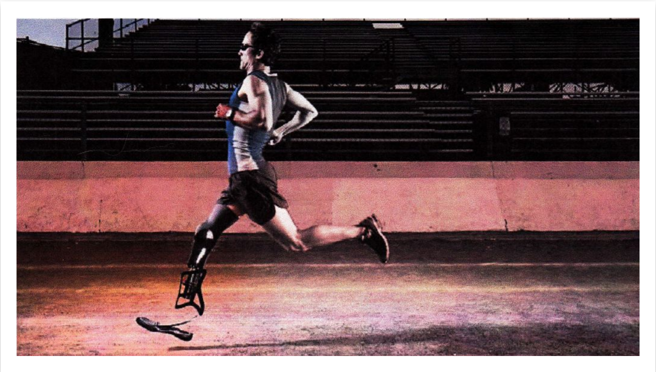
Prosthetic Leg Sensing



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MAE 207 Final Presentation
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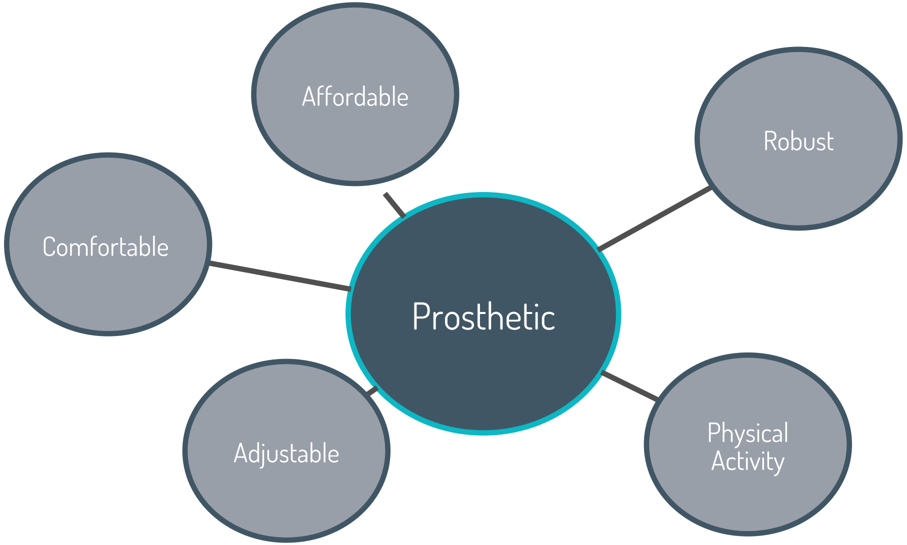
Motivation

- Prosthetics are typ. $5k-20k+
  - A large portion of cost is the expert knowledge of the Prosthetist
- Current prosthetics must be changed frequently as the child matures.
  - From age 6 -16, a child's height can range from 112 to 178 cm and can weigh from 15 to 66 kg [1].
- The prosthetic must account for these changes as the child grows.

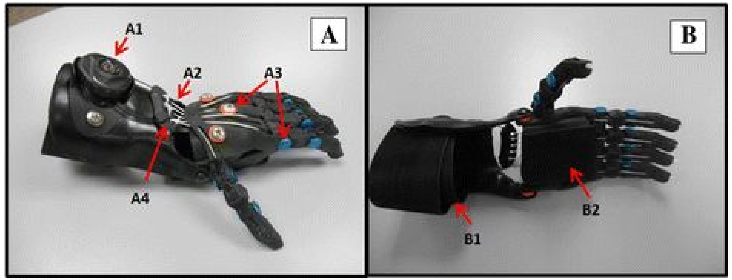


[1] Engsberg, J. R., et al. "Normative ground reaction force data for able-bodied and below-knee-amputee children during walking." Journal of pediatric orthopedics 13.2 (1992): 169-17

Current State of the Art

Prosthetic

- **Stiffness**: Passive compliance to resemble natural biomechanics. [2]
  - Running blades or leaf springs
- **Length**: Expandable prosthetic using hydrogels [3]
- **Low Cost**: 3D printing functional low-cost prosthetic hands [4].
  - Little work has been done for developing low-cost solutions for below-the-knee amputees.

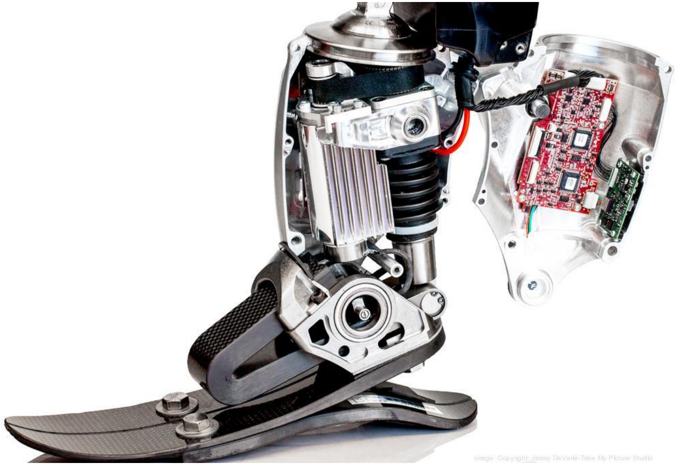


[2] Miller, Laura A., and Dudley S. Childress. "Analysis of a vertical compliance prosthetic foot." Journal of rehabilitation research and development 34.1 (1997): 52.
[3] Richelsoph, Marc E. "Non-invasive expandable prosthesis for growing children." U.S. Patent No. 5,466,261. 14 Nov. 1995.
[4] Zuniga, Jorge, et al. "Cyborg beast: a low-cost 3d-printed prosthetic hand for children with upper-limb differences." BMC research notes 8.1 (2015): 10.

Current State of the Art

Sensing

- IMU sensors used to analyze walking gait [5]
- Treadmill setup
- Motion capture systems $20,000+
- Computer Assisted Prosthetics $20,000+ [6]

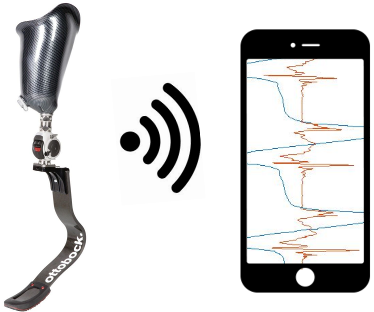


[5] Tao, W.; Liu, T.; Zheng, R.; Feng, H. Gait analysis using wearable sensors. Sensors 2012, 12, 2255–2283.
[6] McGimpsey, Grant, and Terry C. Bradford. "Limb prosthetics services and devices." Bioengineering Institute Center for Neuroprosthetics Worcester Polytechnic Institution (2008).

Proposed Solution:

Phase 1: Develop low cost wearable sensor

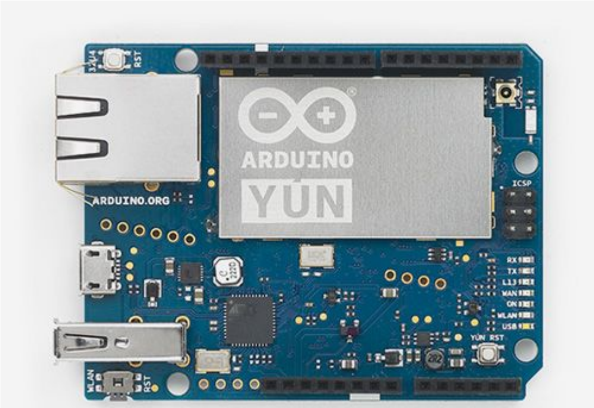
- Provide a tool to train new prosthetists or bypass the prosthetist entirely
- Better understand gait asymmetry in prosthetic patients
- Develop intuition on:
    - Comfort
    - Asymmetry
    - Effect of leg length and leg stiffness



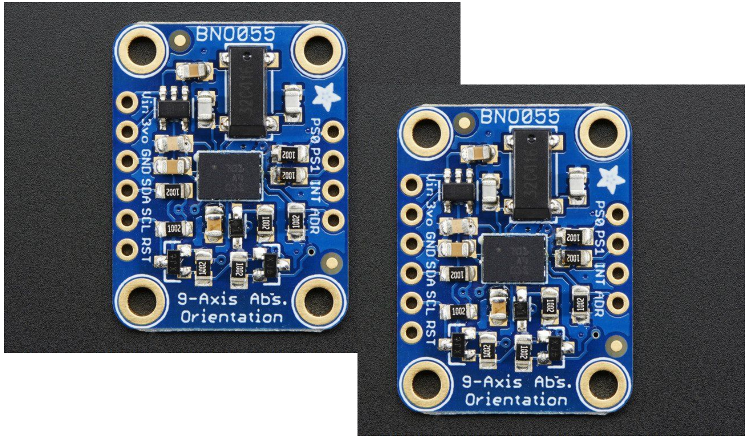
Phase 2: Develop low cost adj. prosthetic <$100

- Adjustable Stiffness
- Adjustable Length
- Low Cost

Hardware



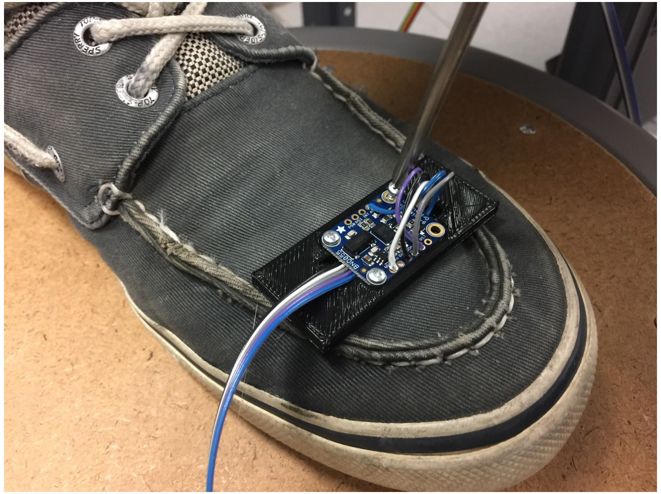
Arduino Yun Datalogger

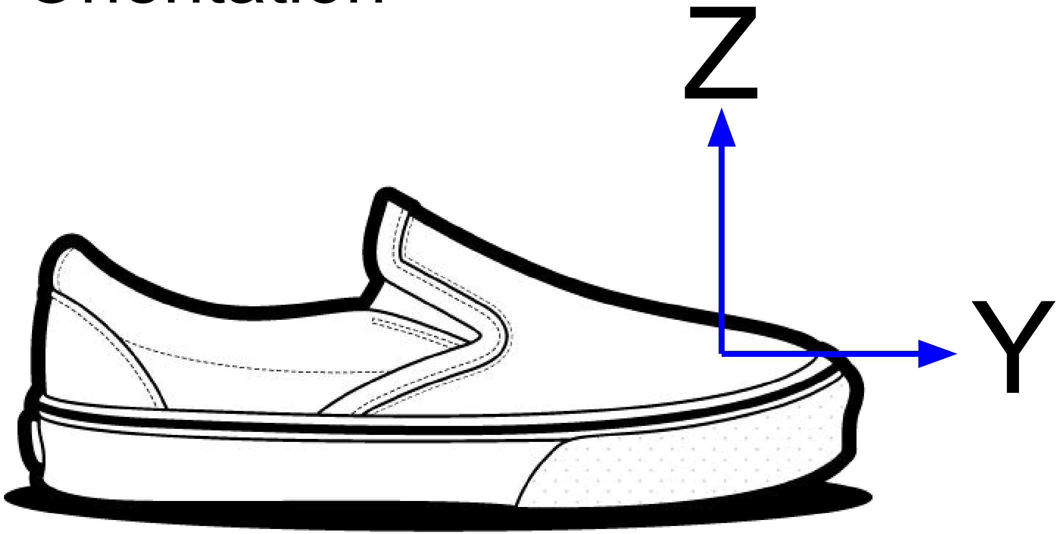


9 axis BNO055 IMU


Shoe

Sensor Placement and Orientation





Toe placement:

- Least amount of sensor “shifting-around” movements
- “No slip” characteristic of the toe

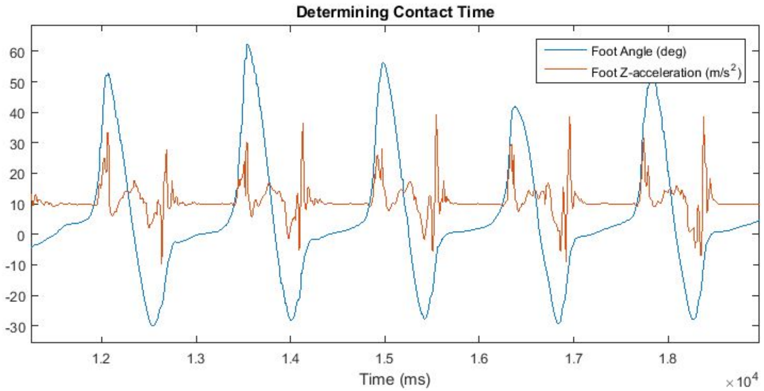
Estimating Three Parameters

Step Length (m)

Step Frequency (Hz)

Contact Time (s)

Example Data:

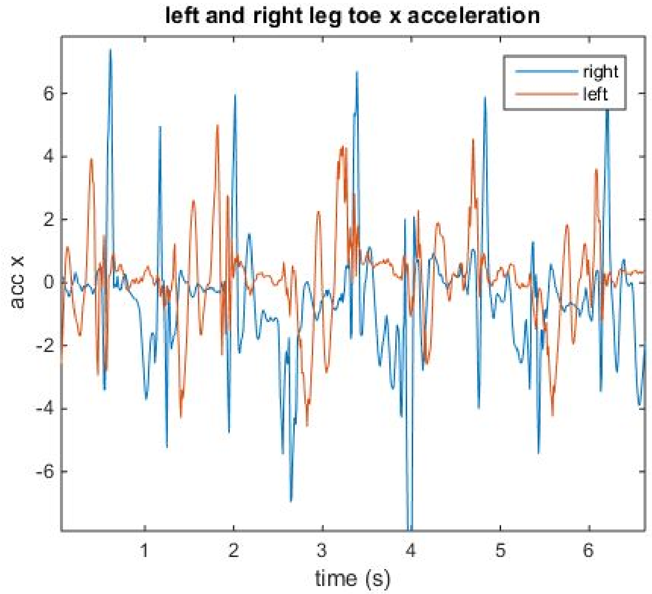


Estimating Step Length

Double integration

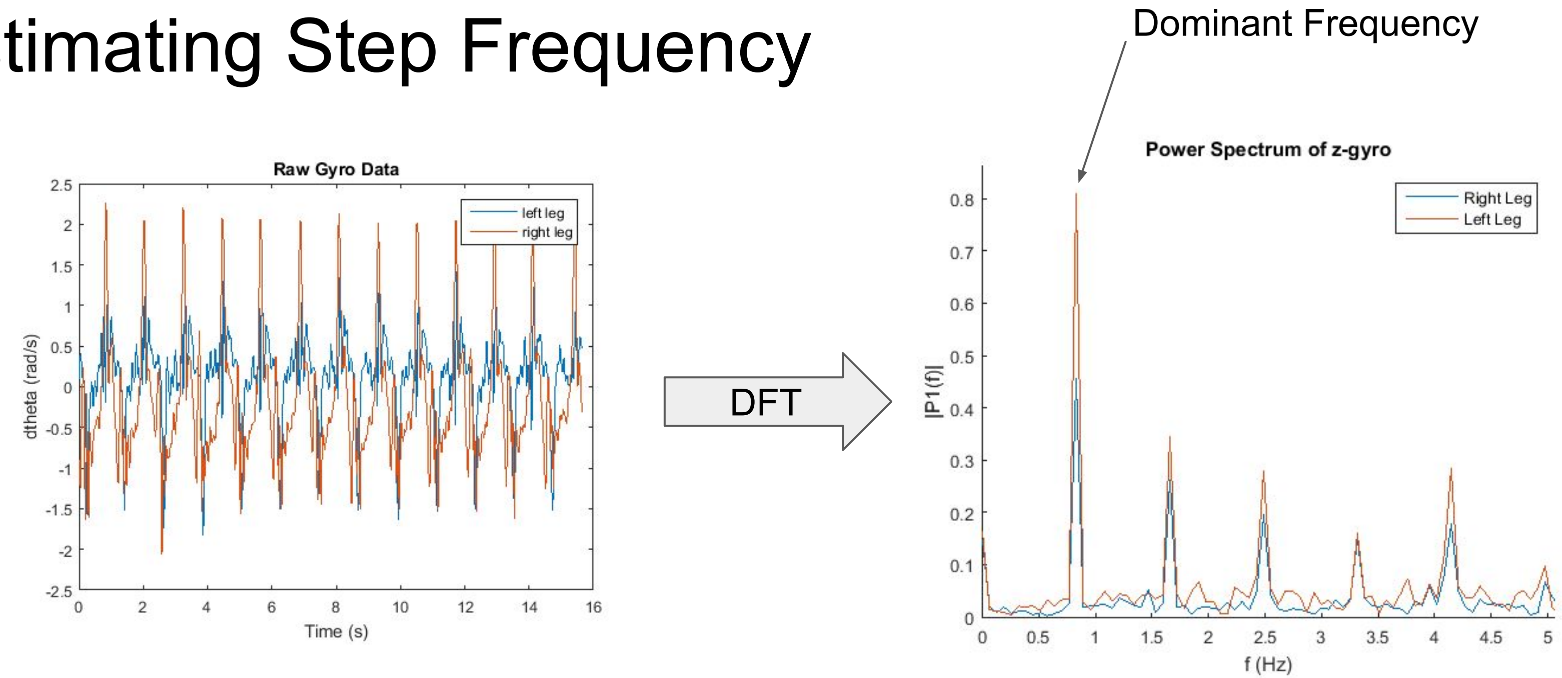
1. Moving average the accel data
2. Remove the accel due to the gravity
3. Determine the fixed frame x-acceleration (forward)
4. Double integrate the x-acceleration to obtain distance

Method used by Bamberg et. al.



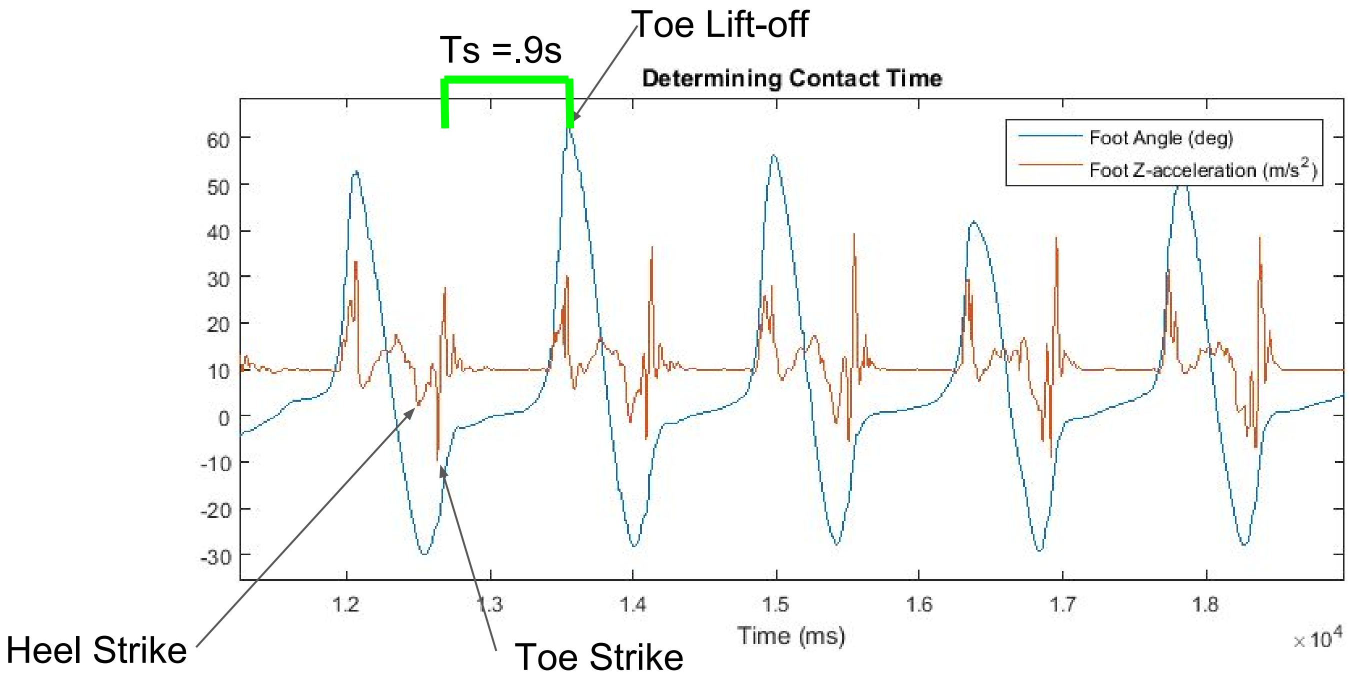
Bamberg, Stacy J. Morris, et al. "Gait analysis using a shoe-integrated wireless sensor system." *IEEE transactions on information technology in biomedicine* 12.4 (2008): 413-423.

Estimating Step Frequency



- The dominant frequency occurs at .8291Hz for both the left and right legs.
- 1.2061 seconds per step
- Method is fairly robust
- Works with all data

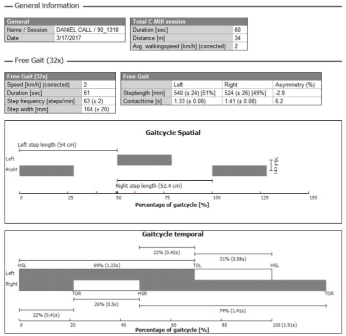
Estimating Contact Time



Experimental Validation:

Force Link C-Mill 3N treadmill

- Typically used for rehabilitating amputees and people with impaired eye-foot coordination
- Force plate detects foot location and force
- Computes gait parameters: asymmetry, contact time, step length, step freq, etc.



— General information —

General	
Name / Session	DANIEL CALL / 90_1318
Date	3/17/2017

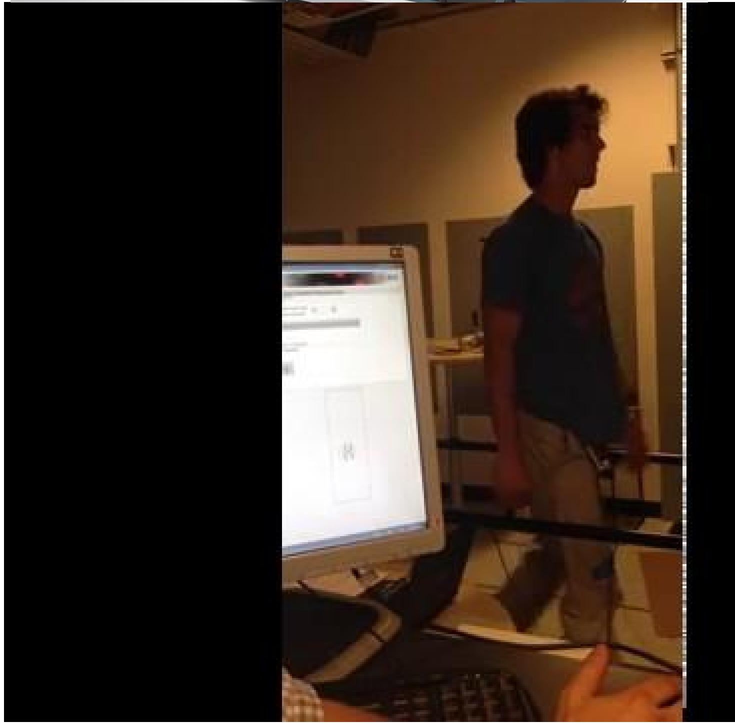
Total C-Mill session	
Duration [sec]	60
Distance [m]	34
Avg. walkingspeed [km/h] (corrected)	2

— Free Gait (32x) —

Free Gait (32x)	
Speed [km/h] (corrected)	2
Duration [sec]	61
Step frequency [steps/min]	63 (± 2)
Step width [mm]	164 (± 20)

Free Gait	Left	Right	Asymmetry (%)
Steplength [mm]	540 (± 24) [51%]	524 (± 26) [49%]	-2.8
Contacttime [s]	1.33 (± 0.08)	1.41 (± 0.08)	6.2

EPARC



Normal Walking

	IMU Result	Treadmill Result	% Difference
Step frequency	0.925 Hz	0.952 Hz	2.96%
Step Length L	-0.730 m	0.540 m	xxx
Step Length R	0.293 m	0.524 m	xxx
Length Asym	140%	-2.8%	
Contact Time L	1.40 s	1.33 s	-5%
Contact Time R	1.44 s	1.41 s	-2.1%
Time Asym	2.93%	6.2%	

Treadmill Result:

General information

General	
Name / Session	DANIEL CALL / 90_1318
Date	3/17/2017

Total C-Mill session	
Duration [sec]	60
Distance [m]	34
Avg. walkingspeed [km/h] (corrected)	2

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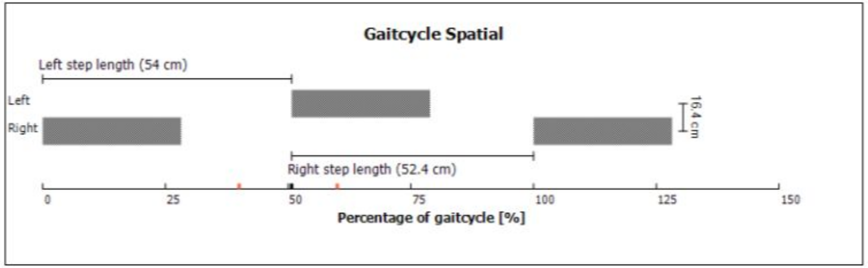
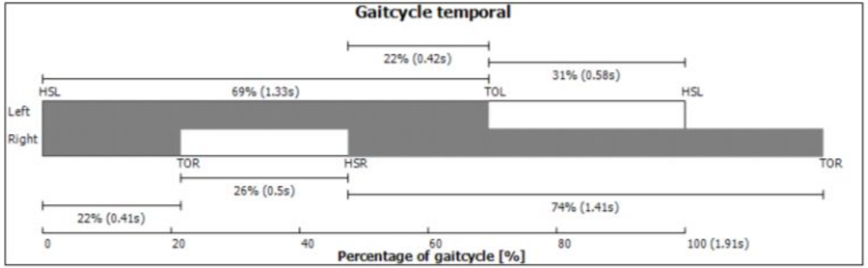
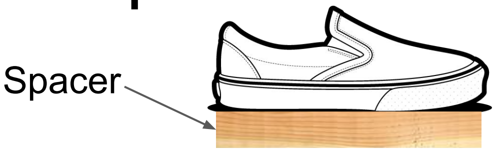




3cm Spacer Walking



	IMU Result	Treadmill Result	% Difference
Step frequency	1.4 Hz	1.4 Hz	0%
Step Length L	0.0196 m	0.563 m	xxx
Step Length R	0.223 m	0.641 m	xxx
Length Asym	1030%	12.2%	
Contact Time L	1.01 s	0.95 s	-5.94%
Contact Time R	0.973 s	0.95 s	-2.36%
Time Asym	2.93%	6.2%	

Treadmill Result:

General information

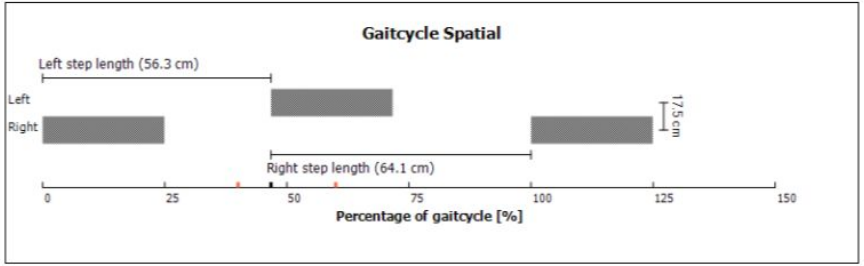
General	
Name / Session	DANIEL CALL / 90_1328
Date	3/17/2017

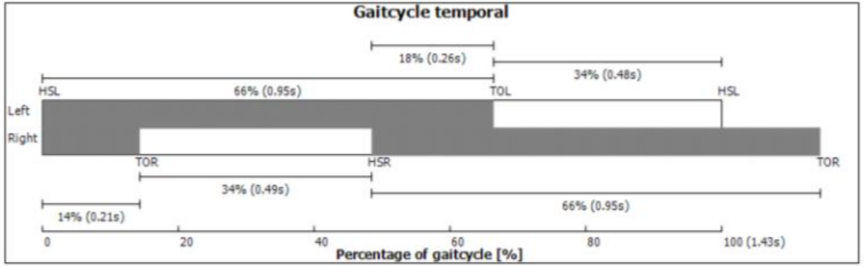
Total C-Mill session	
Duration [sec]	60
Distance [m]	50
Avg. walkingspeed [km/h] (corrected)	3

Free Gait (42x)

Free Gait (42x)	
Speed [km/h] (corrected)	3
Duration [sec]	60
Step frequency [steps/min]	84 (± 1)
Step width [mm]	175 (± 18)

Free Gait	Left	Right	Asymmetry (%)
Steplength [mm]	563 (± 26) [47%]	641 (± 26) [53%]	12.2
Contacttime [s]	0.95 (± 0.04)	0.95 (± 0.04)	-0.5





Conclusions

Our methods are accurate for:

- ‘Peak to peak’ contact time estimate, error < 6%
- Spectral analysis is very accurate for frequency estimate

Double integration failed for step length estimation: data was too noisy

The step length is the most useful metric in comparing discrepancy in leg length

Future "steps"

- Better sensor attachments
  - Reduce sensor movement
  - Reduce sensor noise
- Compare different sensor locations
- Other useful information for modeling gait
- Phase 2: Low cost adjustable prosthetic

Thanks!

Acknowledgments:

We are grateful for the groups and individuals who supported our research.

We would like to thank the **UCSD EPARC** team for giving us time on their C-Mill treadmill for data validation, **Deborah Forster** for connecting us with the EPARC group, and **Andre Szucs** for sharing his knowledge of prosthetics and providing guidance for our project.

Outline

- Motivation
- Current state of the art
- Designs considered
- Hardware and software
- Data collection and processing
- Treadmill Validation experiment
- Comparison of results
- Conclusions
- Future work

Gait Analysis Terminology

Step Length: distance between left and right leg steps

Step frequency: 1/steptime

Contact Time: time the foot is contact with the ground

Heel Strike: when the heel touches the ground

Toe Strike: when the foot is fully in contact with the ground