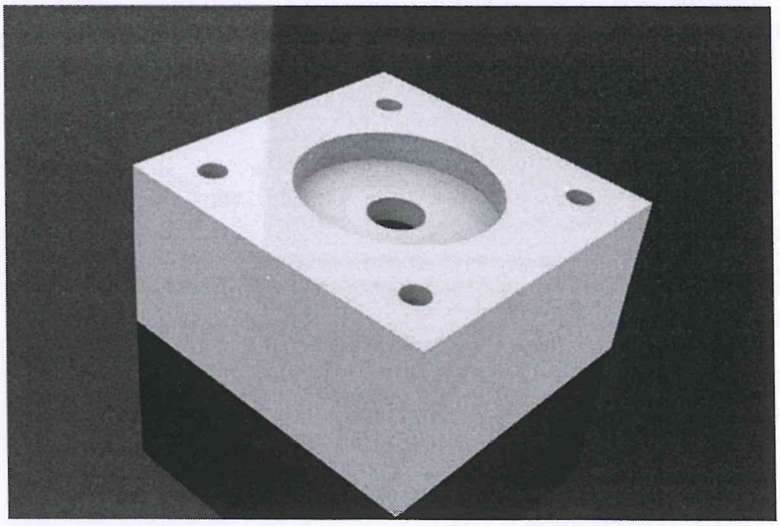


Figure 42: Motor box design

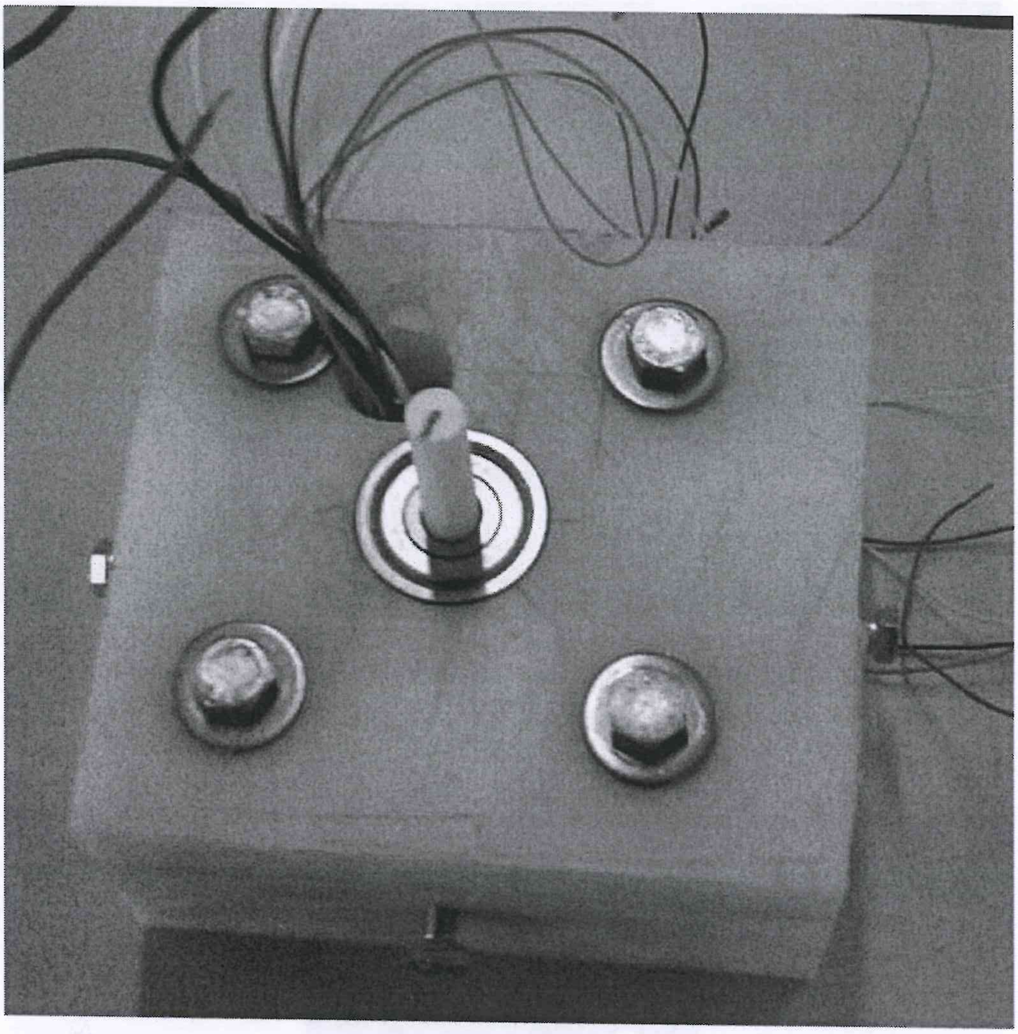


Figure 43: Motor box

Testing device for motors

what kind of aluminum?

Two prototypes were made to simulate a gait cycle in two dimension. Programmers can test the data from the gait analysis, learn how to talk to their motors and control them. The first device from figure 2? was made to control a DC motor with a gear,, it was made from bar of aluminum 20x8 mm, ~~we used aluminum~~ because it is light and easy to work with. The second device from figure 3? is also made for the same purpose but for smaller stepper motors with less holding torque. We used nylon instead of aluminum to make the device lighter and therefore the device is more controllable for the stepper motors. (Huh? This does not follow.)

Testing device for motor and a potential meter

The testing device from figure 4? was made to simulate a movement in one dimension. To be able to determine the position of the motor we attached a steel pin to the device. We used aluminum to make a right angle bar to hold the potential meter and motor. ~~For the platform~~ we used nylon ~~and we also used nylon for~~ the cylinder part that connects the motor and the potential meter. and the platform. what kind of nylon?

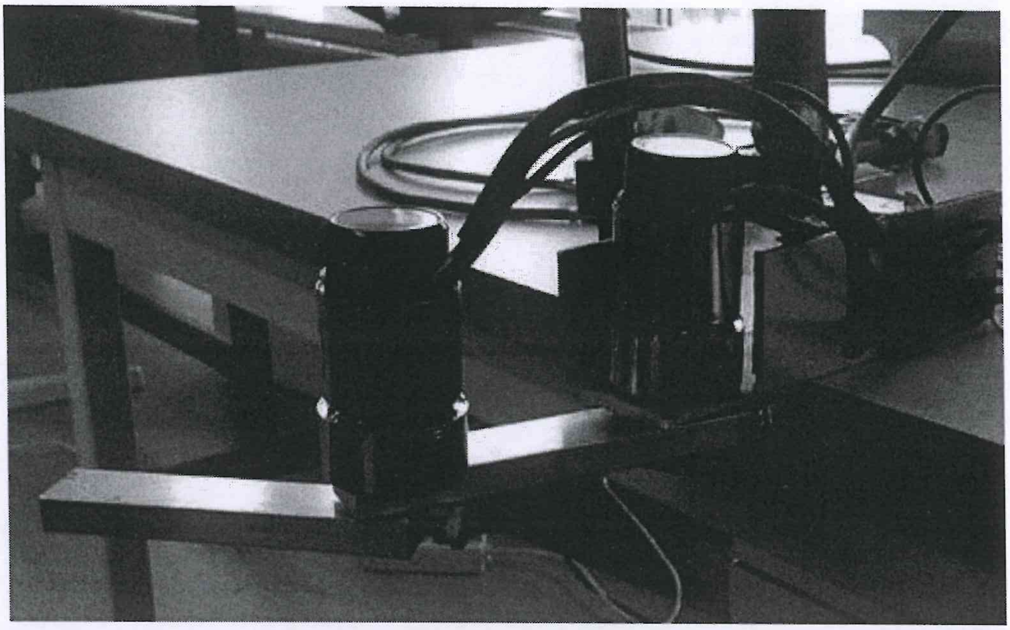


Figure 44: Testing device for the DC motors

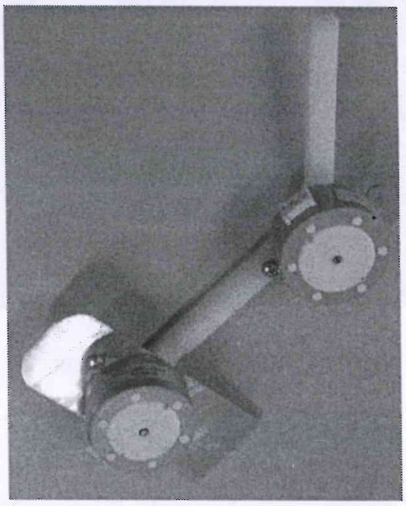


Figure 45: Testing device for the stepper motors

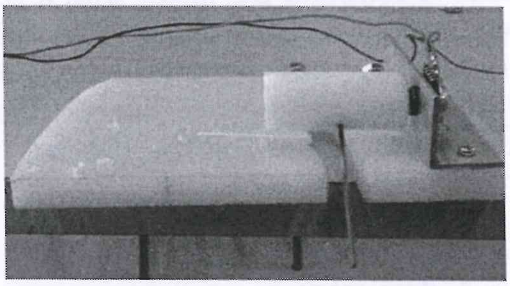


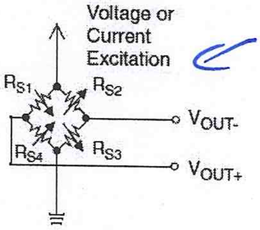
Figure 46: Testing device for motor and a potential meter

Load cell

Össur provided a load cell from an older Power Knee model. The idea was to place the load cell in the femur or the shin and monitor the forces applied to the leg in real time. If the forces exceeded a given value the system would shut down in order to prevent damage to the robot. Due to time constraints and the fact that the robot would not be stepping on the ground it was decided ~~to stop work on the software side of the load cell~~ to not completely integrate this feature. ~~Before this, work was done to figure out~~ we researched the wiring of the cell and the required hardware to visualize the data from it; this ~~was enough~~ allowed us to connect and calibrate the load cell so a future implementation of it into the robot should be straightforward.

The load cell used has two independent resistive wheatstone bridges with four elements each (full bridge configuration). When a positive differential pressure is applied to the four element bridge,two of the elements respond by compressing and the other two change to a tension state. When a negative differential pressure is applied to the sensor, the diaphragm is strained in the opposite direction and the resistors that were compressed go into a tension state, while the resistors that were in a tension state change into a compression state [?]. As shown in figure 47, the bridge has voltage applied to it by an independent voltage source and depending on the pressure on the bridge, the output voltage changes.

(OK. what does this do? why do you care?)



what is the relationship between strain and resistance

Figure 47: Wheatstone bridge [?]

The first attempt to acquire data from the load cell was to use a ~~voltage~~ OpAmp based differential amplifier and an Arduino to read the output voltage. Due to signal noise, this was deemed to be an unacceptable solution. The load cell was then connected to a PC via a National Instruments cDAQ 9174 with a National Instruments 9237 connector [?]. A National Instruments 9949 analog-to-RJ-50 adapter which is designed for a load cell with a full bridge configuration was used to connect the cell to the data acquisition unit [?]. The data was processed using the MatLab Data Acquisition Toolbox [?].

(Very good!)

(where is the wiring diagram?)

Voltage amplifire unacceptable for Straingause amplification???

References Missing!

Very unacceptable!