Appendix

Evaluating Leg Length Discrepancy during Total Hip Arthroplasty

Enhancing Conventional Surgical Workflows

Master Thesis
Jan S. van Ackeren

Evaluating Leg Length Discrepancy during Total Hip Arthroplasty

Enhancing Conventional Surgical Workflows

Master Thesis
November, 2020

Jan Sebastian van Ackeren

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Specialisation Medisign
Faculty of Industrial Design Engineering
Delft University of Technology

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Delft University of Technology

Expert Mentor
Dr. Stephan Vehmeijer
Orthopaedic Surgeon
Reinier de Graaf Gasthuis

Table of Contents

Appendix A
Design Brief

DESIGN FOR our future

TU Delft

IDE Master Graduation

Project team, Procedural checks and personal Project brief

This document contains the agreements made between student and supervisory team about the student's IDE Master Graduation Project. This document can also include the involvement of an external organisation, however, it does not cover any legal employment relationship that the student and the client (might) agree upon. Next to that, this document facilitates the required procedural checks. In this document:

- The student defines the team, what he/she is going to do/deliver and how that will come about.
- SSC E&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

USE ADOBE ACROBAT READER TO OPEN, EDIT AND SAVE THIS DOCUMENT
Download again and reopen in case you tried other software, such as Preview (Mac) or a webbrowser.

STUDENT DATA & MASTER PROGRAMME

Save this form according the format "IDE Master Graduation Project Brief_familyname_firstname_studentnumber_dd-mm-yyyy".
Complete all blue parts of the form and include the approved Project Brief in your Graduation Report as Appendix 1 !

family name	van Ackeren	Your master programme (only select the options that apply to you):	
initials	J.S.	given name Jan Sebastian	IDE master(s): ★ IPD ○ DfI ○ SPD
student number	4763033		2nd non-IDE master:
street & no.			individual programme: - - (give date of approval)
zipcode & city			honours programme: ○ Honours Programme Master
country			specialisation / annotation: ★ Medisign
phone			○ Tech. in Sustainable Design
email			○ Entrepeneurship

SUPERVISORY TEAM **

Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair	Ir. Iemkje A. Ruiter	dept. / section:	HCD / AED
** mentor	MSc. Tianyun (Helen) Yuan	dept. / section:	SDE / MD
2nd mentor	MSc. Hilbrand Bodewes		
organisation:	Zimmer Biomet		
city:	Delft	country:	Netherlands

Chair should request the IDE Board of Examiners for approval of a non-IDE mentor, including a motivation letter and c.v..

Second mentor only applies in case the assignment is hosted by an external organisation.

comments (optional): Additional contact persons include:
Dr. Stephan Vehmeijer (Reinier de Graaf Hospital)
Ir. Matthijs Netten (TU Delft)

Ensure a heterogeneous team. In case you wish to include two team members from the same section, please explain why.

TU Delft

Procedural Checks - IDE Master Graduation

APPROVAL PROJECT BRIEF

To be filled in by the chair of the supervisory team.

chair Ir. Iemkje A. Ruiter date - - signature

CHECK STUDY PROGRESS

To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair.
The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total: _____ EC
Of which, taking the conditional requirements into account, can be part of the exam programme _____ EC
List of electives obtained before the third semester without approval of the BoE

○ YES all 1st year master courses passed
○ NO missing 1st year master courses are:

name date - - signature

FORMAL APPROVAL GRADUATION PROJECT

To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **.
Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: ○ APPROVED ○ NOT APPROVED
Procedure: ○ APPROVED ○ NOT APPROVED

comments

name date - - signature

Initials & Name J.S. van Ackeren Student number 4763033
Title of Project Determining Leg Length Discrepancy (LLD) during Total Hip Arthroplasty

Personal Project Brief - IDE Master Graduation

TU Delft

Determining Leg Length Discrepancy (LLD) during Total Hip Arthroplasty — project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date 08 - 06 - 2020 — 06 - 11 - 2020 end date

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

Orthopaedic Surgery often involves joint reconstruction or joint replacement with an orthopaedic prosthesis. One of the most common procedures, in particular with elderly people, is hip replacement surgery or Total Hip Arthroplasty (THA). There are different approaches to a THA, one of which is the Anterior Approach. With this approach an interval between muscles is chosen to provide access to the hip joint, which is less invasive to the patient (improving recovery time) but limits the surgeons operational field of view. This thesis will primarily be dealing within the context of the Anterior Approach, yet may not be limited to it.

During the procedure, the surgeon will remove the Femoral head, clean and reamer the Acetabulum for receival of the implant cup and liner. Afterwards, the Femur is being prepared for the fitting process. During this process the surgeon will use increasing size templates of the Femoral stem implant (which simultaneously act as reamers - 14 sizes) in combination with a neck piece (3 sizes) and a head (7 sizes), to determine the correct configuration and therefore leg length and femoral offset. This evaluation and selection for the final configuration is aided by various X-Ray images taken during each fitting and compared to the reference image, taken right before surgery. Additionally, an assisting nurse, or in some cases the surgeon him-/herself will evaluate the length of the legs by straightening the pelvis, positioning the patient's feet perpendicular to their body and trying to line up the heels (or in some cases ankles), by pressing against them. This is an iterative process, which is not only time consuming, but also neither precise nor quantified.

In some cases, if not carried out correctly patients will end up suffering from leg length discrepancy (LLD), which not only reduces their quality of life but also the lifespan of the implant and in most cases leads to malpractice lawsuits against the orthopaedic surgeon. Post-operative LLD is reported after almost 1/3 of THAs and can range from 3 - 70 mm, leading to great discomfort of the patient.* Additionally, post-operative LLD may lead to other problems with the musculoskeletal and nervous system (e.g. Sciatica).

Subsequently, an opportunity presents itself for increasing the accuracy of the implant configuration and evaluation process, while streamlining the work flow and efficiency of the surgical procedure itself. Furthermore, tackling this problem effectively would result in more positive post surgical results and less negative consequences for all parties.

(*Source: Dundon, J. M., & Mays, R. R. (2019, July 15). Revising Substantial Leg Length Discrepancy in Total Hip Arthroplasty Using Computer-assisted Navigated Systems: A Case Series of Three Patients. Retrieved March 1, 2020, from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6741389/)

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Personal Project Brief - IDE Master Graduation

TU Delft

introduction (continued): space for images

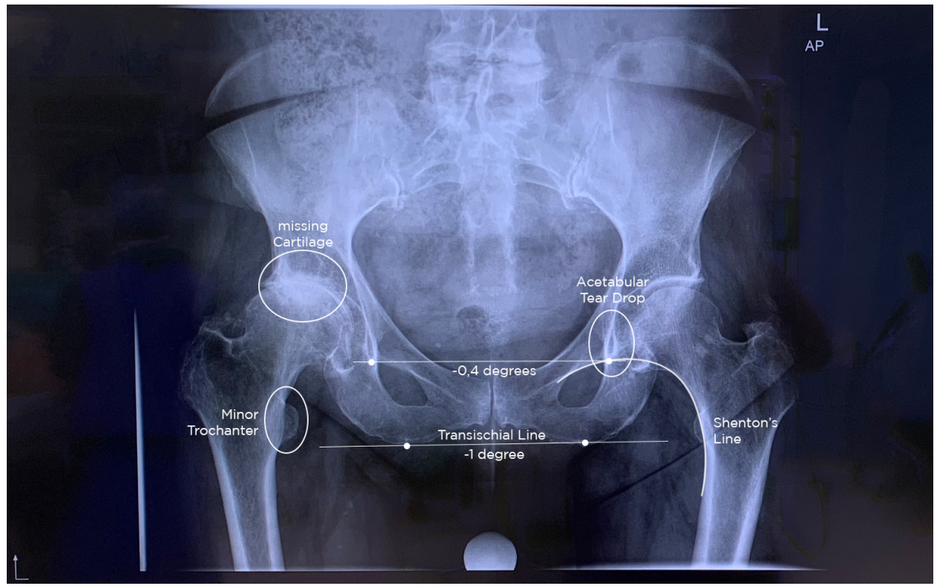


image / figure 1: Important reference points when evaluating pre-operative LLD (on X-Ray)

image / figure 2: Left: Fitting instruments Right: Nurse evaluating LLD by pushing against the heels

Personal Project Brief - IDE Master Graduation

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

Assessing LLD during THA is not only one of the most time consuming parts of the procedure, but it is also among the most important evaluations during the procedure. Based on the evaluation surgeons will choose the implant configuration that the patient will have to live with for 10-15 years. In case of the implant not being placed correctly, the patient will need to compensate with corrective shoe insoles, corrective surgery may be performed and subsequent malpractice lawsuits towards the surgeon (and team) may follow. Either scenario is unfavourable to the patient, surgeon and clinic, as it may result in discomfort (patient), damage to reputation (surgeon and clinic) and increased costs for all parties involved.

The primary scope of this project will therefore be to make the procedure of assessing leg length in real-time during THA more accurate, reliable and efficient. The secondary scope will be to factor in femoral offset and include it into the evaluation process.

THA is the primary documented cause of post-operative LLD. Yet, Literature suggests that there may be other orthopaedic surgeries that cause perceived post-operative LLD, such as knee replacement surgery or total knee arthroplasty (TKA).** Therefore the stretch goal of this project, will be to develop a solution that is not only applicable for THA, but could be used for other procedures that require accurate reference taking, evaluation and repositioning of the human anatomy, such as TKA.

(**Source: Tipton, S., Sutherland, J., & Schwarzkopf, R. (2015, September). Change in Limb Length After Total Knee Arthroplasty. Retrieved March 1, 2020, from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4536512/)

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

In order to tackle the proposed problem, this research will examine existing literature describing methods for LLD evaluation. Thereafter, research will be expanded to evaluate the feasibility and desirability of various Indoor Positioning, Spacial Reference and Tracking systems: mechanical, electronic and digital.

Research question:
How can Indoor Positioning, Spacial Reference and Tracking Systems help to prevent post-operative Leg Length Discrepancy (LLD) in real-time during Lower Limb Arthroplasty (LLA)?

Research:
Current LLD evaluation methods, upcoming technologies and contextual bottlenecks.
Research into systems, such as Ultrasound Identification, Infrared, Ultrawide band, Laser trackers; and mechanical.

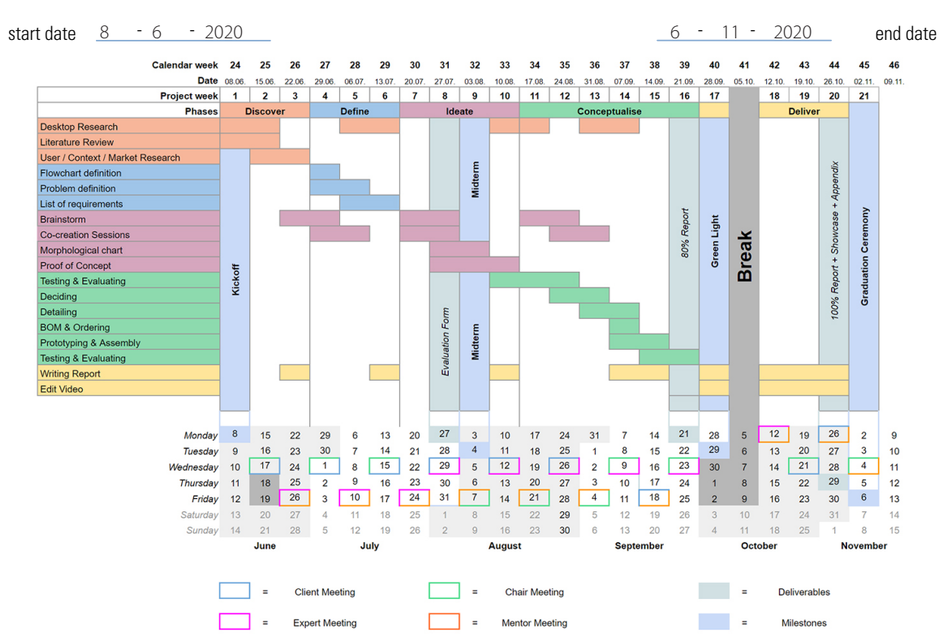
Design:
Develop a (non-)invasive device or method to enable real-time evaluation of leg length during an THA in the OR, using methods based on current technologies and trends. The solution may be mechanical, electronic or digital (software) based; or potentially a combination.

Create:
A detailed concept and physical prototype, ready for pre-production engineering.
A human centred approach is imperative, so that the solution will be supportive of the user's tasks without negatively impacting any aspect of the surgical procedure.

Personal Project Brief - IDE Master Graduation

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.



The planning for this project is divided into five phases: Discover, Define, Ideate, Conceptualise and Deliver. During each phase, adequate methods, tasks and activities have been chosen in order to facilitate the progress. Some tasks, such as desktop research or brainstorms, are iterative in nature and will occur in many phases throughout the entire process.

The analytical phases (discover and define) will be executed in the first third of the project, so that by the Midterm meeting, opportunity areas, clear directions and initial ideas can be discussed. During the Ideation and Conceptualisation phases, the project will turn more concrete and tangible by the day. In anticipation for a lack of time towards the end, each phase will be finalised and documented through report writing.

The calendar indicates meetings, deliverables and milestones. Meetings are scheduled in 2 week intervals and will take place in alternating pairs. The pairs change in 6 week intervals and get randomised in the last month. It is to be taken into consideration, that these pairs are flexible in their arrangement and may be adjusted during the course of the project.

The project will be executed in a full-time fashion, whereas I will be working on a part-time Student Assistant (SA) position in my free time. The planning with regards to the SA position will be re-evaluated by the Midterm meeting. Furthermore, I will allow myself a small break end September, just after the Green Light meeting.

Personal Project Brief - IDE Master Graduation

TU Delft

MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

Whereas others feel estranged in hospitals and ORs, they feel strangely familiar to me.

To give you some background, I come from a medical family and everyone who isn't a surgeon, is a scientist of some sort in related fields (e.g. biology). I assisted my father in a cataract surgery for the first time, when I was 16; after which he told me about the first time he assisted my grandfather during open heart surgery at the age of 16. My grandfather from my mom's side was a teacher of engineering at the military academy in former Yugoslavia and although I barely have any recollection of him, our family home is filled with things he made. This was my reality while growing up and I always wondered how I can combine my creative interests with my family values and heritage.

Creating is what drives me. In particular creating useful products or tools for people to use is what drives me. A useful product or tool can be the difference between a mediocre job and a job well done. Tools are what differentiates us Humans from many other species and formed us into the high performance species we are today. On the contrary it means, that when we want to achieve peak performance, we are at the mercy of our tools. Surgeons in particular need to be high performing and therefore deserve the adequate tools to do so. This has been my motivation, not only for this Thesis, but for some time now and is the reason for me wanting to work on a project, that is not only medical, but surgical in nature.

I am excited that after having started IPD with a Medisign specialisation two years ago and having managed to secure a project of surgical nature, I get to work with and hopefully improve the work of healthcare professionals in the OR.

But aside from creating a complementary tool for Orthopaedic surgery, there are other ambitions that I have for this project. I want to deepen my understanding of mechatronic systems and work on integration of tangible and digital product features. Additionally, I want to demonstrate (more to myself than anyone else) that I am fully capable of independently developing a complex product, so that I can be sure that I will be a reliable team player in the future.

After all, product development as well as surgery is a team sport.

FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.

Initials & Name J.S. van Ackeren Student number 4763033

Title of Project Determining Leg Length Discrepancy (LLD) during Total Hip Arthroplasty

Appendix B

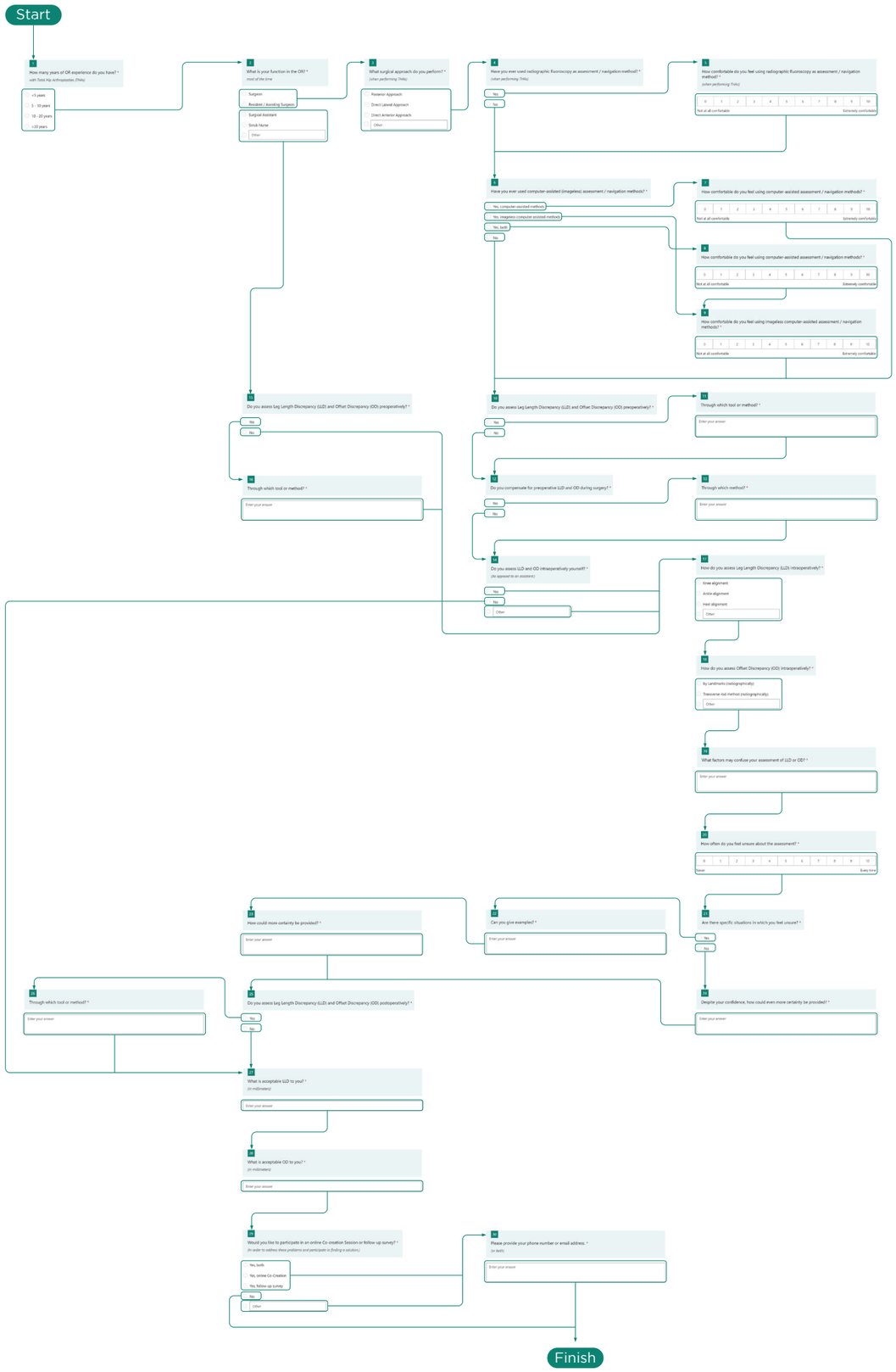
LROI Report 2019

Due to the size of the report the access link is provided instead:

https://www.lroi-report.nl/app/uploads/2020/10/PDF-Online-LROI-annual-report-2019-min.pdf

Appendix C

Survey Flowchart
+ Questions



1. Would you like to participate in this study?

More Details

Yes	11
No	0

2. How many years of OR experience do you have?

More Details

<5 years	1
5 - 10 years	4
10 - 20 years	3
>20 years	3

3. What is your function in the OR?

More Details

Surgeon	6
Resident / Assisting Surgeon	3
Surgical Assistant	0
Scrub Nurse	2
Other	0

4. What surgical approach do you perform?

More Details

Posterior Approach	3
Direct Lateral Approach	3
Direct Anterior Approach	7
Other	0

5. Have you ever used radiographic fluoroscopy as assessment / navigation method?

More Details

Yes	5
No	4

6. How comfortable do you feel using radiographic fluoroscopy as assessment / navigation method?

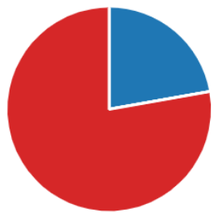
More Details

Promoters	1
Passives	4
Detractors	0

7. Have you ever used computer-assisted (imageless) assessment / navigation methods?

More Details

Yes, computer-assisted methods	2
Yes, imageless computer assist...	0
Yes, both	0
No	7



8. How comfortable do you feel using computer-assisted assessment / navigation methods?

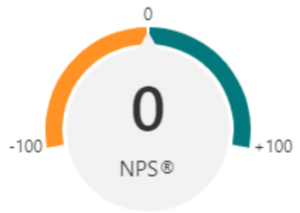
More Details

Promoters	0
Passives	1
Detractors	1

9. How comfortable do you feel using computer-assisted assessment / navigation methods?

More Details

Promoters	0
Passives	0
Detractors	0



10. How comfortable do you feel using imageless computer-assisted assessment / navigation methods?

More Details

Promoters	0
Passives	0
Detractors	0

11. Do you assess Leg Length Discrepancy (LLD) and Offset Discrepancy (OD) preoperatively?

More Details

Yes	9
No	0

12. Through which tool or method?

More Details

9

Responses

Latest Responses

"X-ray"

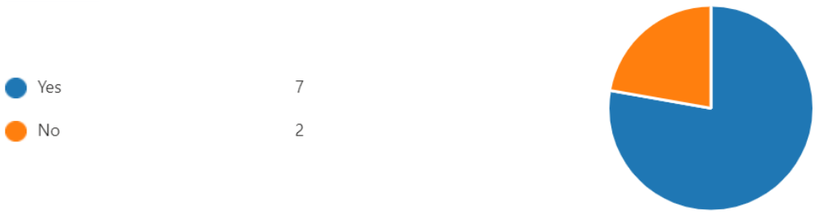
12. Through which tool or method?

9 Responses

ID ↑	Name	Responses
1	anonymous	Physical examination LLD and bij rontgen evaluation OD
2	anonymous	Templating software Orthoview mainly, and manually during surgery, anatomical landmarks (obturator, greater and lesser trochanter)
3	anonymous	Physical examination with boards
4	anonymous	X ray, kliniek
5	anonymous	just checking the heels of the patient in supine position and on the out patient clinic in standig position feeling the iliac crest hight.
6	anonymous	Physical examination X pelvis level of lesser trochanter
7	anonymous	Manual
8	anonymous	On conventional x-ray
9	anonymous	X-ray

13. Do you compensate for preoperative LLD and OD during surgery?

More Details



14. Through which method?

More Details

7
Responses

Latest Responses

"Fluoroscopy, and clinical assessment"

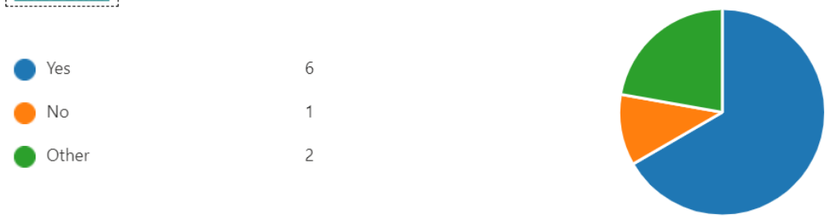
14. Through which method?

7 Responses

ID ↑	Name	Responses
1	anonymous	By radiographic fluoroscopy
2	anonymous	Based on pre-op templating, manually during surgery, anatomical landmarks (obturator, greater and lesser trochanter)
3	anonymous	Sizing the prosthesis and head length
4	anonymous	Offset, kopje
5	anonymous	Xray
6	anonymous	Resection osteotomie higher or lower, stem of prothesis which different Angle.
7	anonymous	Fluoroscopy, and clinical assessment

15. Do you assess LLD and OD intraoperatively yourself?

More Details



15. Do you assess LLD and OD intraoperatively yourself?

9 Responses

ID ↑	Name	Responses
1	anonymous	Yes
2	anonymous	Yes
3	anonymous	Yes
4	anonymous	Yes
5	anonymous	Yes
6	anonymous	Offset template. Lld intra op
7	anonymous	Yes
8	anonymous	No
9	anonymous	Done by the runner nurse

16. Do you assess Leg Length Discrepancy (LLD) and Offset Discrepancy (OD) preoperatively?

More Details

17. Through which tool or method?

More Details

2
Responses

Latest Responses

"by heelposition of both legs and by the ankle position of both legs (la...

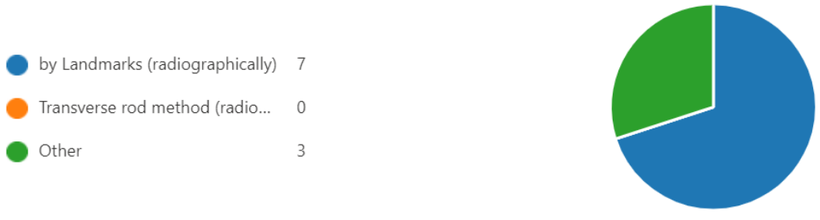
"X-ray en enkel in 90 graden "

18. How do you assess Leg Length Discrepancy (LLD) intraoperatively?

More Details

19. How do you assess Offset Discrepancy (OD) intraoperatively?

More Details



18. How do you assess Leg Length Discrepancy (LLD) intraoperatively?

10 Responses

ID ↑	Name	Responses
1	anonymous	Heel alignment
2	anonymous	All three above and tissue/ligament laxity
3	anonymous	Knee alignment
4	anonymous	Tip trochanter, centrum van rotatie
5	anonymous	Heel alignment
6	anonymous	Heel and telescoping
7	anonymous	Heel alignment
8	anonymous	Ankle and heel
9	anonymous	Heel alignment
10	anonymous	Heel alignment

19. How do you assess Offset Discrepancy (OD) intraoperatively?

10 Responses

ID ↑	Name	Responses
1	anonymous	by Landmarks (radiographically)
2	anonymous	Rely on pre-op templated offset
3	anonymous	Inkt preopetatively
4	anonymous	by Landmarks (radiographically)
5	anonymous	by Landmarks (radiographically)
6	anonymous	None, template only
7	anonymous	by Landmarks (radiographically)
8	anonymous	by Landmarks (radiographically)
9	anonymous	by Landmarks (radiographically)
10	anonymous	by Landmarks (radiographically)

20. What factors may confuse your assessment of LLD or OD?

More Details

10
Responses

Latest Responses
"Poisition pelvis"
"position of the patient on the OR table and the position of the OR ta...
"Stability "

20. What factors may confuse your assessment of LLD or OD?

10 Responses

ID ↑	Name	Responses
1	anonymous	Rotation, total hip replacement or hip dysplasia on the other side
2	anonymous	Change of patiënt position during surgery
3	anonymous	Tilting of the pelvis intra operatively
4	anonymous	Ligging, cuppositie
5	anonymous	when the patient is lying on their left or right side
6	anonymous	Quality and leg position(rotation) on pre op pelvic X-ray
7	anonymous	Settings on xray
8	anonymous	Stability
9	anonymous	position of the patient on the OR table and the position of the OR table itsself
10	anonymous	Poisition pelvis

21. How often do you feel unsure about the assessment?

More Details

Promoters	0
Passives	0
Detractors	10

22. Are there specific situations in which you feel unsure?

More Details

Yes	4
No	6

23. Can you give examples?

More Details

4
Responses

Latest Responses

23. Can you give examples?

4 Responses

ID ↑	Name	Responses
1	anonymous	When there are situations like dysplAsia of the other side
2	anonymous	Sterke varus of valgus heupen
3	anonymous	when the assement is not in line with my expectations
4	anonymous	Unstable hip

24. How could more certainty be provided?

More Details

4
Responses

Latest Responses

24. How could more certainty be provided?

4 Responses

ID ↑	Name	Responses
1	anonymous	By having a standardized reference tool
2	anonymous	Doirlichting
3	anonymous	?
4	anonymous	More anatomic landmarks

25. Despite your confidence, how could even more certainty be provided?

More Details

6
Responses

Latest Responses
"Device"
"x ray on the OR"
"X"

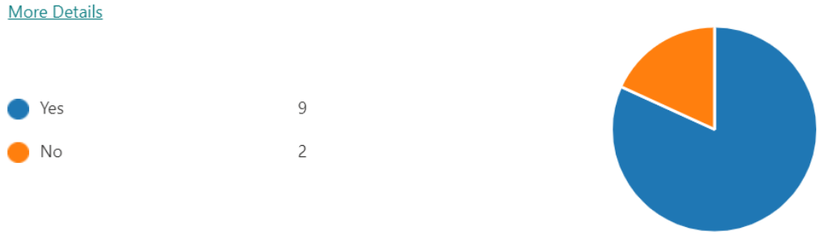
25. Despite your confidence, how could even more certainty be provided?

6 Responses

ID ↑	Name	Responses
1	anonymous	Xray
2	anonymous	Don't know, May be with CAS of it is really surgeon friendly
3	anonymous	Knee measurement
4	anonymous	X
5	anonymous	x ray on the OR
6	anonymous	Device

26. Do you assess Leg Length Discrepancy (LLD) and Offset Discrepancy (OD) postoperatively?

More Details



27. Through which tool or method?

More Details

9
Responses

Latest Responses
"X-ray and patient perception"
"Enkel methode"

27. Through which tool or method?

9 Responses

ID ↑	Name	Responses
1	anonymous	Physical exam
2	anonymous	Manually and post op ap pelvis xray
3	anonymous	Weight bearing x-ray and boards
4	anonymous	Foto
5	anonymous	heel alignement in bed and on postoperative x-ray
6	anonymous	LLB on table after removal of drapes Ofset post op X-ray compare to pre op
7	anonymous	X-Ray
8	anonymous	Enkel methode
9	anonymous	X-ray and patient perception

28. What is acceptable LLD to you?

More Details

11
Responses

Latest Responses
"5 mm"
"10"
"I'm not a doctor "

28. What is acceptable LLD to you?

11 Responses

ID ↑	Name	Responses
1	anonymous	Up to 10 mm
2	anonymous	5
3	anonymous	1-1,5 cm
4	anonymous	0,5
5	anonymous	<1cm
6	anonymous	Line lesser trochanter
7	anonymous	0,5 mm
8	anonymous	5-10mm
9	anonymous	I'm not a doctor
10	anonymous	10
11	anonymous	5 mm

29. What is acceptable OD to you?

More Details

11
Responses

Latest Responses
"5mm"
"5"
"I'm not a doctor "

30. Would you like to participate in an online Brainstorm / Co-creation Session or follow-up survey?

More Details

29. What is acceptable OD to you?

11 Responses

ID ↑	Name	Responses
1	anonymous	Up to 5 mm
2	anonymous	5
3	anonymous	0,5. - 1 cm
4	anonymous	0,5
5	anonymous	no cut off point
6	anonymous	Never measure. When looks okay to me in happy
7	anonymous	5 mm
8	anonymous	5mm
9	anonymous	I'm not a doctor
10	anonymous	5
11	anonymous	5mm

32. Is there any final comment you would like to make?

9 Responses

ID ↑	Name	Responses
1	anonymous	Good luck
2	anonymous	Clinical relevance to be kept in mind. Perceived vs actual leg length discrepancy. And correlation with patiënt satisfaction
3	anonymous	No
4	anonymous	Hoop dat relevantie LLD en OD literatuur meegenomen wordt. LLD belang overschat zolang het minder dan 1 cm is
5	anonymous	good luck! looking forward to your conclusions
6	anonymous	Keep it simple
7	anonymous	Nice research
8	anonymous	Good luck
9	anonymous	Great survey

Appendix D

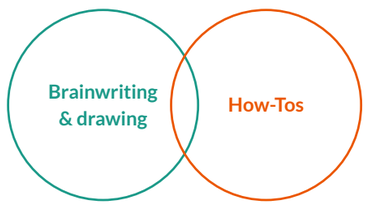
Co-Creation
Session Slides

Co-Creation Session #1

Evaluating Leg Length Discrepancy during Total Hip Arthroplasty (THA)

Enhancing Conventional Surgical Workflows

Methodology



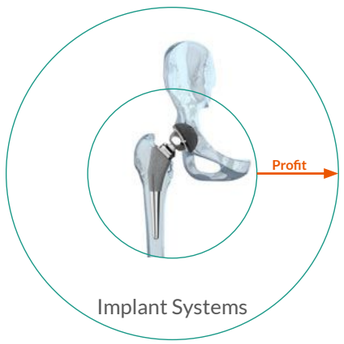
1. Read your 'How-To…'
2. Write, draw, copy & paste… everything goes!
3. Time up? Finish last idea …
4. Study next slide ...
5. Repeat!

Program

Company Introduction

Introduction - Company

"Zimmer Biomet designs, develops, manufactures and markets **orthopaedics products**, including knee, hip, shoulder, elbow, foot and ankle artificial joints and dental prostheses."



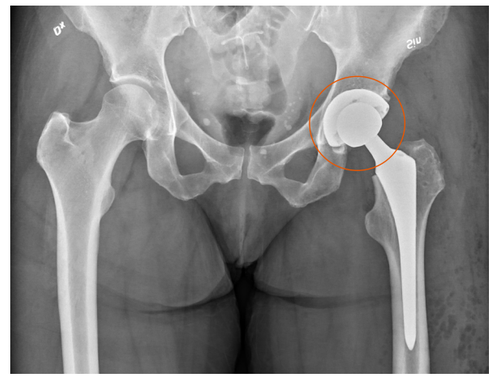
Implant Systems

Tools

Context Introduction

Introduction - Context

"During THA the **diseased ball and socket of the hip joint are completely removed** and replaced with artificial materials. A femoral component (stem, neck & head) is inserted into the femur (thigh bone) and an acetabular cup is placed in the acetabulum socket of the pelvis."



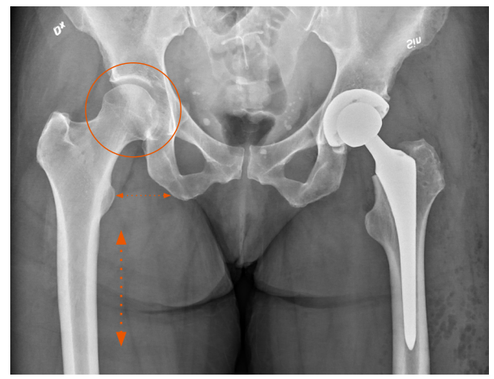
Introduction - Context

Possible Unintended Consequences

1. Leg Length change
2. Offset change

Conclusion

Pre-, Intra & Postoperative evaluations of Leg Length and Offset are desirable.



Market Introduction

Introduction - Market

Mechanical Tools

- Iliac Fixation Pins
- Intraoperative Calipers
- PCA Limb Lengthening Gauge

Computer Assisted Systems

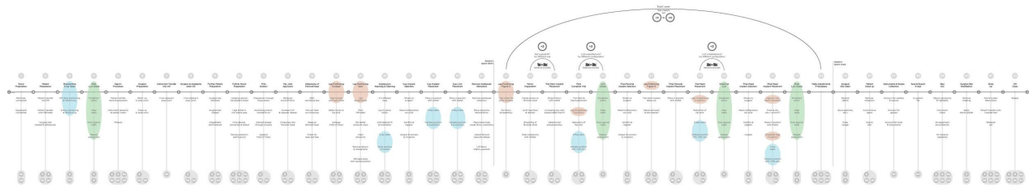
- Real-time Analysis Software
- Software Navigation Systems
- Tracking Systems

Robot Assisted Systems

- Robotic Arm System

Surgical Protocol Introduction

Introduction - Surgical Protocol



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Solution Criteria

General

In case of Genius… Ignore!

1. Patient in supine position (on their back)
2. 1 min measurement (max.)
3. Non-invasive measurement
4. Symmetric measurement
5. Loaded measurement

Co-Creation Set-up

Set-up

- 1 Problem Statement per slide
- 5 Slides = 6 rounds
- 2 min per round
- 1 min to drop ideas onto slide
- Repeat

Use

- A4 paper
- Drawing Tablet
- Google Images
- Text Box

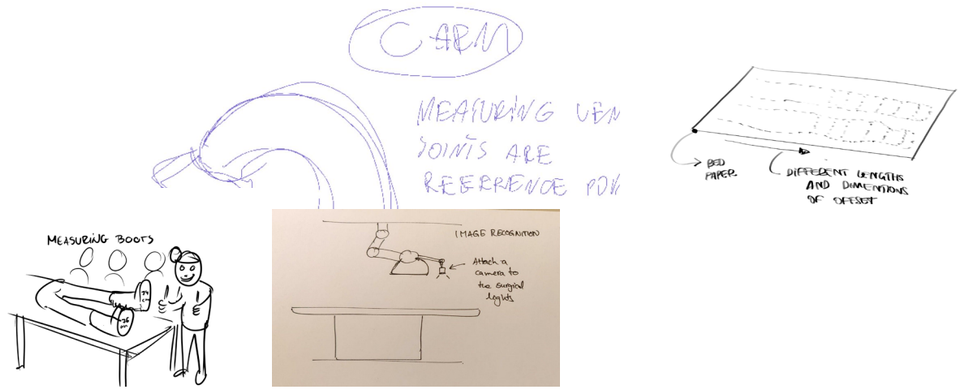
Co-Creation Sessions

Round 1

Slide 1

How to measure leg length or offset non-invasively?

(asymmetric - single leg OR symmetric - both legs)

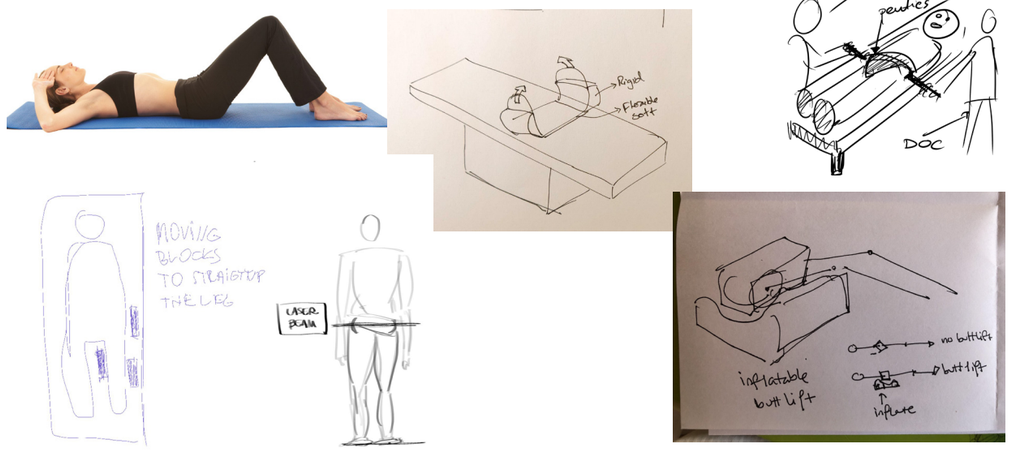


Taking the data from CT to analyse

Slide 2

How to square up the pelvis before a measurement?

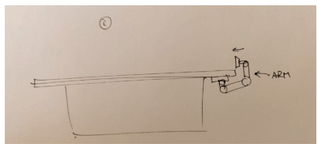
(for symmetry)

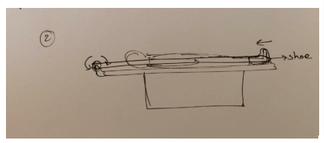


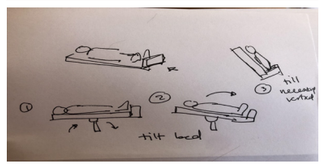
Slide 3

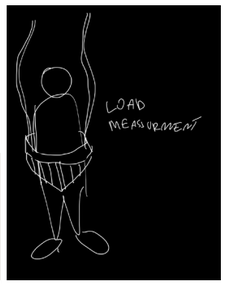
How to simulate (weight-bearing) loads on the patient's legs?

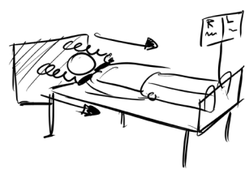
(while in supine position)

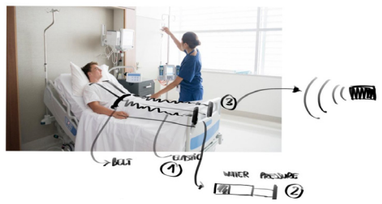


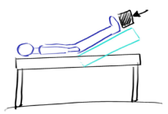












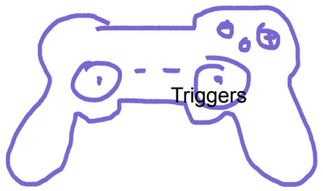
Slide 5

How to give the user a sense of empowerment and control?

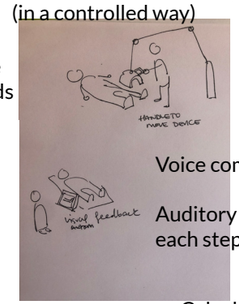
(during a measurement)

Feedback loop

Integrate different options of measurement and ask for choice from medic between the methods

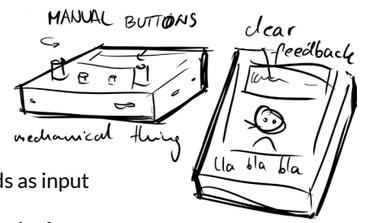


Create errors voluntarily (in a controlled way)



Voice commands as input

Auditory feedback after each step as beeps



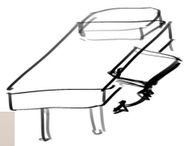
Calculate but ask for evaluation

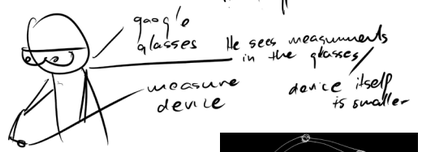
Ask for physical check aside from an automated measurement

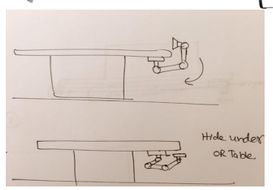
Slide 4

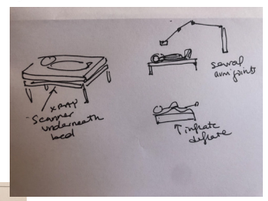
How to create a non-obtrusive device?

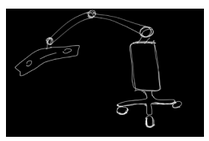
(only present when needed / never in the way)

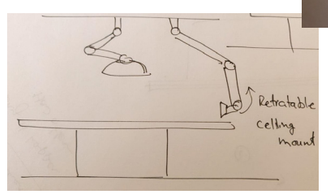










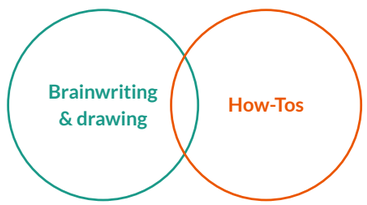


Co-Creation Session #2

Evaluating Leg Length Discrepancy during Total Hip Arthroplasty (THA)

Enhancing Conventional Surgical Workflows

Methodology



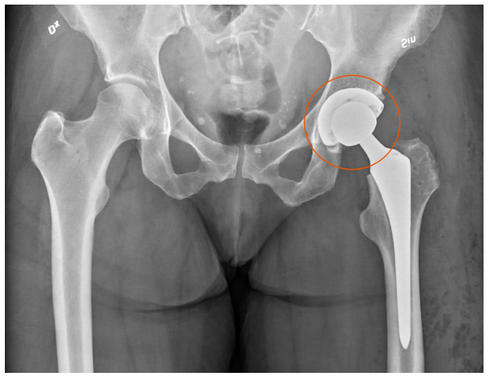
1. Read your 'How-To…'
2. Write, draw, copy & paste… everything goes!
3. Time up? Click a picture & send …
4. Study next slide ...
5. Repeat!

Program

Context
Introduction

Introduction - Context

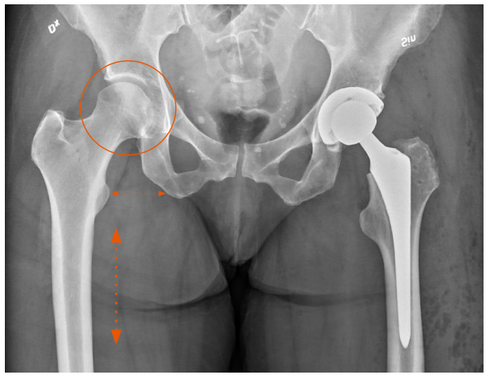
"During THA the **diseased ball and socket of the hip joint are completely removed** and replaced with artificial materials. A femoral component (stem, neck & head) is inserted into the femur (thigh bone) and an acetabular cup is placed in the acetabulum socket of the pelvis."



Introduction - Context

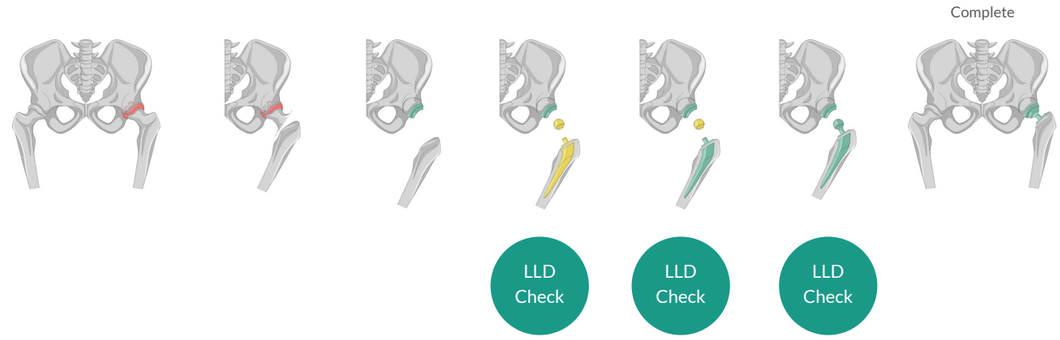
Possible Unintended Consequences

1. Leg Length change
2. Offset change

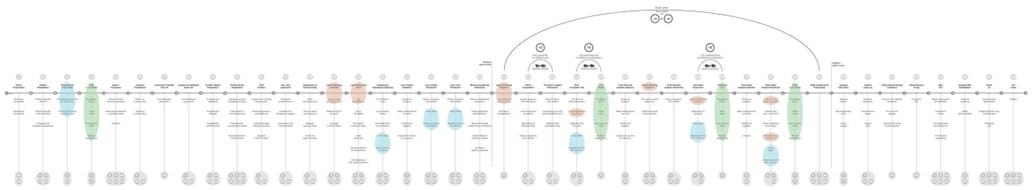


Surgical Protocol Introduction

Introduction - Surgical Protocol



Introduction - Surgical Protocol



https://prezi.com/1mvkmhw0gkno/untitled-prezi/?present=1

OR
Introduction

Introduction - Context

Preoperative

1. Line up Heels
2. Straighten Pelvis
   (move feet around)
3. Centre Feet
4. Apply pressure
   (via thumbs)
5. Feel Difference

1. Centre Feet
   (pointing out at 45°)
2. Line up with Chin
   (straighten pelvis)
3. See difference

Introduction - Context

OR Setup

1. Surgical site
   (sterile zone)
2. Feet
   (non-sterile zone)
3. Vertical Drape
   (transparent)
4. X-Ray
   (on screen)

1. Surgical site
   (sterile zone)
2. Feet
   (sterile zone)
3. Vertical Drape
   (non-transparent)
4. Template
   (on screen)

Introduction - Context

Solution Criteria

Solution Criteria

General

In case of Genius… Ignore!

1. Non-invasive
2. Non-disruptive to Workflow
3. Simplicity over complexity!

Co-Creation Set-up

Set-up

- 1 Problem Statement per slide
- 7 Slides = 7 rounds
- 2 min per round
- 1 min to study next slide
- Repeat

Use

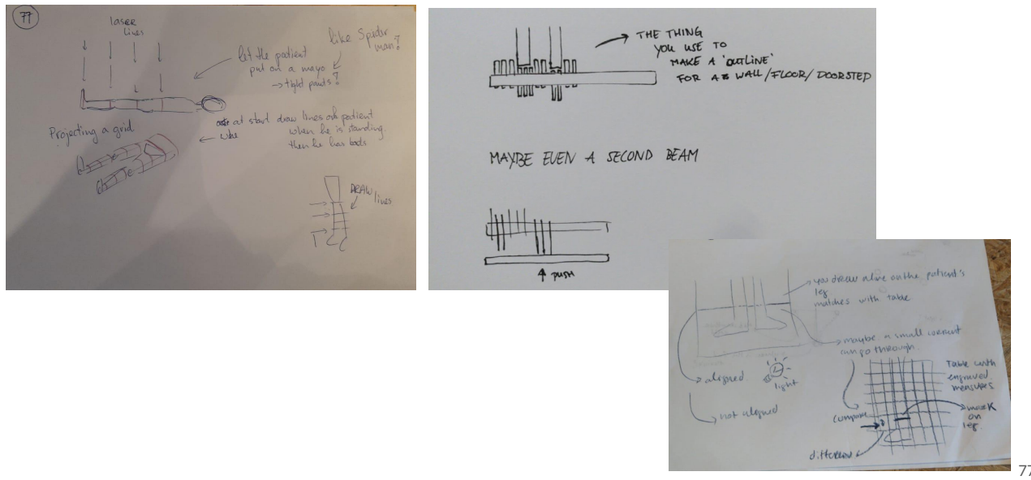
- A4 paper
- Drawing Tablet
- Google Images
- Text Box

Co-Creation Sessions

Round 1

Slide 1

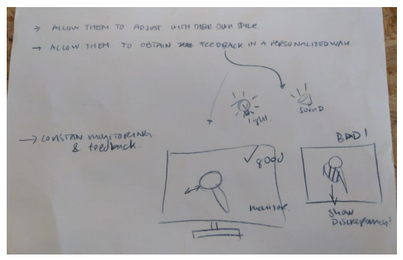
How to measure leg length (discrepancy)?

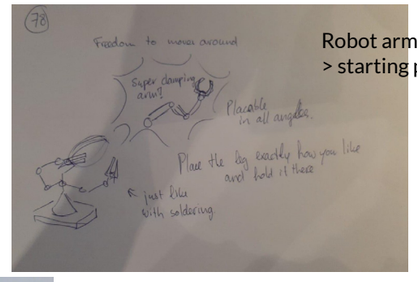


Slide 2

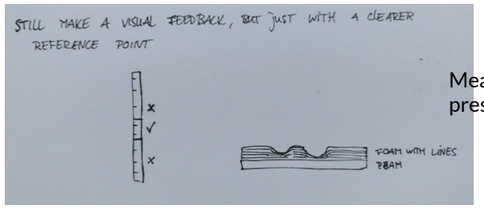
How to give the user a sense of empowerment and control?

(during a measurement)





Robot arm for reference
> starting position

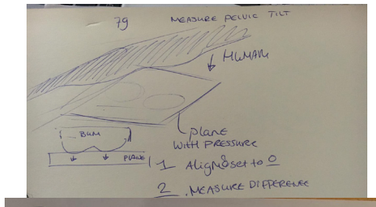


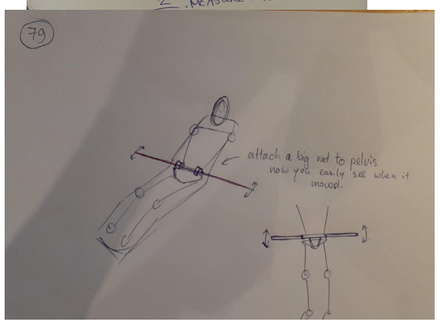
Measure
pressure

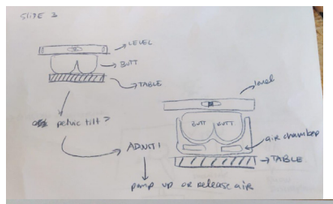
Instead of table
Hang person in harness

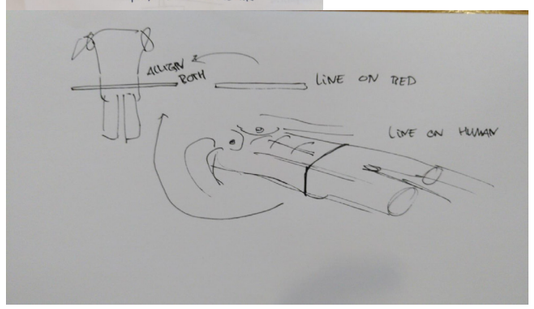
Slide 3

How to measure pelvic tilt?









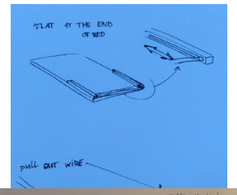
Tu delft
Robotic hand
(soft robotics)

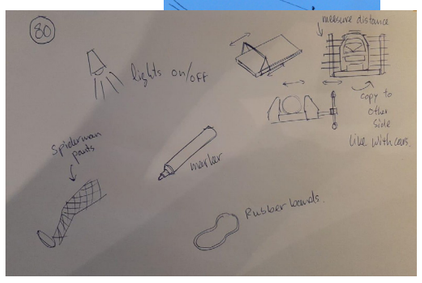
Slide 4

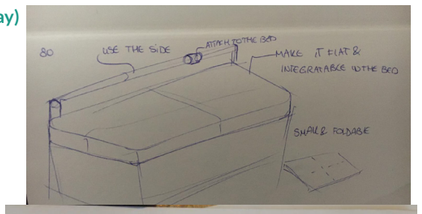
How to make a non-obtrusive device?

(only present when needed / never in the way)

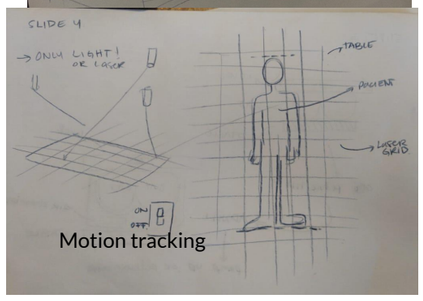
Bike frame
Alignment
(look up)







Automotive
Clay modelling
Rod measuring tool

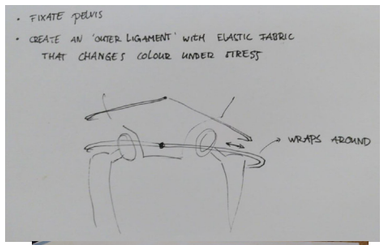


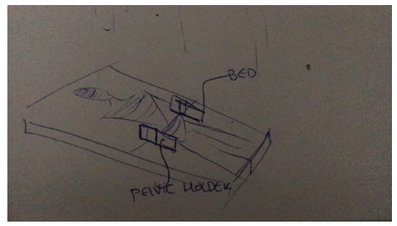
Motion tracking

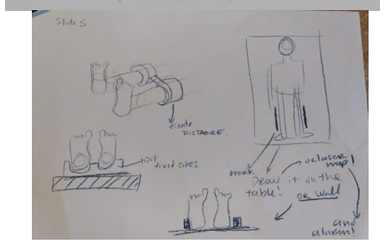
Nemo ,museum
Sand projection box

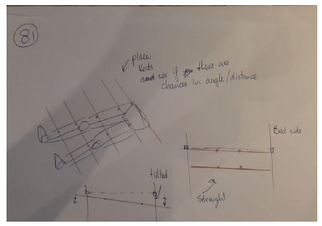
Slide 5

How to measure leg offset (discrepancy)?



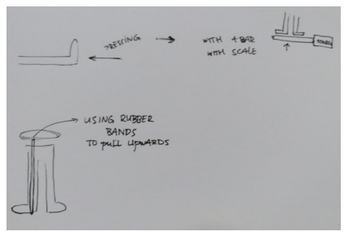


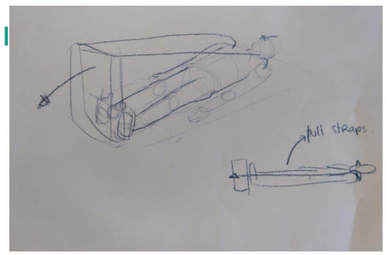


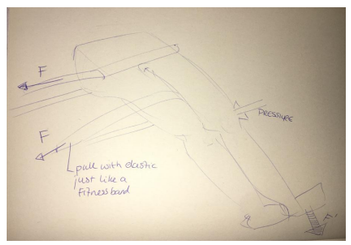


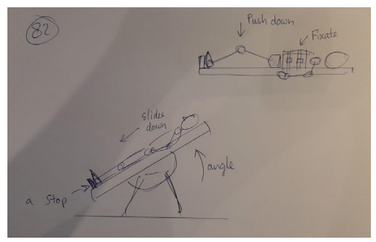
Slide 6

How to simulate loads on the patient's l



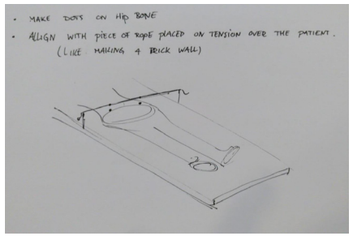


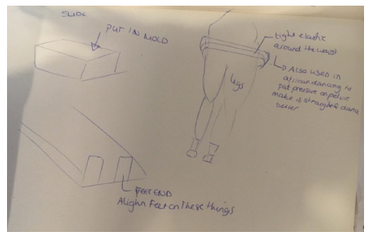


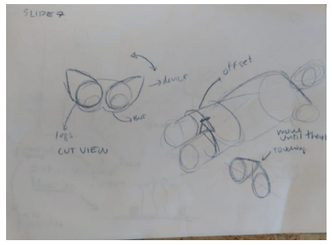


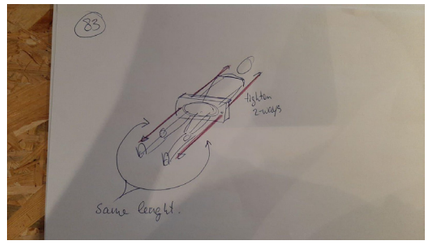
Slide 7

How to straighten the pelvis before a measurement?







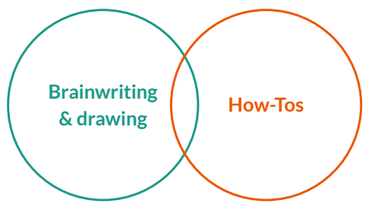


Co-Creation Session #3

Evaluating Leg Length Discrepancy during Total Hip Arthroplasty (THA)

Enhancing Conventional Surgical Workflows

Methodology



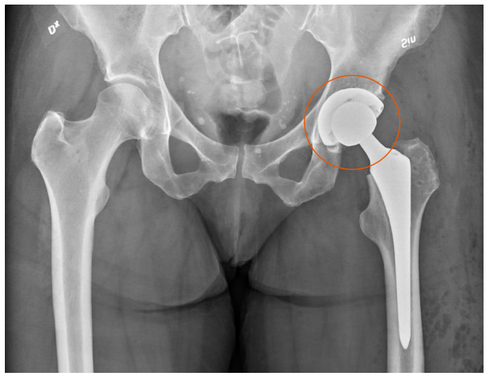
1. Read your 'How-To…'
2. Write, draw … everything goes!
3. Time up? Click a picture & send …
4. Study next slide …
5. Repeat!

Program

Problem Introduction

Introduction - Problem

"During THA the **diseased ball and socket of the hip joint are completely removed** and replaced with artificial materials. A femoral component (stem, neck & head) is inserted into the femur (thigh bone) and an acetabular cup is placed in the acetabulum socket of the pelvis."

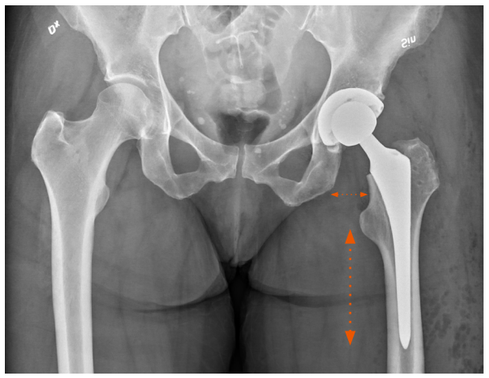


Introduction - Problem

Possible
Unintended Consequences

1. Leg Length change
2. Offset change

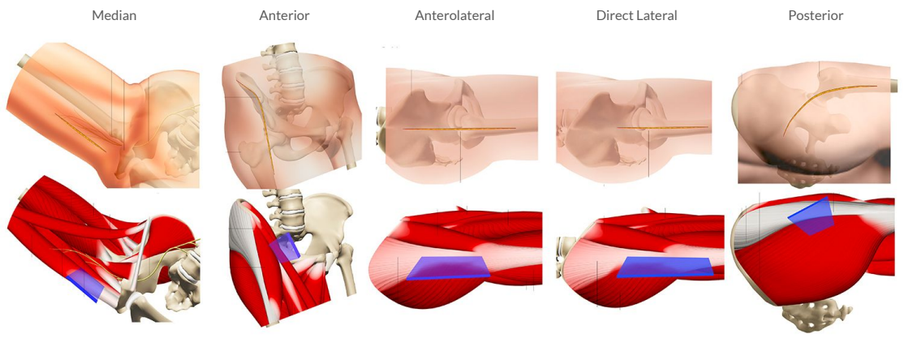
What are we looking for?
A validation solution!



Surgical Context Introduction

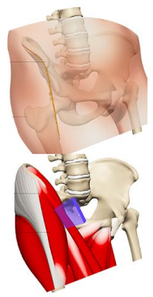
Introduction - Surgical Context

Approaches to the Hip Joint



Approaches to the Hip Joint

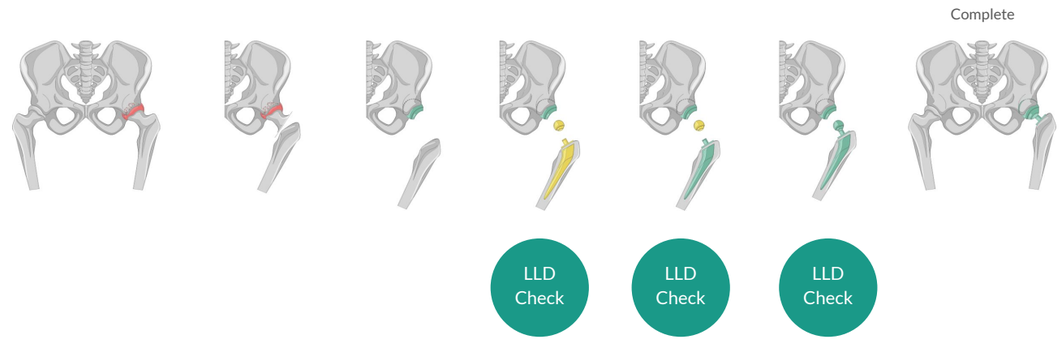
Anterior



1. Least invasive
   (fastest recovery)
2. Supine Position
   (Patient lying on back)

Every Surgeon customises their workflow..
The solution must not be disruptive to any workflow!

Surgical Protocol Introduction



OR Context Introduction

Preoperative

1. Line up Heels
2. Straighten Pelvis
   (move feet around)
3. Centre Feet
4. Apply pressure
   (via thumbs)
5. Feel Difference

1. Centre Feet
   (pointing out at 45°)
2. Line up with Chin
   (straighten pelvis)
3. See difference

Intraoperative

1. Loaded check
   (horizontal)
2. Feel difference
   (scrub nurse)

1. Aligned check
   (tilted)
2. See / Feel difference
   (surgeon)
3. Tension test
   (muscles & ligaments)

OR Setup

1. Surgical site
   (sterile zone)
2. Feet
   (non-sterile zone)
3. Vertical Drape
   (transparent)
4. X-Ray
   (on screen)

1. Surgical site
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3. Vertical Drape
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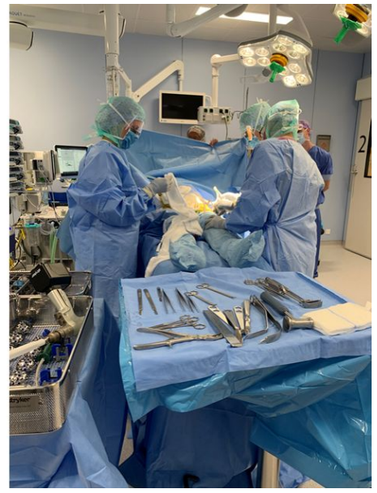

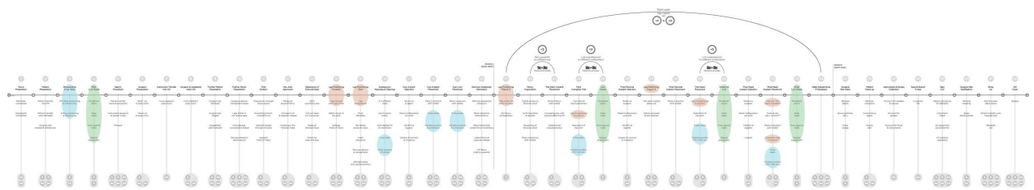

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Solution Criteria

General

Simplicity over Complexity!

1. Non-invasive to patient
2. Non-disruptive to Workflow
3. Purely for validation

In case of Genius **... Ignore!**

Co-Creation Set-up

Set-up

- 1 Problem Statement per slide
- 7 Slides = 7 rounds
- 2 min per round
- 1 min to study next slide
- Repeat

Use

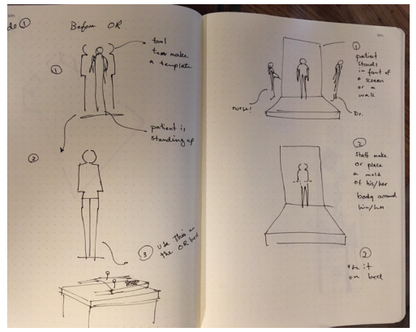
- A4 paper
- Drawing Tablet
- Text Box

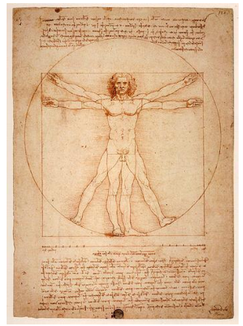
Co-Creation Sessions

Start!

Slide 1

How to measure leg length (discrepancy)?



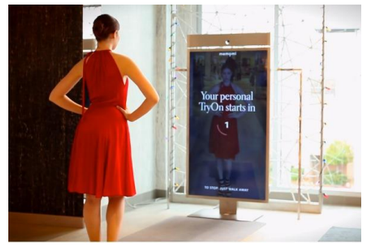


I assume it's the bed's duty to check legs length.

Or maybe in some specific positions of body, we could be in exact measurements...

smart scanner box for measurement

measurement pants



Having something like SMART MIRRORS using in fitting rooms

Focus on pressure of the body Wight on some sensors after you made pelvic tilt straight more than measure of the length

Slide 2

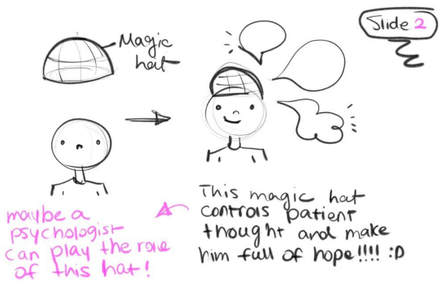
How to give the user a sense of empowerment and control?
(during a measurement)

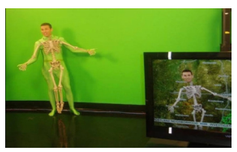
Easy to control method
Humanized procedure

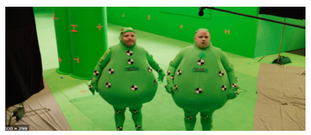
virtual reality (user imagine s lie down in beach)

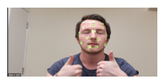
maybe using some special material that could be melt and be a part of the bone

Like one of you projects... the resizable bag.., if the piece size could be changed and fixed after surgery...





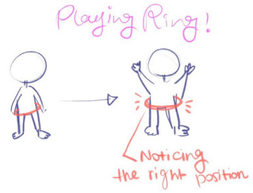




Slide 3

How to measure pelvic tilt?

What if the surface of the bed could be used for measuring by measuring the negative space of the bed.



Triangular tow side of the hip with a point like the middle of the very last spine near them and embedded device on the surface of bed to keep pelvic tilt steady

Slide 4

How to make a non-obtrusive device?

(only present when needed / never in the way)

What if the drying process of the piece occurs after surgery, when the he could stand up and check his legs length. (During therapy)

The device should be on beneath the patient like a touch surface and interacted with a sensor or a camera on the top of the bed

tools that take shape of body or simulate force from out side

Slide 5

How to measure leg offset (discrepancy)?

using a camera application or scanner application

Make two sides of the hip steady (pelvic tilt) the choose the symmetric points on both legs to make perfect rectangle

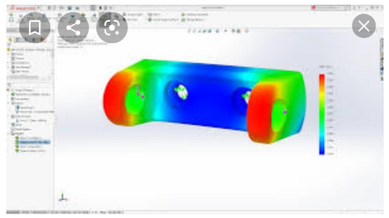
Fix one hip or the patient to the bed

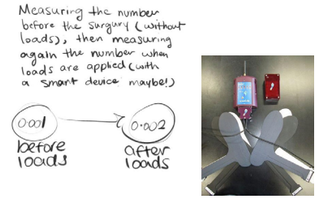
What if we could control the tool size after surgery, without doing other surgeries... (resizable piece)

Slide 6

How to simulate loads on the patient's legs?

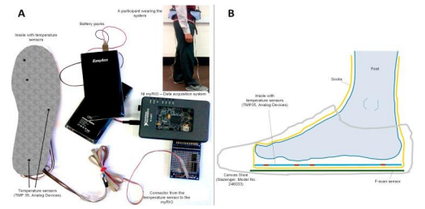
We can measure it before the Surgery and use it in solidworks





Virtual reality 😐😂

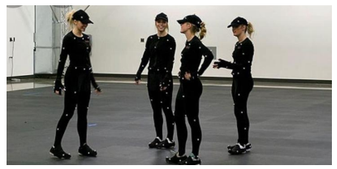
Do the surgery in a standing position



Slide 7

How to straighten the pelvis before a measurement?

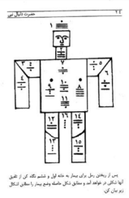
We can use the sensors that use in creating animation process.



A fixed piece on the bed can help the doctor to straighten the pelvic.
The doctor can change the position of the pelvic until its position is right(it is straight). By that time that piece will alarms and notice the doctor that pelvice is straight

instead of normal operation clothing, patient wears a cloth like a wet suit that is tightly attached to the body, then (next photo)

mark the body and location of the hip area, then by pushing the legs or moving it it is more evident how the lines or dots are moving



Maybe a smart scanner could check the position with the idealistic one

make a right position mold before surgery and install it on the bed. The patient must stay on his mold

Smart bed . If the position was false, the bed edit it

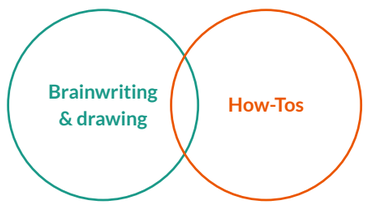
find the most bulge point of the hip from both sides and fixed it on the bed

Co-Creation Session #4

Evaluating Leg Length Discrepancy during Total Hip Arthroplasty (THA)

Enhancing Conventional Surgical Workflows

Methodology



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Program

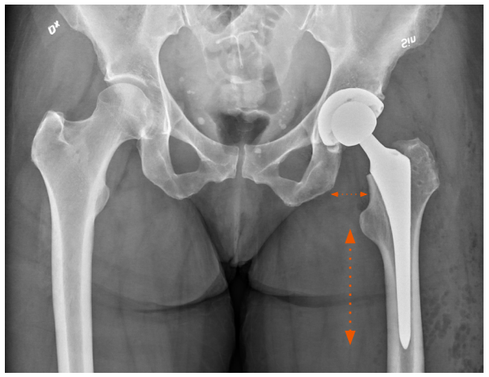
Problem Introduction

Introduction - Problem

Possible
Unintended Consequences

1. Leg Length change
2. Offset change

What are we looking for?
A validation solution!



Surgical Context Introduction

Introduction - Surgical Context

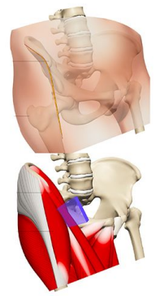
Workflow Customisation

Every Surgeon customises their workflow.
The solution must not be disruptive to any workflow!

Introduction - Surgical Context

Approaches to the Hip Joint

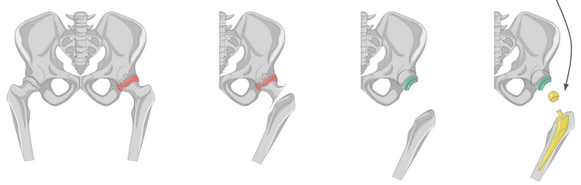
Anterior



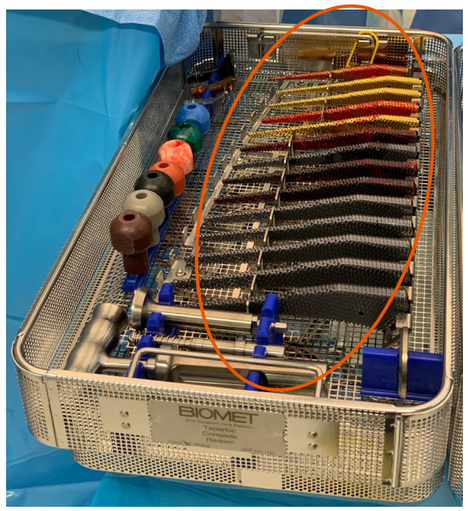
1. Least invasive
   (fastest recovery)
2. Supine Position
   (Patient lying on back)
3. Growing in Popularity
   (offers opportunities)

The solution must not be invasive to the patient and should utilise the supine position.

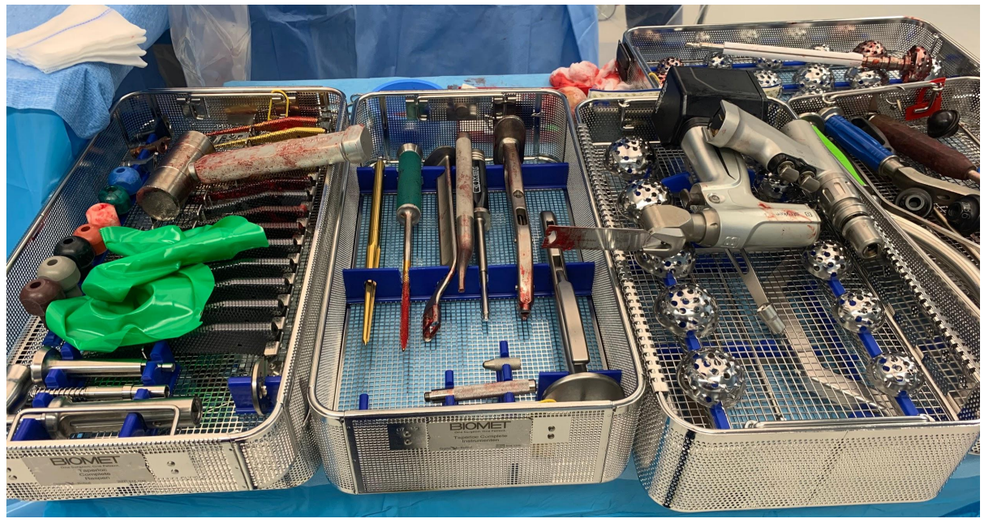
Introduction - Surgical Context



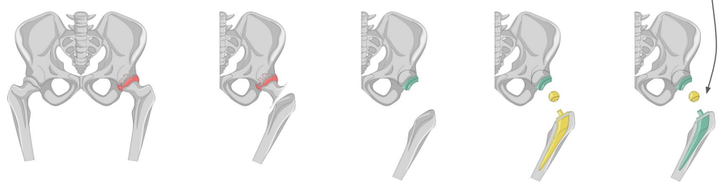
Place Trial
Stem, Neck
& Head



Introduction - Surgical Context



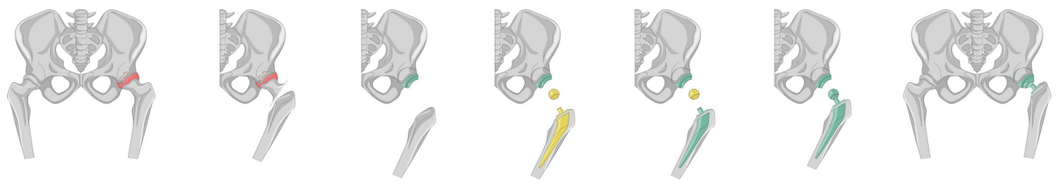
Introduction - Surgical Context



Place Final
Stem, Neck &
Trial Head

LLD
Check

Introduction - Surgical Context



Complete

LLD
Check

LLD
Check

LLD
Check

OR Context Introduction

49

Introduction - Context

Fluoroscopy

OR Setup

1. Surgical site (sterile zone)
2. Feet (non-sterile zone)
3. Vertical Drape (transparent)
4. X-Ray (on screen)

1. Surgical site (sterile zone)
2. Feet (sterile zone)
3. Vertical Drape (non-transparent)
4. Template (on screen)

Templating

Introduction - Context

Fluoroscopy

Preoperative LLD Assessment

1. Line up Heels
2. Straighten Pelvis (move feet around)
3. Centre Feet
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5. Feel Difference

Templating

Introduction - Context

Fluoroscopy

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1. Centre Feet (pointing out at 45°)
2. Line up with Chin (straighten pelvis)
3. See difference

Templating

Introduction - Context

Fluoroscopy

Intraoperative LLD Assessment

1. Loaded check
   (horizontal)
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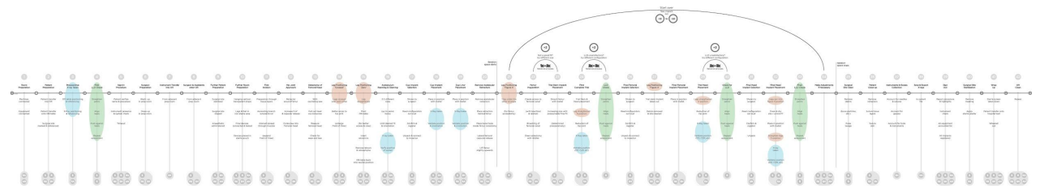
   (scrub nurse)

1. Aligned check
   (tilted)
2. See / Feel difference
   (surgeon)
3. Tension test
   (muscles & ligaments)

Templating

Surgical Protocol Introduction

Introduction - Surgical Protocol



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Solution Criteria

Solution Criteria

General

Simplicity over Complexity!

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- 2 min per round
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Use

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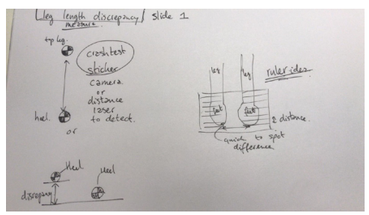
Co-Creation Sessions

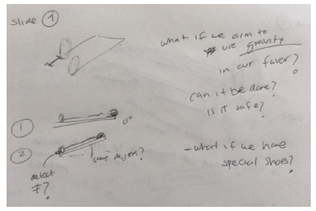
Start!

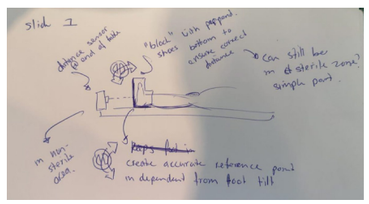
Slide 1

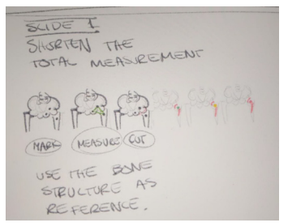
How to measure leg length discrepancy?

(non-invasively)





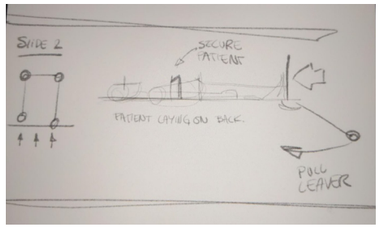


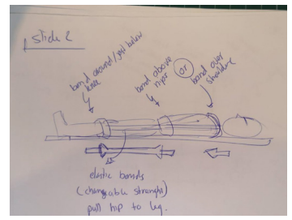


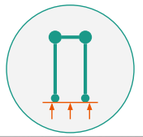
Slide 2

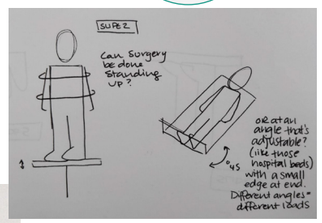
How to simulate loads on the patient's legs?

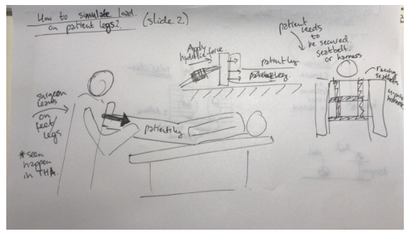
(during a measurement)

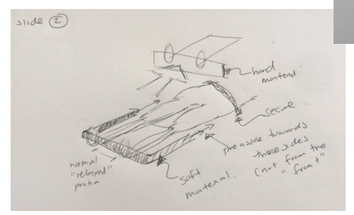








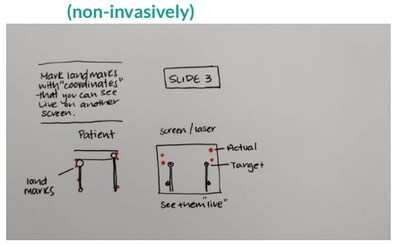


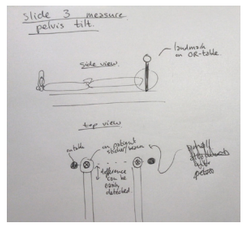


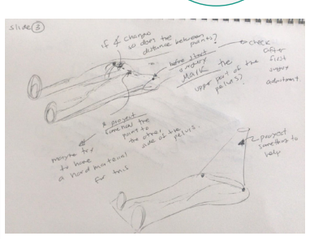
Slide 3

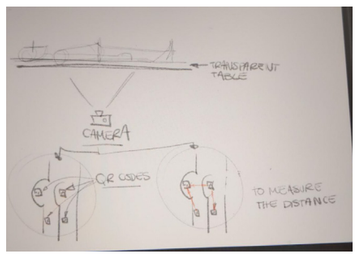
How to measure pelvic tilt?

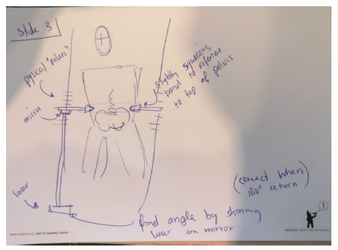
(non-invasively)







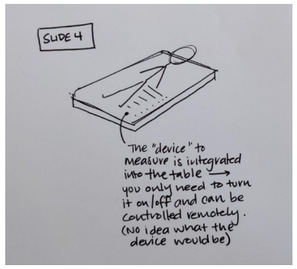


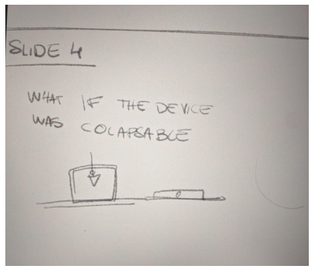


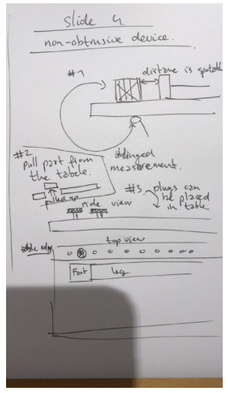
Slide 4

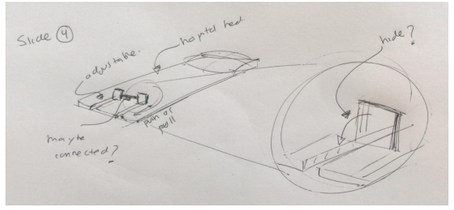
How to make a non-obtrusive device?

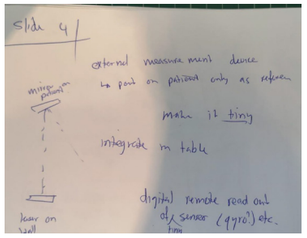
(only present when needed / never in the way)







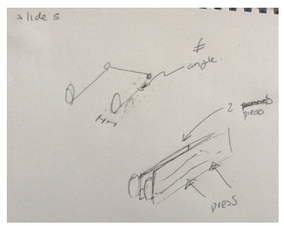


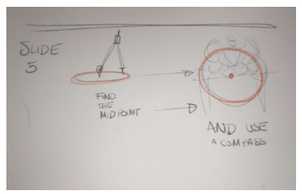


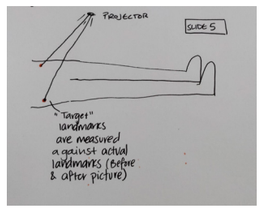
Slide 5

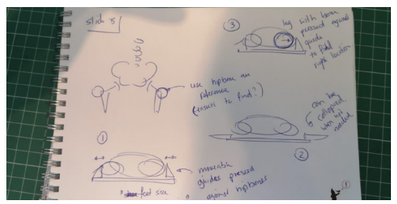
How to measure leg offset discrepancy?

(non-invasively)





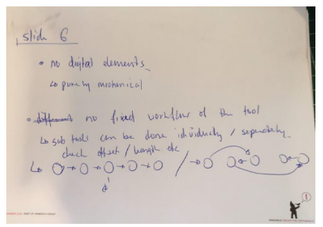


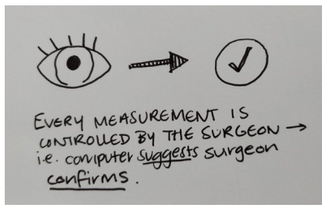


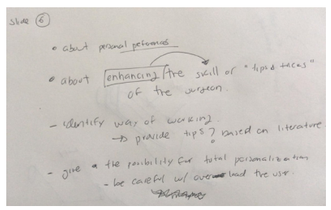
Slide 6

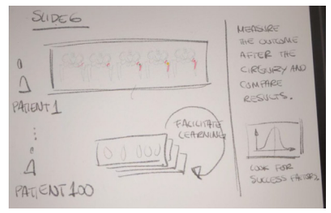
How to give the user a sense of empowerment and control?

(during a measurement)





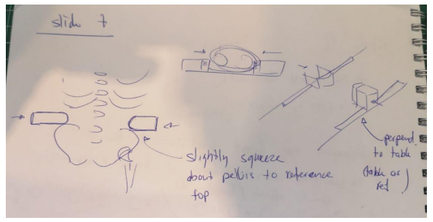


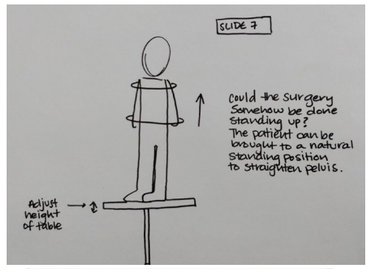


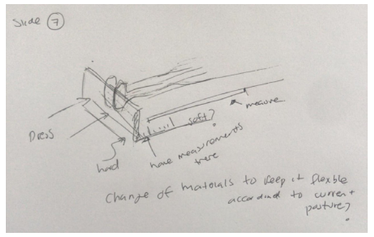
Slide 7

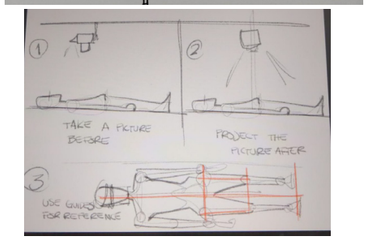
How to straighten the pelvis?

(before a measurement)







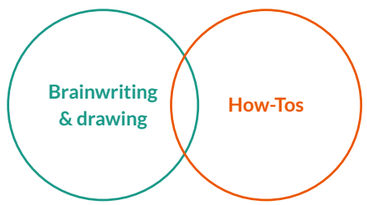


Co-Creation Session #5

Evaluating Leg Length Discrepancy during Total Hip Arthroplasty (THA)

Enhancing Conventional Surgical Workflows

Methodology



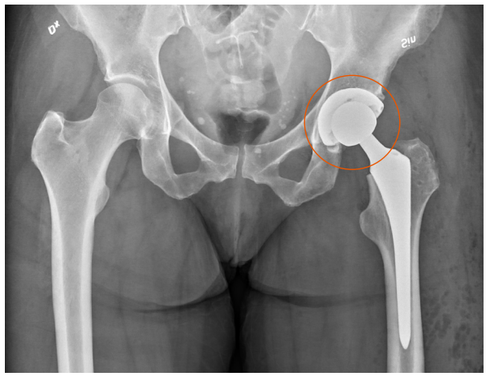
1. Read your 'How-To…'
2. Write, draw … everything goes!
3. Time up? Click a picture & send …
4. Study next slide ...
5. Repeat!

Program

1. Introduction
   a. Problem
   b. Surgical Context
   c. Fluoroscopy Timeline
2. Solution Criteria
3. Co-Creation
   a. Set-up
   b. Sessions
4. Wrap-up

Problem Introduction

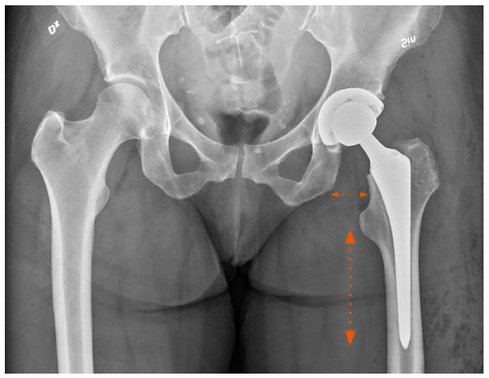
"During THA the **diseased ball and socket of the hip joint are completely removed** and replaced with artificial materials. A femoral component (stem, neck & head) is inserted into the femur (thigh bone) and an acetabular cup is placed in the acetabulum socket of the pelvis."

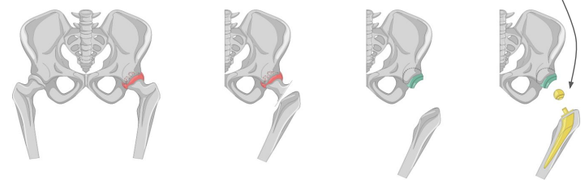


Possible Unintended Consequences

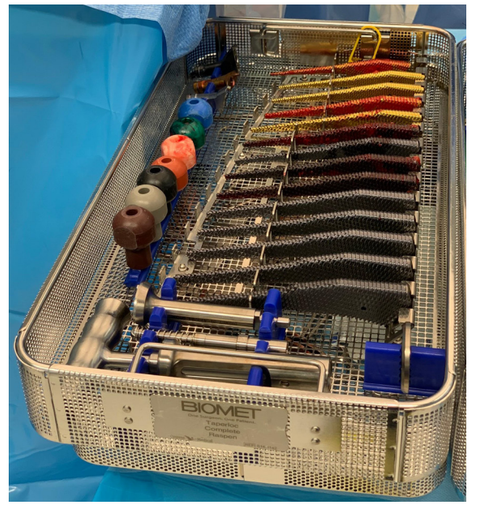
1. Leg Length change
2. Offset change

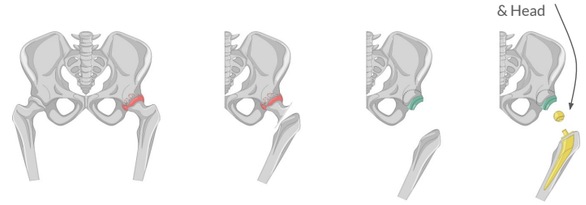
How does that happen?





LLD Check





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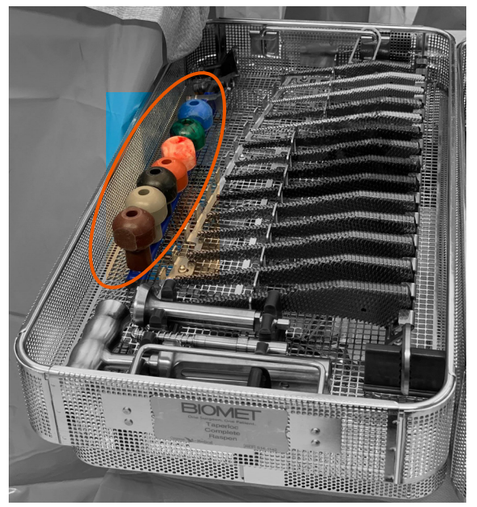
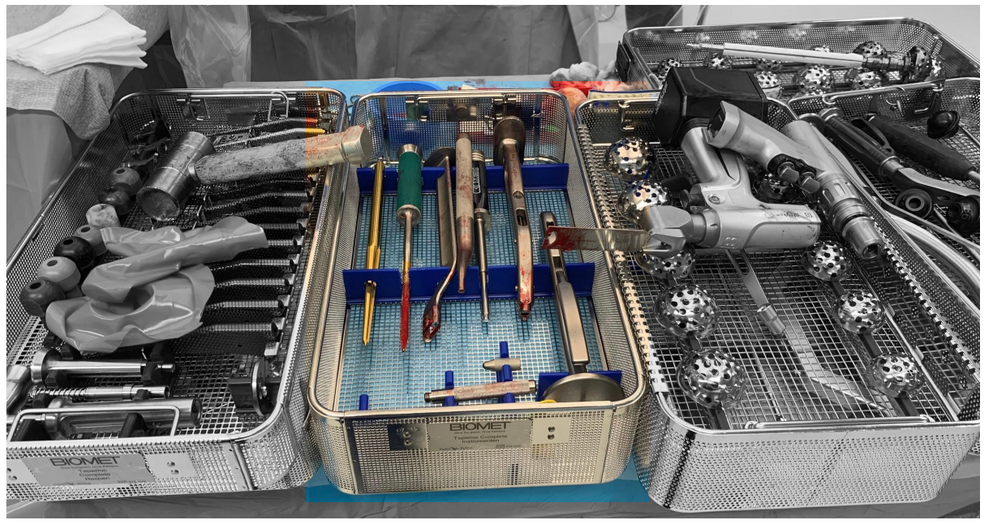
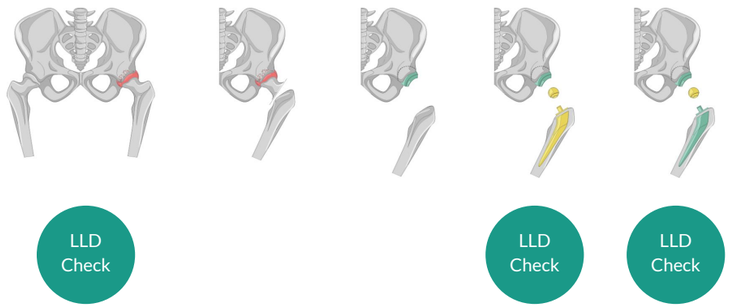
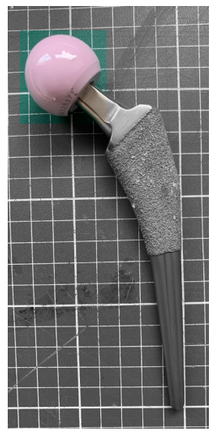


Introduction - Problem

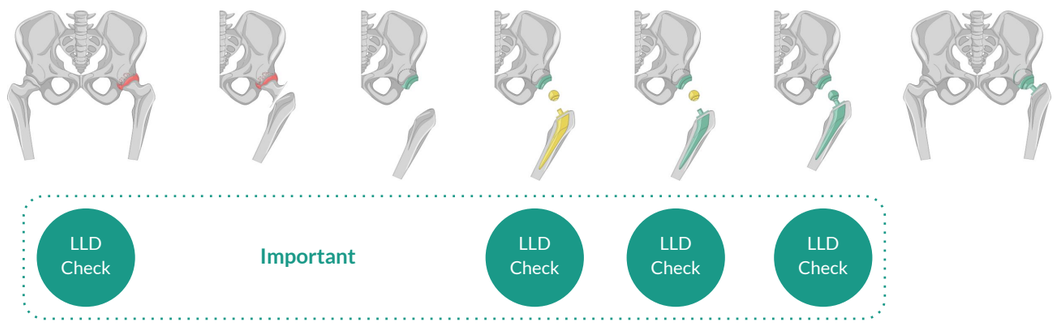


Introduction - Problem



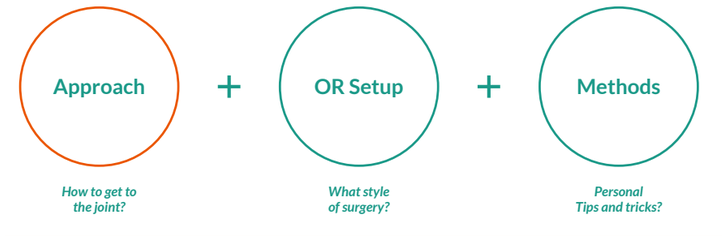


Introduction - Problem



Surgical Context Introduction

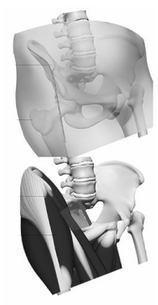
Workflow Customisation



Workflow Customisation

Approach

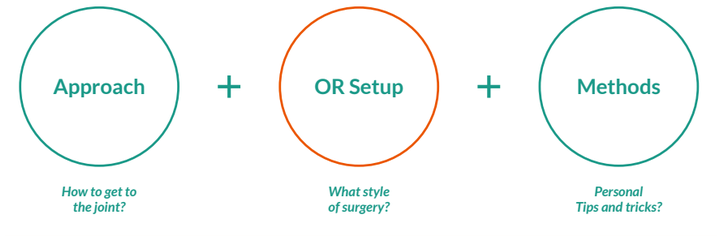
How to get to the joint?

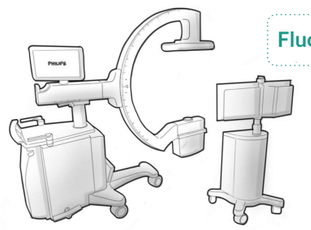


Anterior

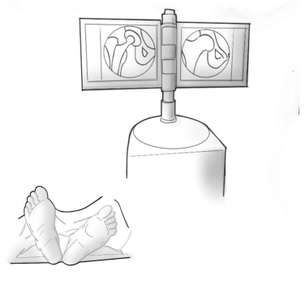
1. Fastest Recovery
   (least invasive)
2. Patient lying on back
   (supine position)
3. Growing in Popularity
   (offers opportunities)

Workflow Customisation





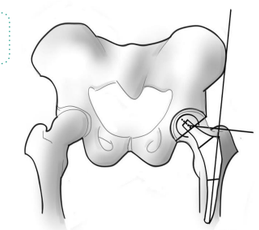
Fluoroscopy

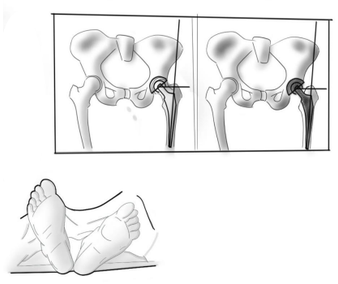


OR Setup

What style of surgery?

Templating





OR Setup

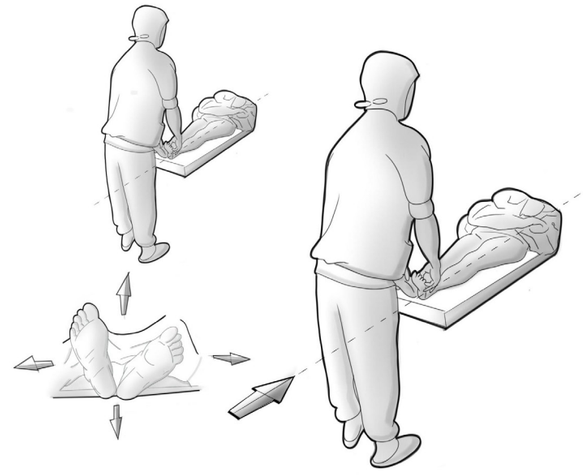
What style of surgery?

Workflow Customisation

Approach + **OR Setup** + **Methods**

How to get to the joint? | *What style of surgery?* | *Personal Tips and tricks?*

Education | **Training** | **Experience**



Methods

Personal Tips and tricks?

Preoperative LLD Assessment

1. Line up Heels
2. Straighten Pelvis
   (move feet around)
3. Centre Feet
4. Apply pressure
   (via thumbs)
5. Feel Difference

1. Centre Feet
   (pointing out at 45°)
2. Line up with Chin
   (straighten pelvis)
3. See difference

Introduction - Context

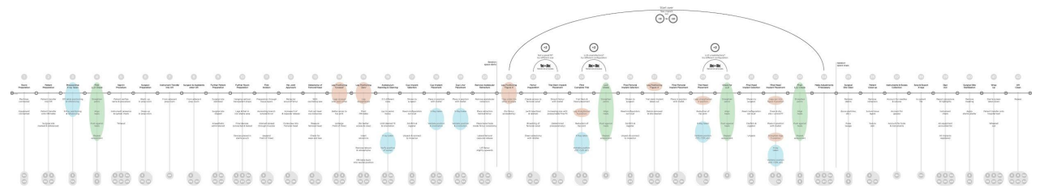
Intraoperative LLD Assessment

1. Loaded check
   (horizontal)
2. Feel difference
   (scrub nurse)

1. Aligned check
   (tilted)
2. See / Feel difference
   (surgeon)
3. Tension test
   (muscles & ligaments)

Fluoroscopy Timeline Introduction

Introduction - Surgical Protocol



https://prezi.com/1mvkmhw0gkno/untitled-prezi/?present=1

Solution Criteria

Solution Criteria

General

Simplicity over Complexity!

1. Non-invasive to patient
2. Non-disruptive to Workflow
3. Purely validation

In case of Genius **... Ignore!**

Co-Creation Set-up

Set-up

- 1 Problem Statement per slide
- 7 Slides = 7 rounds
- 2 min per round
- 1 min to study next slide
- Repeat

Use

- A4 paper
- Drawing Tablet
- Text Box

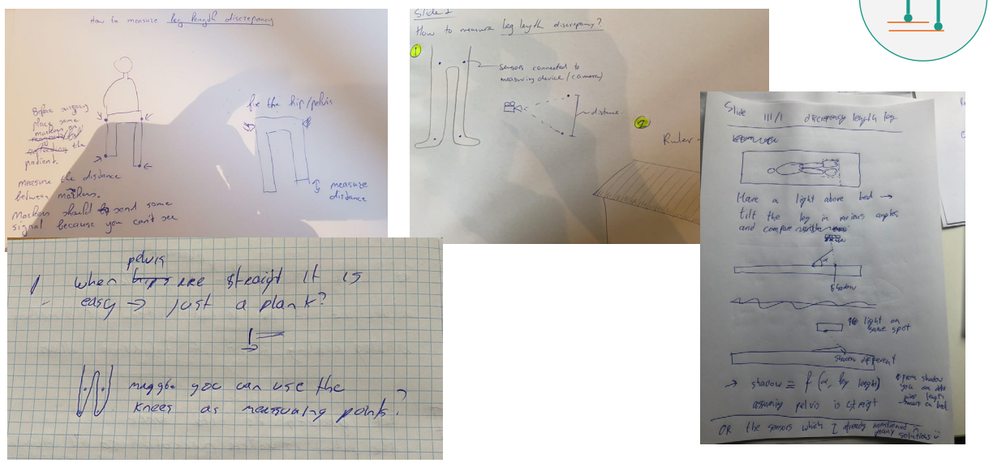
Co-Creation Sessions

Start!

Slide 1

How to measure leg length discrepancy?

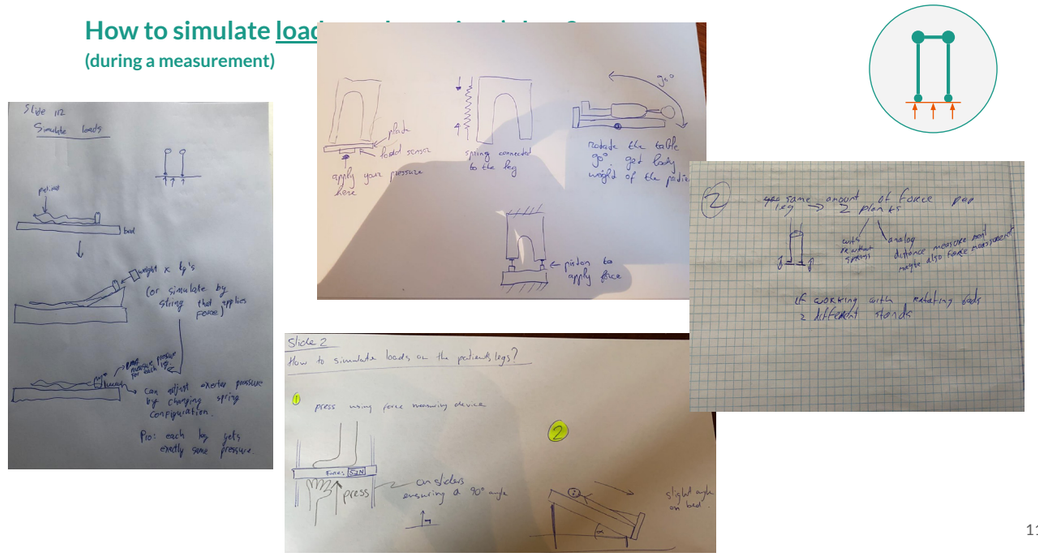
(non-invasively)



Slide 2

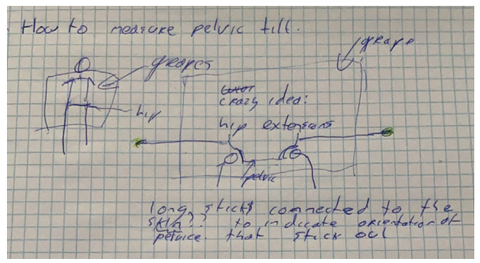
How to simulate load

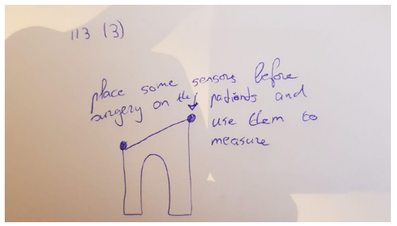
(during a measurement)

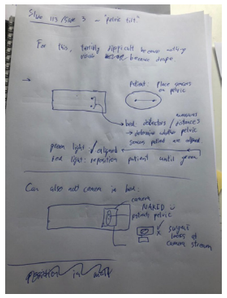


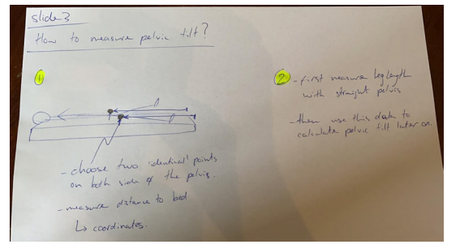
Slide 3

How to measure pelvic tilt?





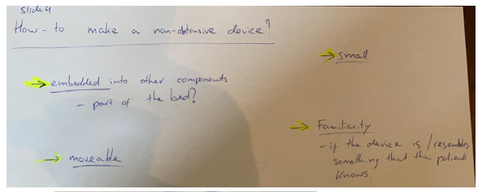


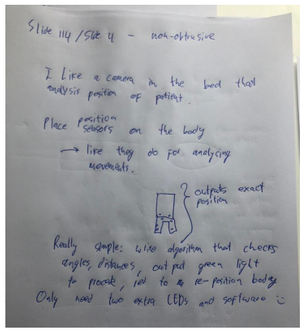


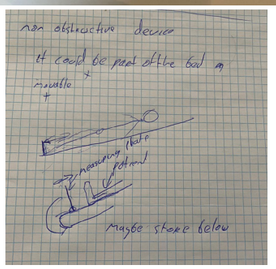
Slide 4

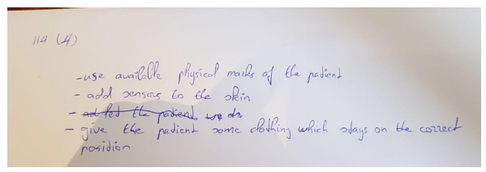
How to make a non-obtrusive device?

(only present when needed / never in the way)





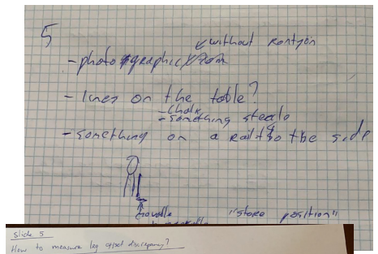


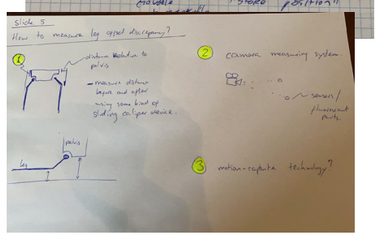


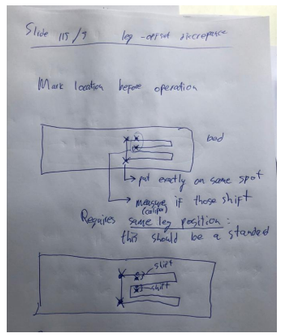
Slide 5

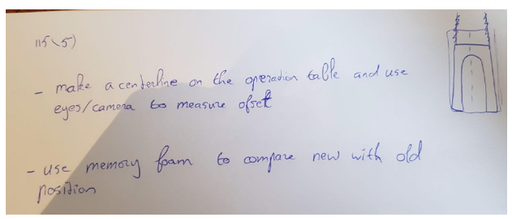
How to measure leg offset discrepancy?

(non-invasively)



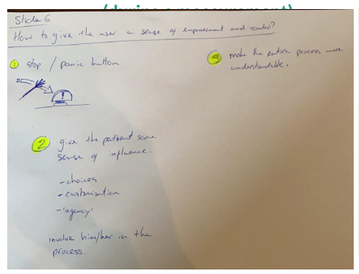


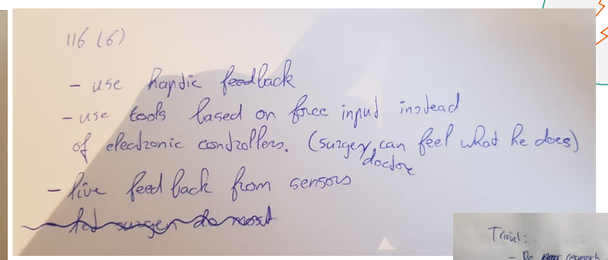


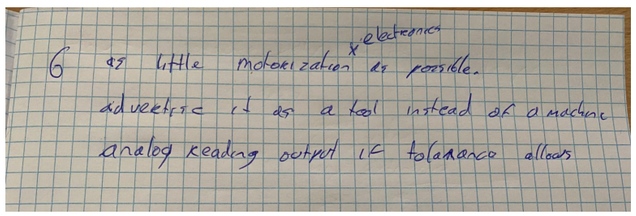


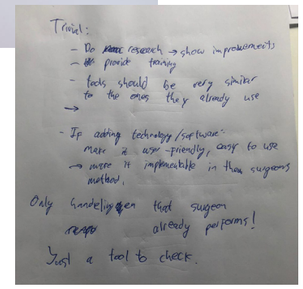
Slide 6

How to give the user a sense of empowerment and control?



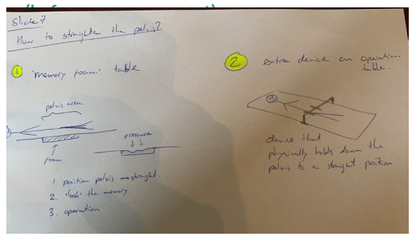


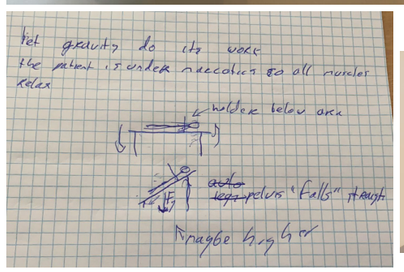


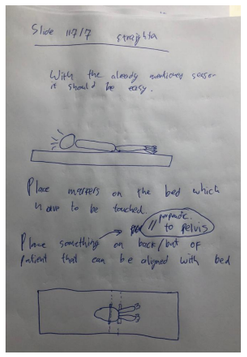


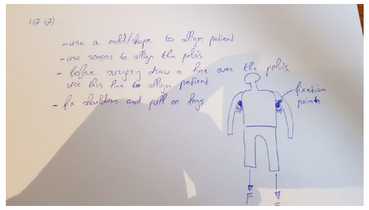
Slide 7

How to straighten the pelvis?







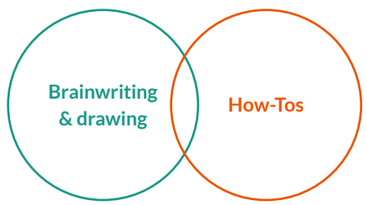


Co-Creation Session #6

Evaluating Leg Length Discrepancy during Total Hip Arthroplasty (THA)

Enhancing Conventional Surgical Workflows

Methodology



1. Read your 'How-To…'
2. Write, draw … everything goes!
3. Time up? Click a picture & send …
4. Study next slide ...
5. Repeat!

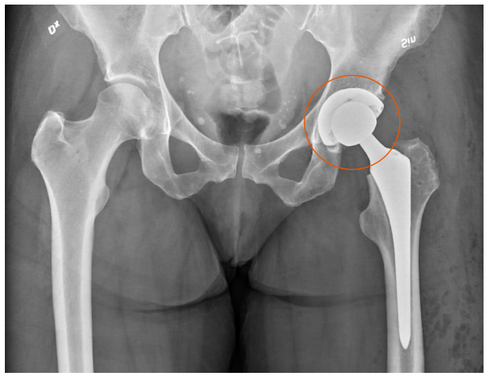
Program

1. Introduction
   a. Problem
   b. Surgical Context
   c. Fluoroscopy Timeline
2. Solution Criteria
3. Co-Creation
   a. Set-up
   b. Sessions
4. Wrap-up

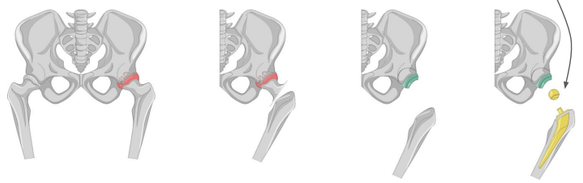
Problem Introduction

Introduction - Problem

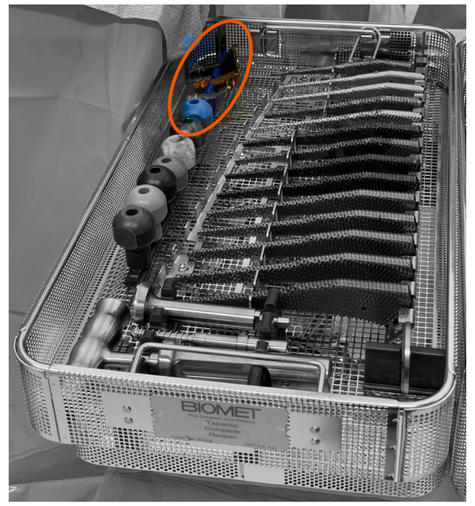
"During THA the **diseased ball and socket of the hip joint are completely removed** and replaced with artificial materials. A femoral component (stem, neck & head) is inserted into the femur (thigh bone) and an acetabular cup is placed in the acetabulum socket of the pelvis."



Introduction - Problem



LLD
Check

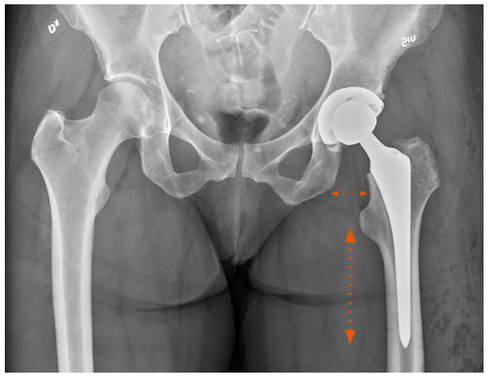


Introduction - Problem

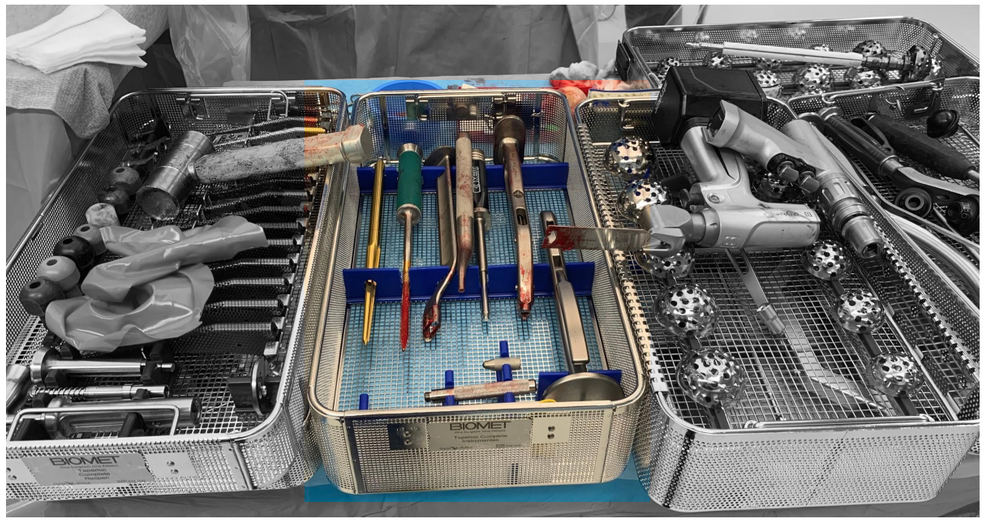
Possible
Unintended Consequences

1. Leg Length change
2. Offset change

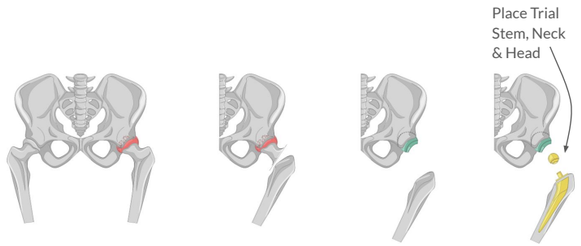
How does that happen?



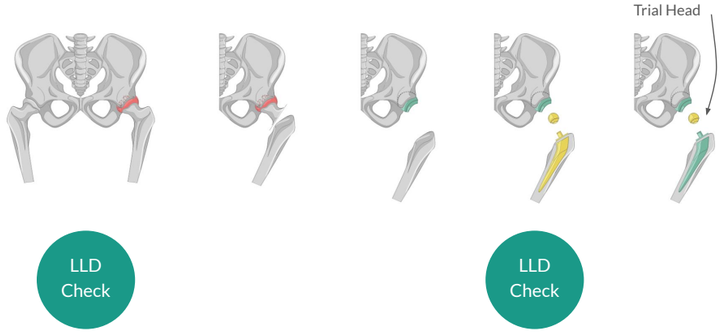
Introduction - Problem



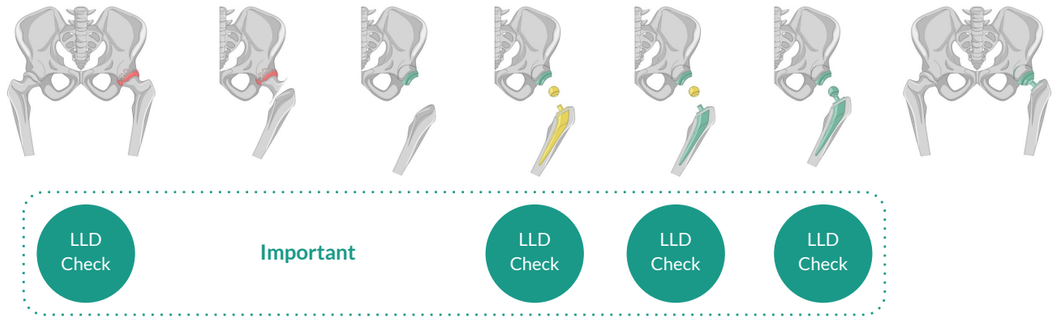
Introduction - Problem



Introduction - Problem

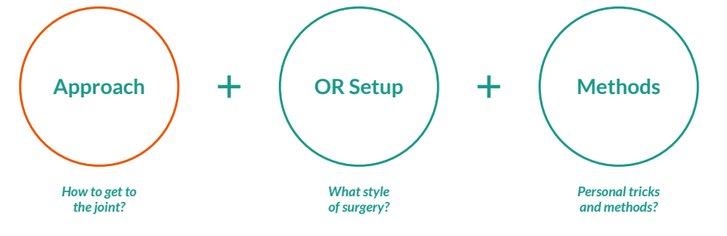


Introduction - Problem



Surgical Context Introduction

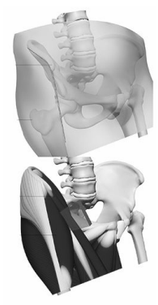
Workflow Customisation



Workflow Customisation

Approach

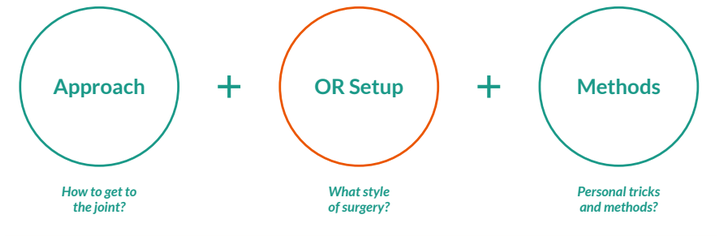
How to get to the joint?

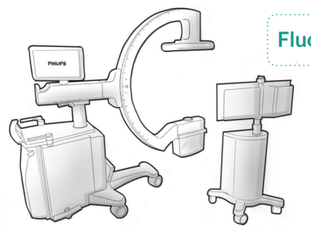


Anterior

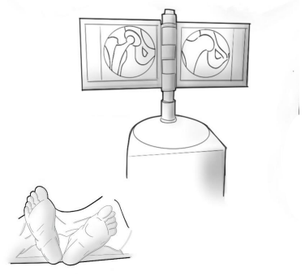
1. Fastest Recovery
   (least invasive)
2. Patient lying on back
   (supine position)
3. Growing in Popularity
   (offers opportunities)

Workflow Customisation





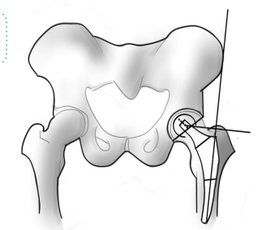
Fluoroscopy

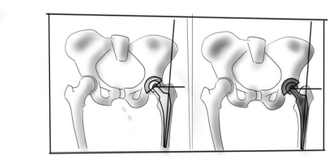


OR Setup

What style of surgery?

Templating





OR Setup

What style of surgery?

Fluoroscopy

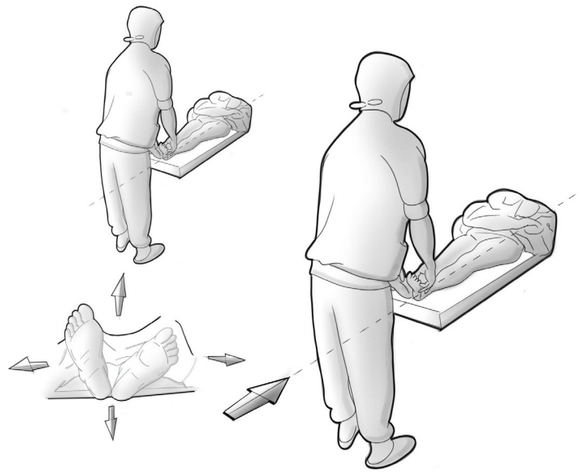
Templating

Workflow Customisation

Approach + **OR Setup** + **Methods**

How to get to the joint? | *What style of surgery?* | *Personal Tips and tricks?*

Education | **Training** | **Experience**

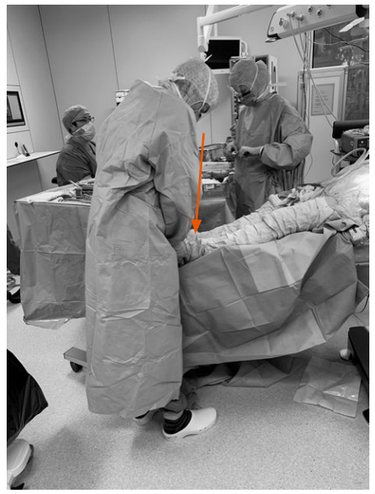


Methods

Personal Tips and tricks?

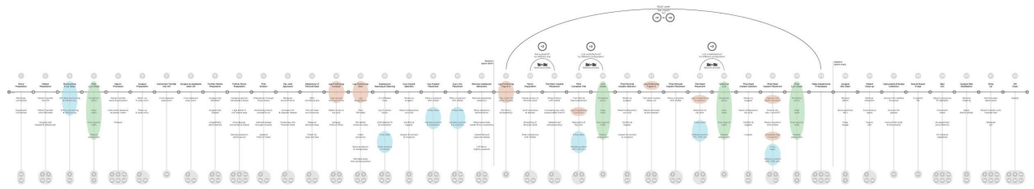
Introduction - Surgical Context

Introduction - Surgical Context



Fluoroscopy Timeline Introduction

Introduction - Surgical Protocol



https://prezi.com/1mvkmhw0gkno/untitled-prezi/?present=1

Solution Criteria

General

Simplicity over Complexity!

1. Non-invasive to patient
2. Non-disruptive to Workflow
3. Purely validation

In case of Genius **... Ignore!**

Co-Creation Set-up

Set-up

- 1 Problem Statement per slide
- 7 Slides = 7 rounds
- 2 min per round
- 1 min to study next slide
- Repeat

Use

- A4 paper
- Drawing Tablet
- Text Box

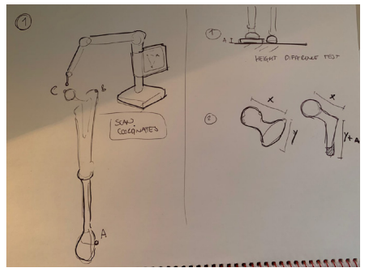
Co-Creation Sessions

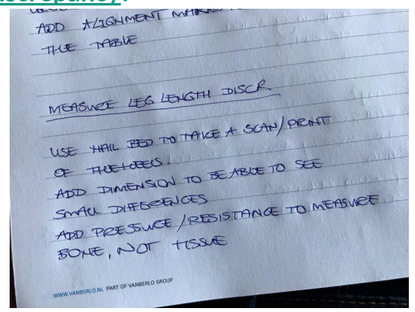
Start!

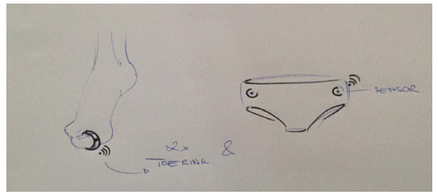
Slide 1

How to measure leg length discrepancy?

(non-invasively)



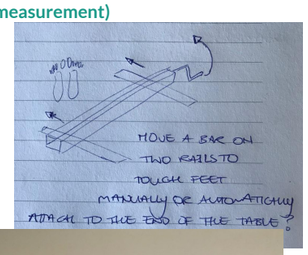


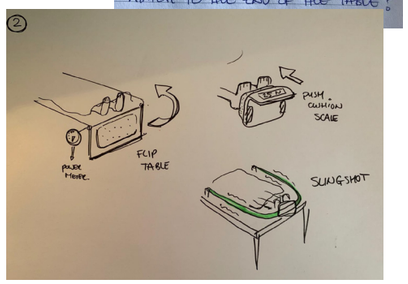


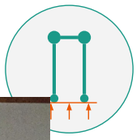
Slide 2

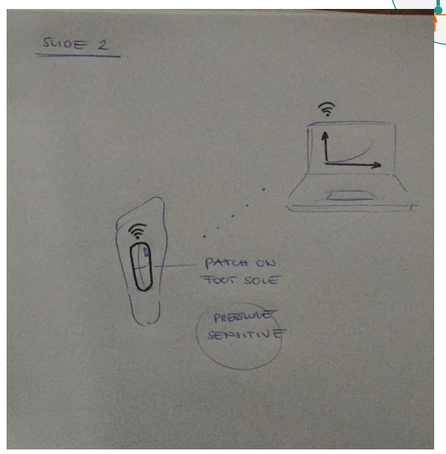
How to simulate loads on the patient's legs?

(during a measurement)



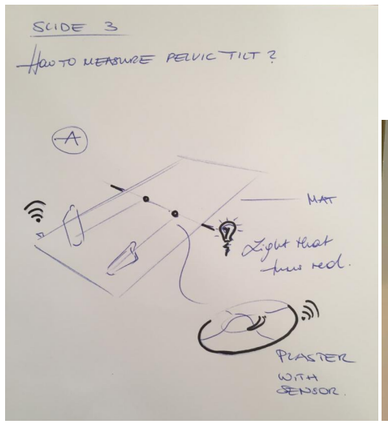


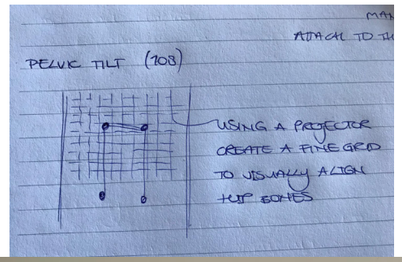


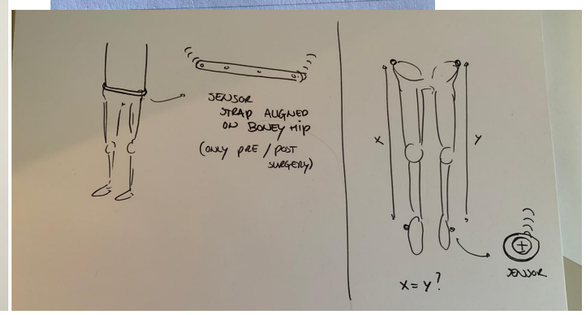


Slide 3

How to measure pelvic tilt?
(non-invasively)

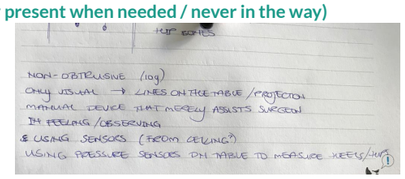


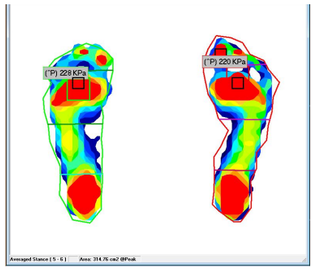


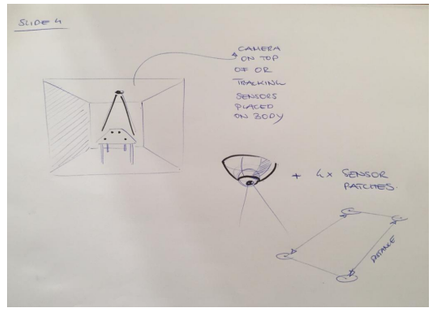


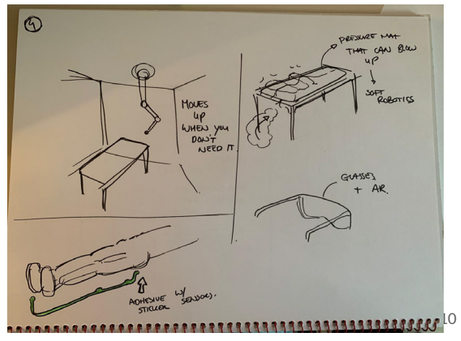
Slide 4

How to make a non-obtrusive device?
(only present when needed / never in the way)



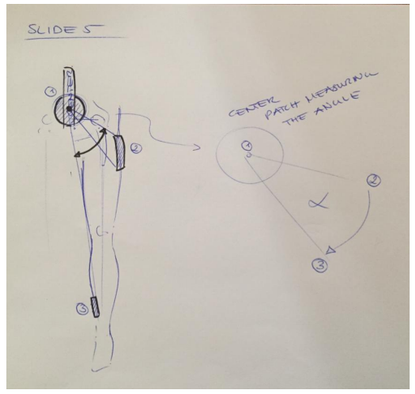


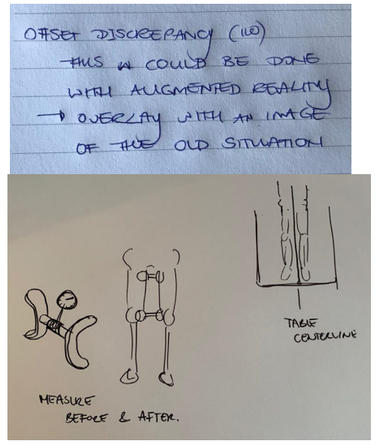




Slide 5

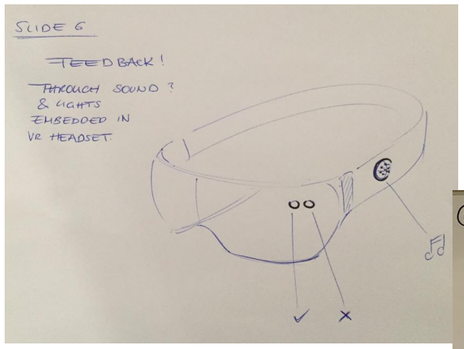
How to measure leg offset discrepancy?
(non-invasively)

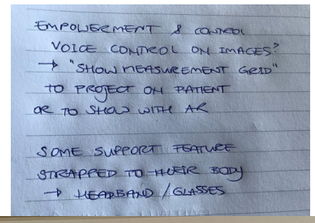


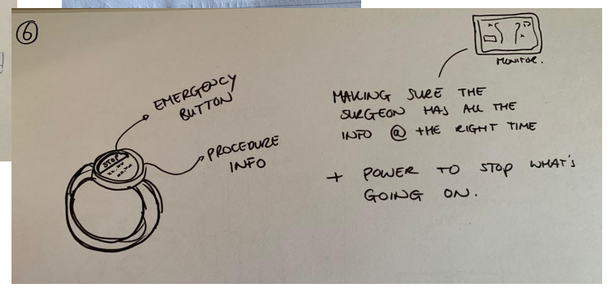


Slide 6

How to give the user a sense of empowerment and control?
(during a measurement)



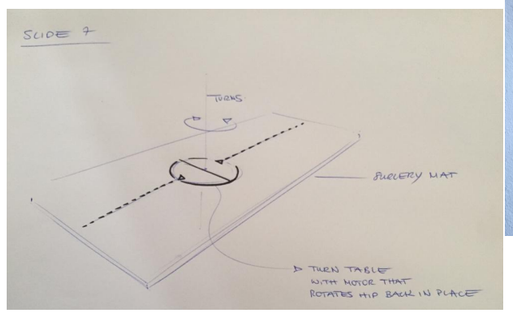


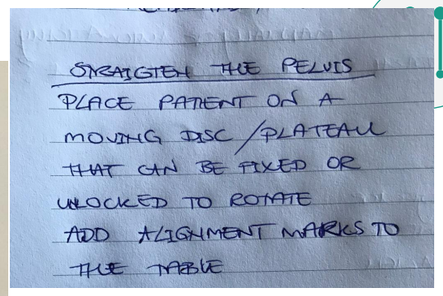


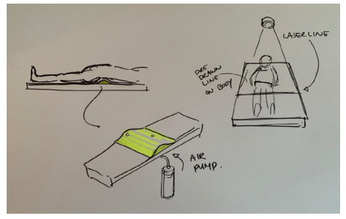
Slide 7

How to straighten the pelvis?

(before a measurement)







Appendix E

Expert Session Slides

Expert Session

#1

4763033 - Jan Sebastian van Ackeren

TU Delft

RECAP

18.09.2020

BRAINSTORM

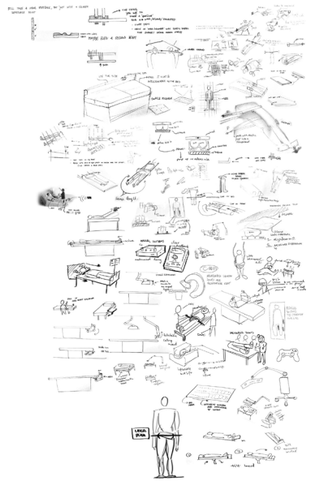
Last Steps

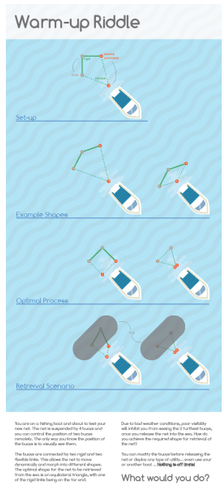
- Warm-up Riddle
- Compiling sketches
- Put relevant ideas on Post-it

RECAP

18.09.2020

CO-CREATION SESSIONS





Last Steps

- Warm-up Riddle
- Compiling sketches

RECAP

18.09.2020

POST-IT-OLOGICAL CHART

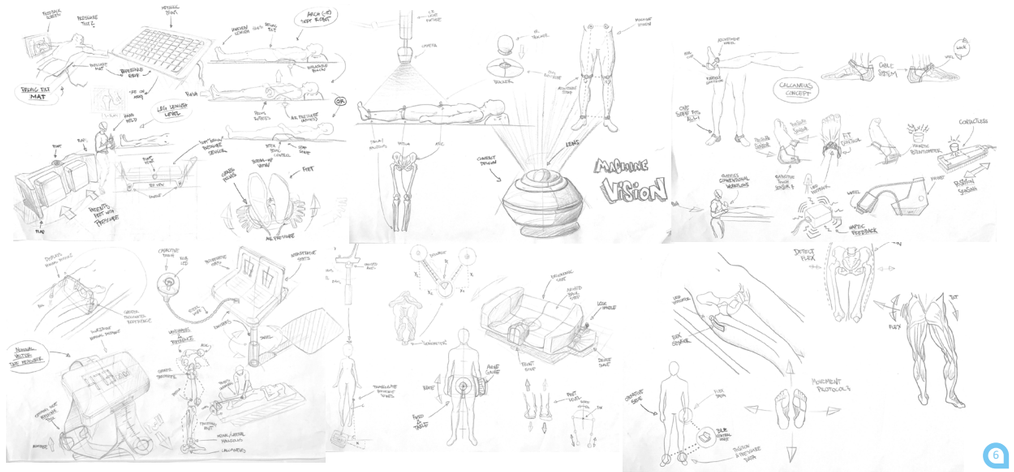
Last Steps

- Warm-up Riddle
- Compiling sketches
- Put relevant ideas on Post-it
- Sorting Ideas
  - Post-It ological Chart
    - LLD Assessment
    - Pelvic Tilt (PT)
    - OD Assessment
    - Pelvis Straightening
    - Pelvic Fixation
    - LLD / PT / OD Triangulation Tracking
    - LLD / PT / OD Mechatronic
    - LLD / Tension Assessment
    - Advanced Tech
    - Alignment Markers / Backgrops
    - Small Ideas

RECAP

18.09.2020

IDEATION SKETCHES



RECAP

18.09.2020

CONCEPT DIRECTIONS

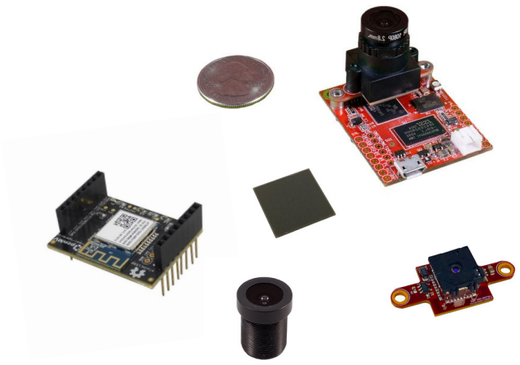
Last Steps

- Warm-up Riddle
- Compiling sketches
- Put relevant ideas on Post-it
- Sorting Ideas
  - Post-It ological Chart
    - LLD Assessment
    - Pelvic Tilt (PT)
    - OD Assessment
    - Pelvis Straightening
    - Pelvic Fixation
    - LLD / PT / OD Triangulation Tracking
    - LLD / PT / OD Mechatronic
    - LLD / Tension Assessment
    - Advanced Tech
    - Alignment Markers / Backgrops
    - Small Ideas

RECAP

18.09.2020

CONCEPT DIRECTIONS



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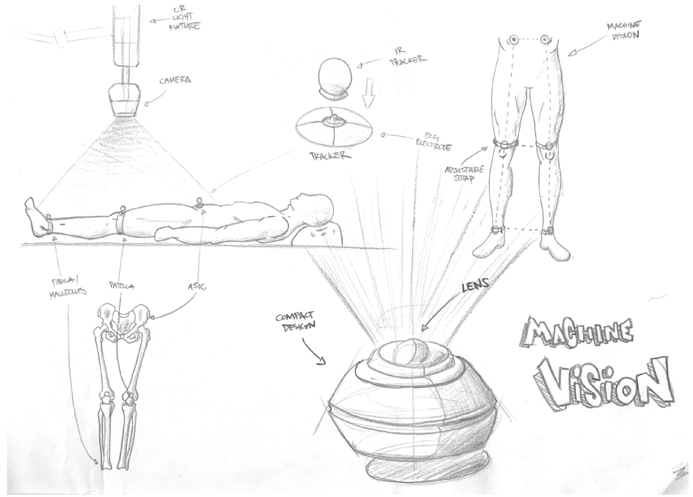

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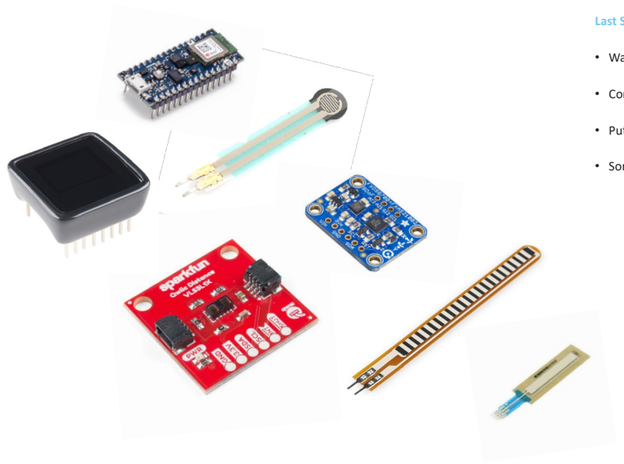

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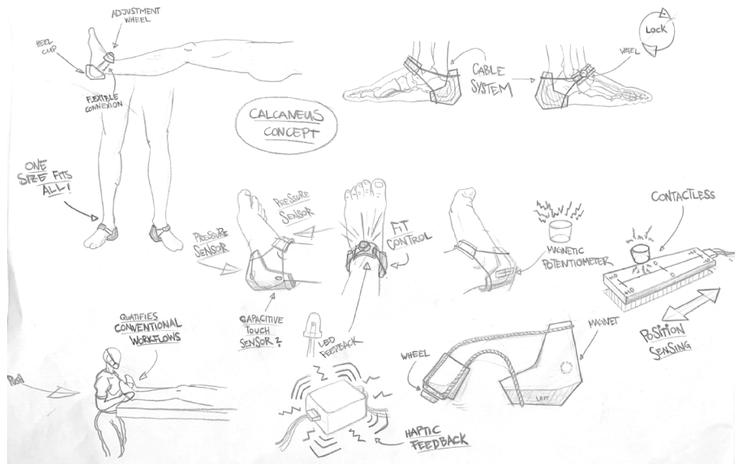

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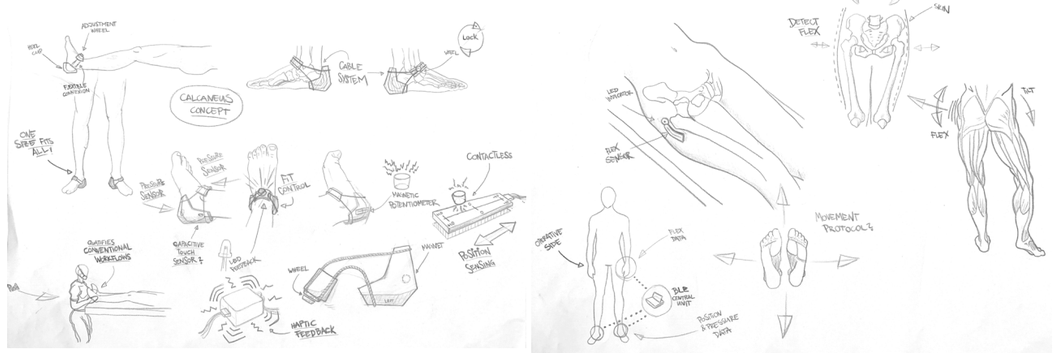

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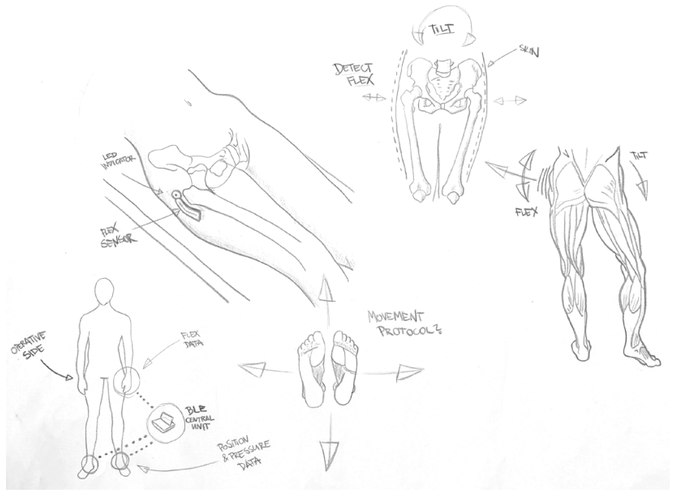

BI-WEEKLY MEETING 09.09.2020

PROOF OF CONCEPTS

PoC #1 – Gesture Tracking

- Facilitating Leap Motion
  - Using diagnostic software

BI-WEEKLY MEETING 18.09.2020

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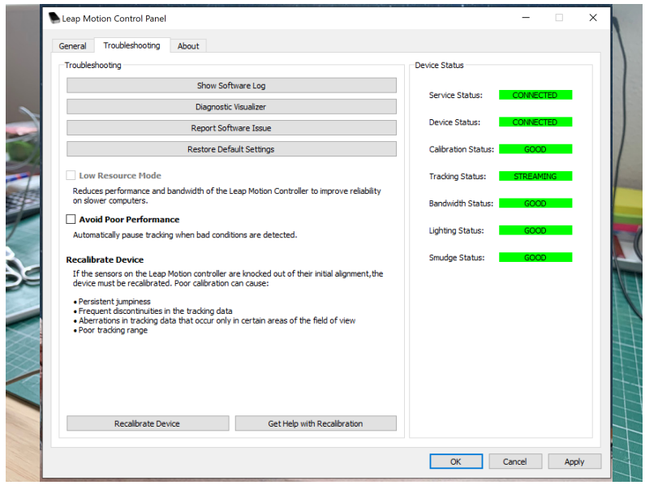

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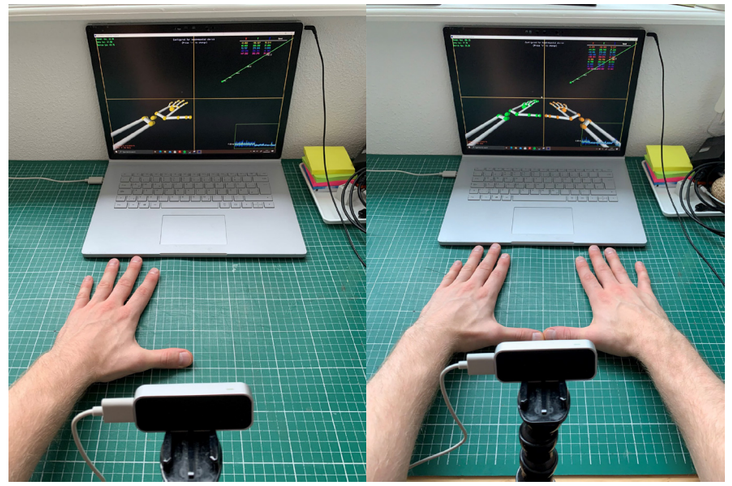

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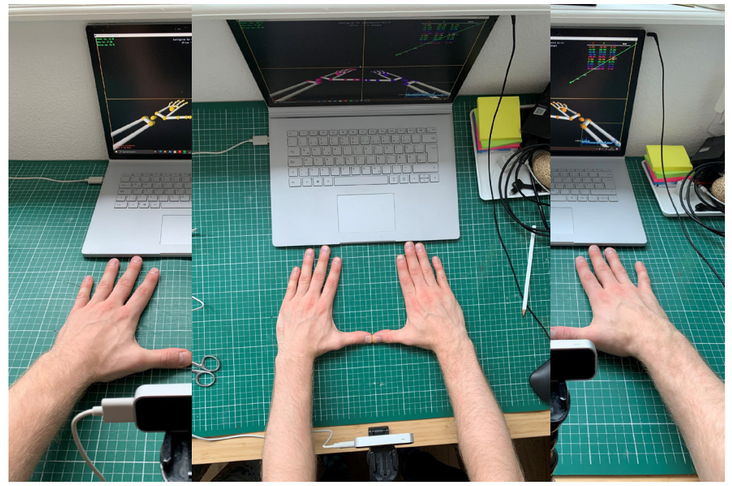
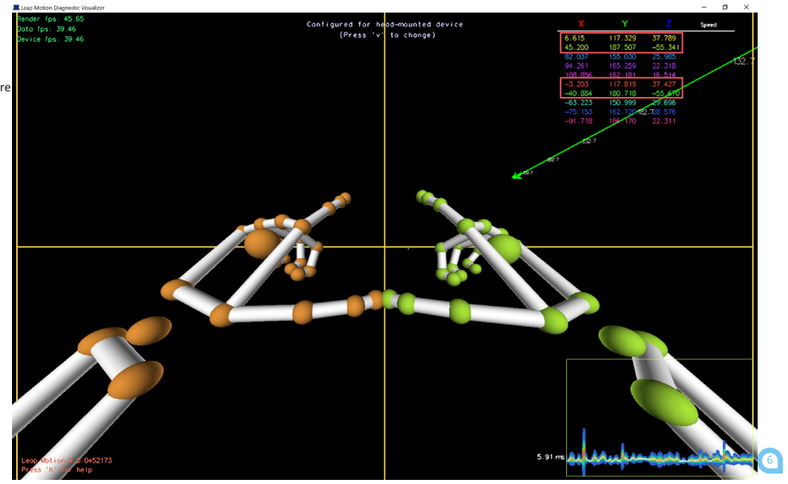


BI-WEEKLY MEETING 18.09.2020

PROOF OF CONCEPTS

PoC #1 – Gesture Tracking

- Facilitating Leap Motion
  - Using diagnostic software
- Findings
  - Mediocre accuracy
  - Tolerance of +- 5mm



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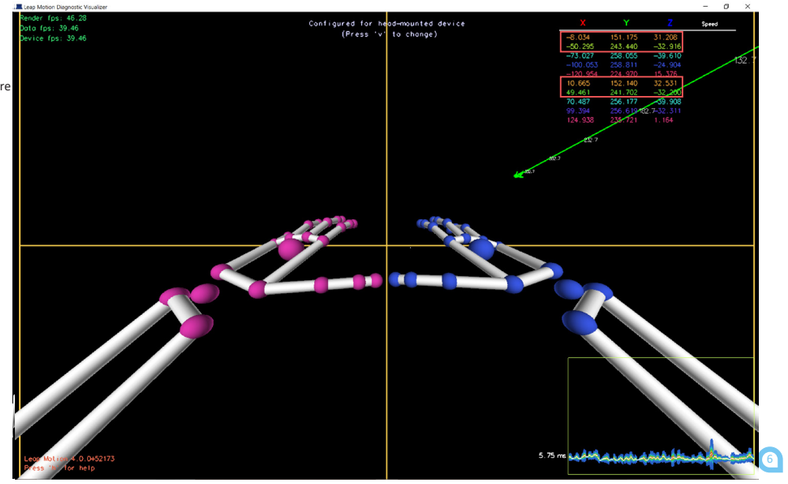

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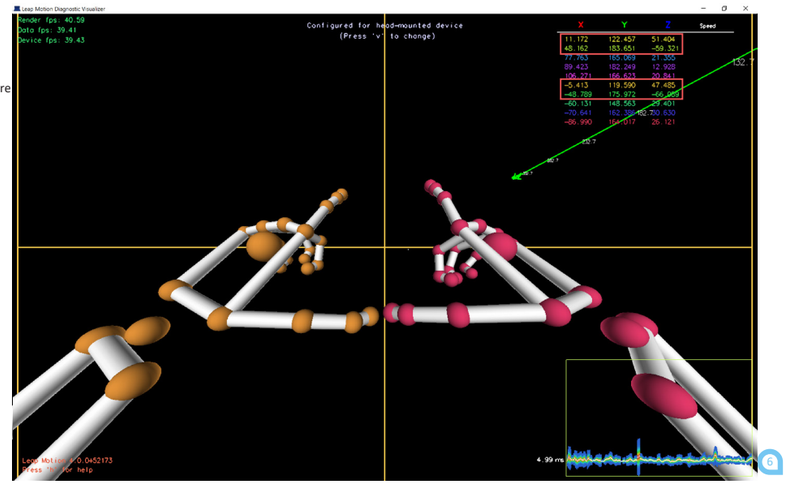

BI-WEEKLY MEETING 18.09.2020

PROOF OF CONCEPTS

PoC #1 – Gesture Tracking

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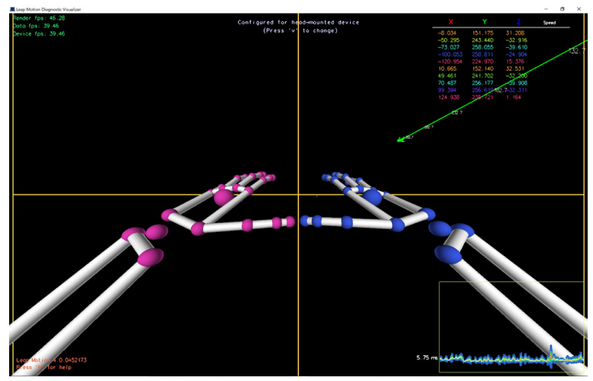
  - Using diagnostic software
- Findings
  - Mediocre accuracy
  - Tolerance of +- 5mm
- Conclusion
  - Interesting but currently not feasible



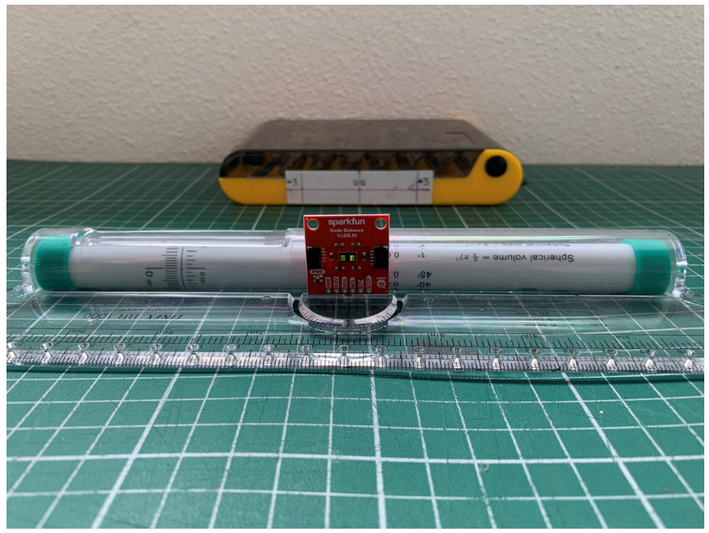
BI-WEEKLY MEETING

18.09.2020

PROOF OF CONCEPTS

PoC #2 – VCSEL Sensor

- Simple testing script
  - Cutting mat
  - Target surface



BI-WEEKLY MEETING

18.09.2020

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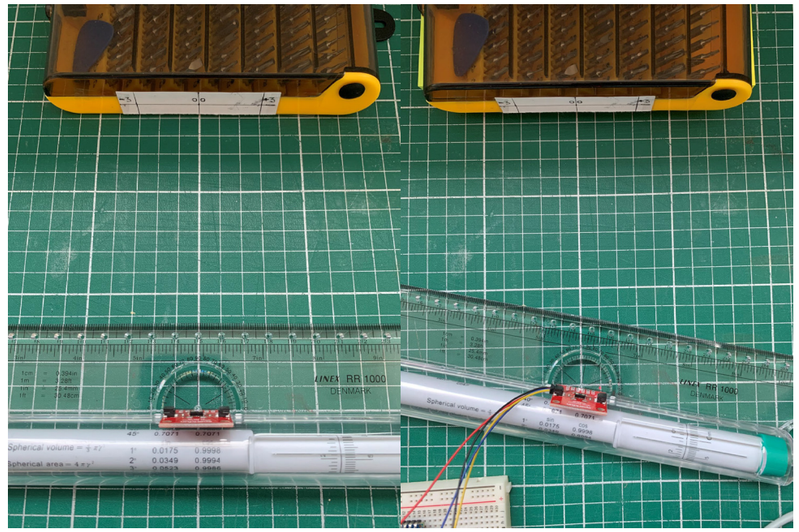

6

BI-WEEKLY MEETING

18.09.2020

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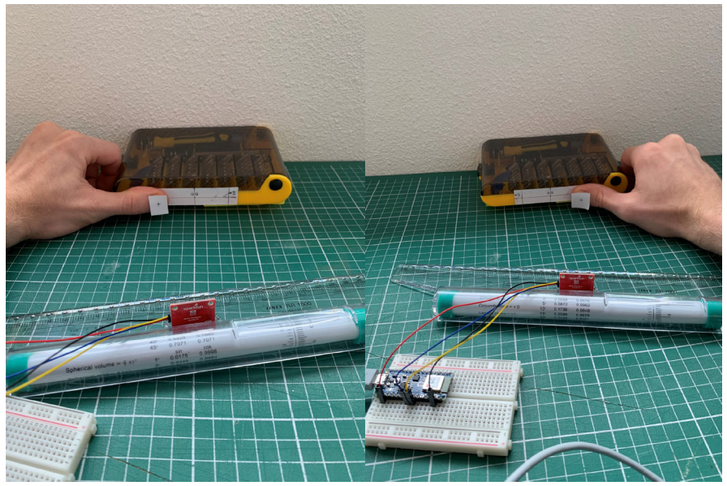


6

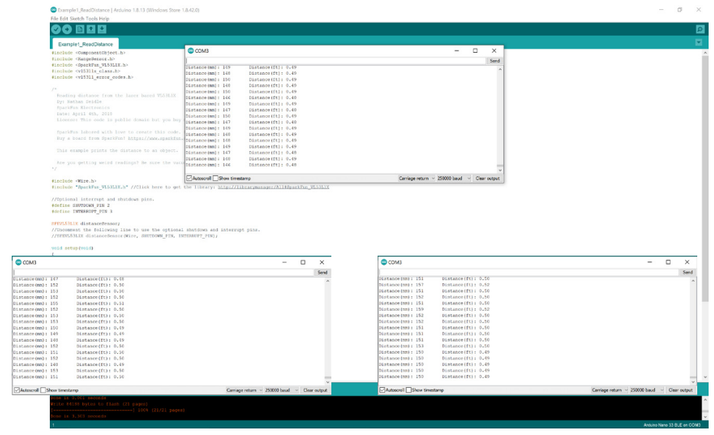
BI-WEEKLY MEETING

18.09.2020

PROOF OF CONCEPTS

PoC #2 – VCSEL Sensor

- Simple testing script
  - Cutting mat
  - Target surface
- Findings
  - Good accuracy
  - Tolerance of +- 3mm
- Conclusion
  - Feasible
  - Complex setup required



6

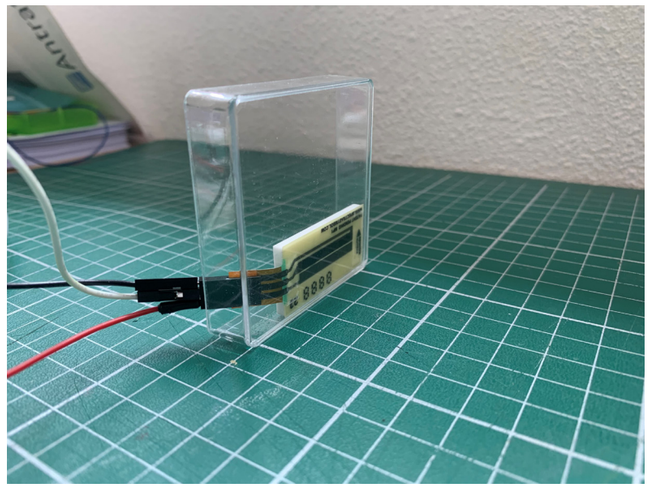
BI-WEEKLY MEETING

18.09.2020

PROOF OF CONCEPTS

PoC #3 – MagnetoPot

- Simple testing script
  - Magnet
  - Caliper
  (for displacement measurement)



BI-WEEKLY MEETING

18.09.2020

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PoC #3 – MagnetoPot

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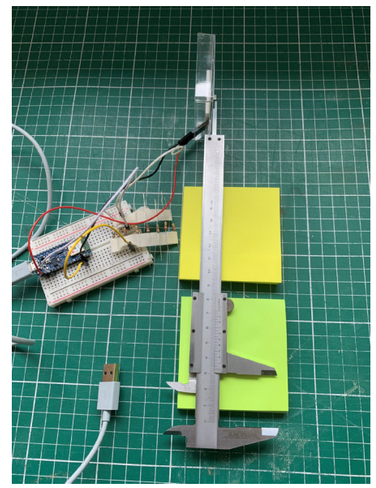

BI-WEEKLY MEETING

18.09.2020

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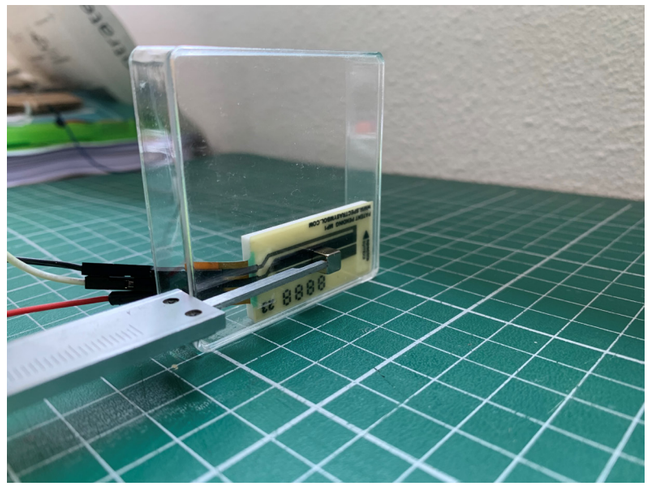


BI-WEEKLY MEETING

18.09.2020

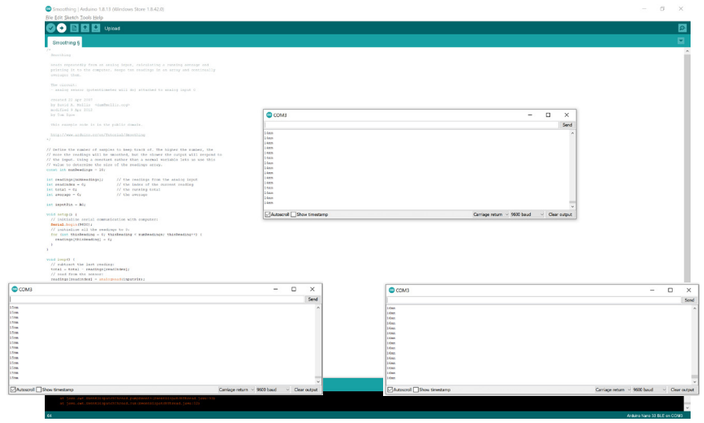
PROOF OF CONCEPTS

PoC #3 – MagnetoPot

- Simple testing script
  - Magnet
  - Caliper
  (for displacement measurement)

- Findings
  - Good accuracy
  - Tolerance of +- 1mm

- Conclusion
  - Feasible
  - Reduction of tolerance possible

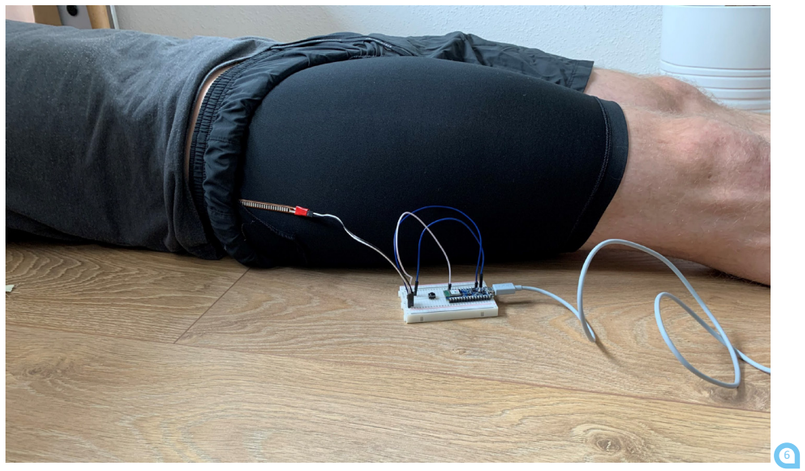


BI-WEEKLY MEETING 18.09.2020

PROOF OF CONCEPTS

PoC #4 – Flex Sensor

- Simple testing script
  - Double-sided tape

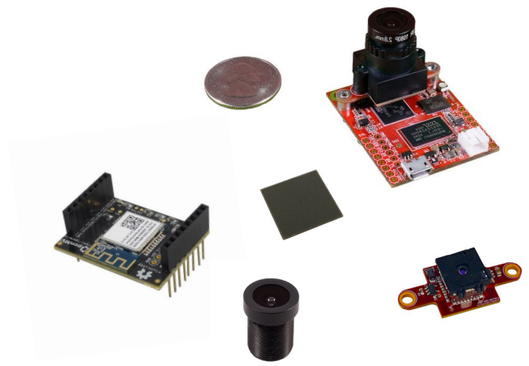


BI-WEEKLY MEETING 18.09.2020

PROOF OF CONCEPTS

PoC #5 – OpenMV

- Delayed Arrival
  - 2 days ago

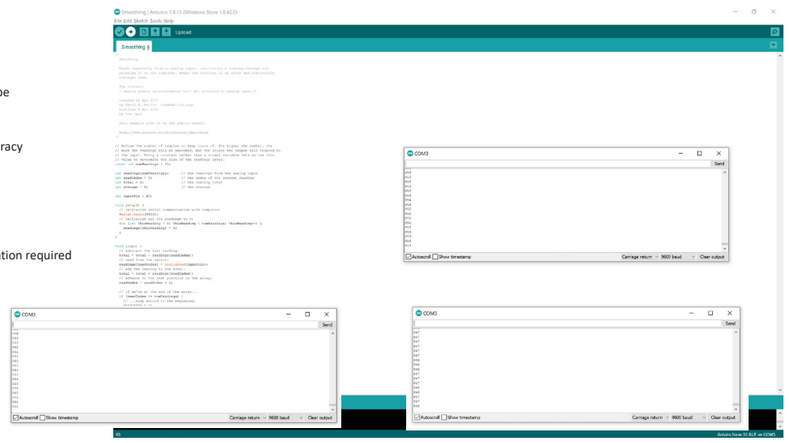


BI-WEEKLY MEETING 18.09.2020

PROOF OF CONCEPTS

PoC #4 – Flex Sensor

- Simple testing script
  - Double-sided tape
- Findings
  - Reasonable accuracy (after smoothing)
- Conclusion
  - Feasible
  - Tolerance calibration required (bi-directional tilt)



Questions?

Expert Session

#2

4763033 - Jan Sebastian van Ackeren

TU Delft

Agenda

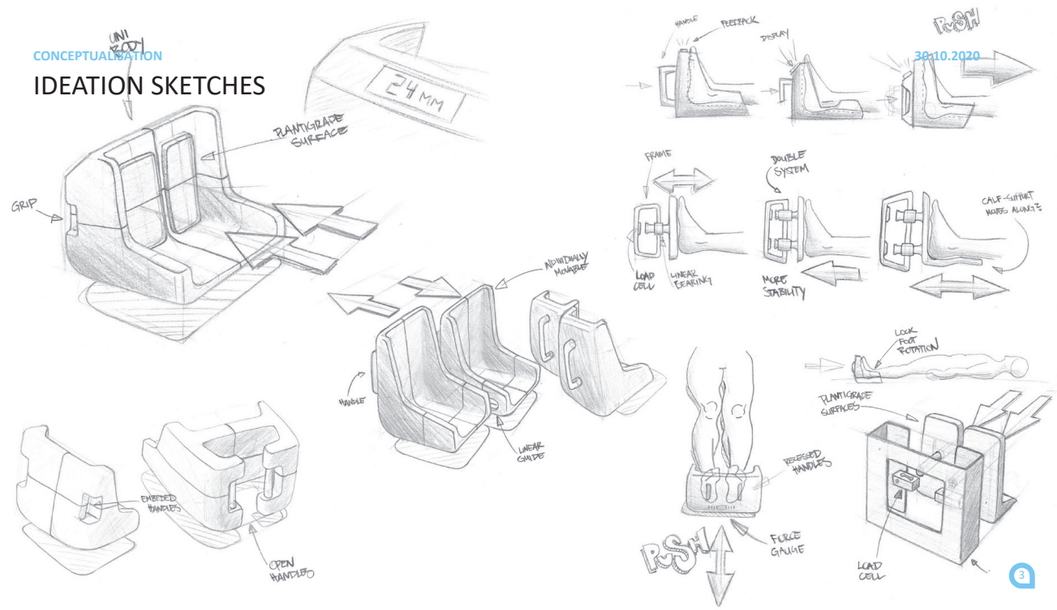
Conceptualisation
- Ideation Sketches
- Ergonomics Study
- Concept

Updates & Next Steps
- Planning
- Trello

CONCEPTUALISATION

30.10.2020

IDEATION SKETCHES



CONCEPTUALISATION

30.10.2020

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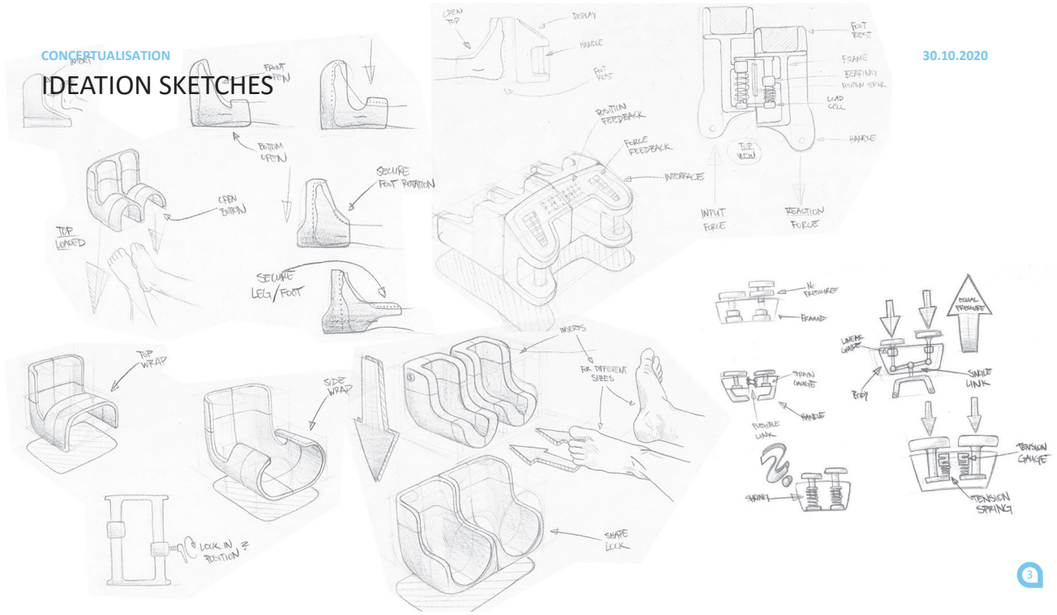


CONCEPTUALISATION

30.10.2020

ERGONOMICS STUDY

Overview

- 5x cardboard plastic mockup
  - 2x unibody
  - 3x splitbody
- 2x converted luggage scale

CONCEPTUALISATION

30.10.2020

ERGONOMICS STUDY

Unibody 2

- Top Loaded
- Feet weight down device
- Still difficult to load feet (fidly)
- Heel locks nicely
- Easy to apply force

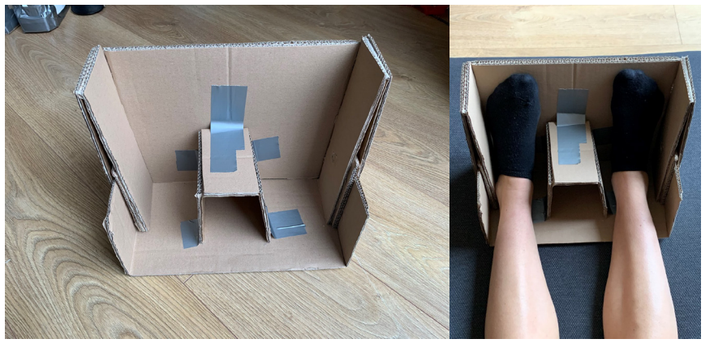
CONCEPTUALISATION

30.10.2020

ERGONOMICS STUDY

Unibody 1

- Bottom Loaded
- Feet weight down device
- Difficult to load feet (fidly)
- Easy to apply force



CONCEPTUALISATION

30.10.2020

ERGONOMICS STUDY

Splitbody 1

- Bottom Loaded
- Feet weight down device
- Easy to load feet (individual)
- Easy to apply force
- Easy to slide in parallel
- Flat horizontal surfaces help orientation

CONCEPTUALISATION

30.10.2020

ERGONOMICS STUDY

Splitbody 2

- Bottom Loaded
- Feet weight down device
- Easy to load feet (individual)
- Easy to apply force
- Easy to slide in parallel
- Difficult to orientate

CONCEPTUALISATION

30.10.2020

ERGONOMICS STUDY

Luggage Scale Handle

- Verified: Different Loads applied
- Handle is not ergonomic for pushing
- Limited control when pulling / pushing
- User should grab the device fully
- Shape of device should be ergonomic
- ‘Embracing grab’

CONCEPTUALISATION

30.10.2020

ERGONOMICS STUDY

Splitbody 3

- Bottom Loaded
- Feet weight down device
- Easy to load feet (individual)
- Heel locks nicely
- Easy to apply force
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CONCEPTUALISATION

30.10.2020

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30.10.2020

CONCEPT

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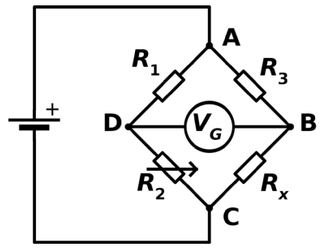
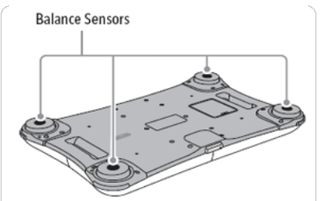
  - Wired into a Wheatstone Bridge
  - For better precision





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CONCEPTUALISATION

30.10.2020

CONCEPT

Overview

- Load sensors
  - Wired into a Wheatstone Bridge
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- Wii Balance Board / Smart Scale
  - Split in two
  - Introduce flexible link

CONCEPTUALISATION

30.10.2020

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  - Shape design for position sensing
    - ‘complete the shape’

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- Magnets for connecting two halfs
  - Completely enclose system
    - Sterile cleaning
  - Wireless charging?

CONCEPTUALISATION

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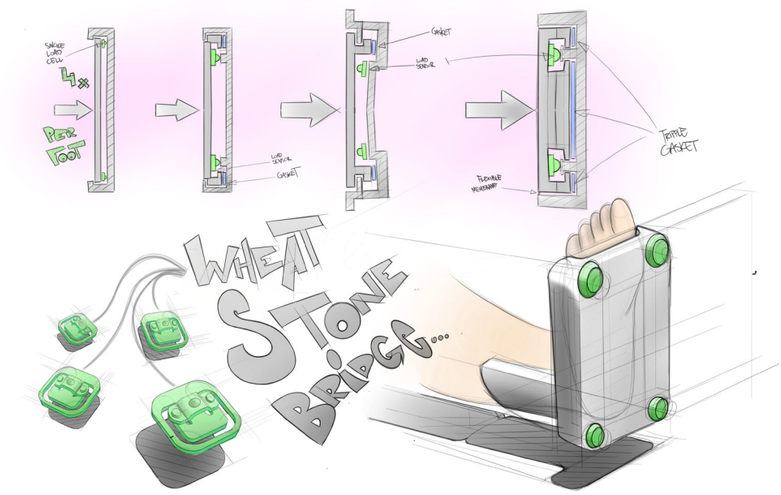

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Expert Session

#3

4763033 - Jan Sebastian van Ackeren

TU Delft

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CONCEPTUALISATION

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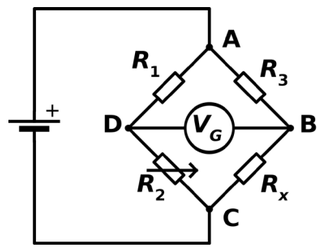

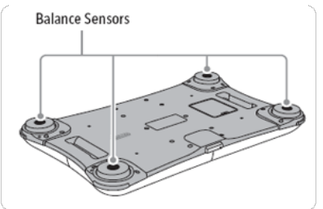

CONCEPTUALISATION

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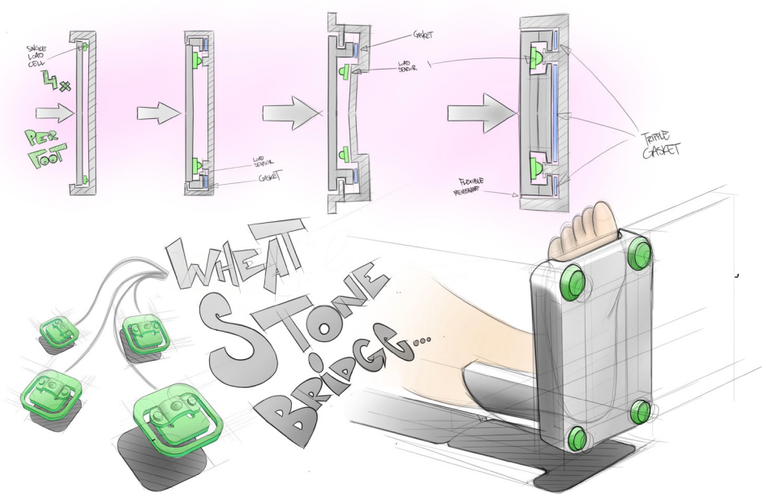
CONCEPTUALISATION

30.10.2020

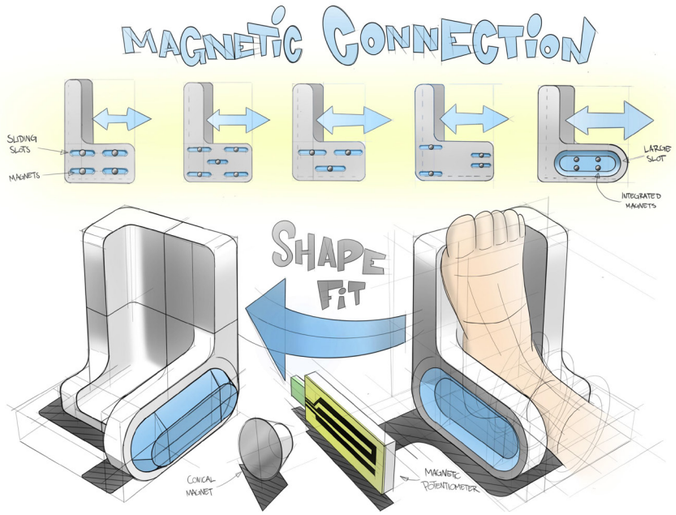
CONCEPT



CONCEPTUALISATION

30.10.2020

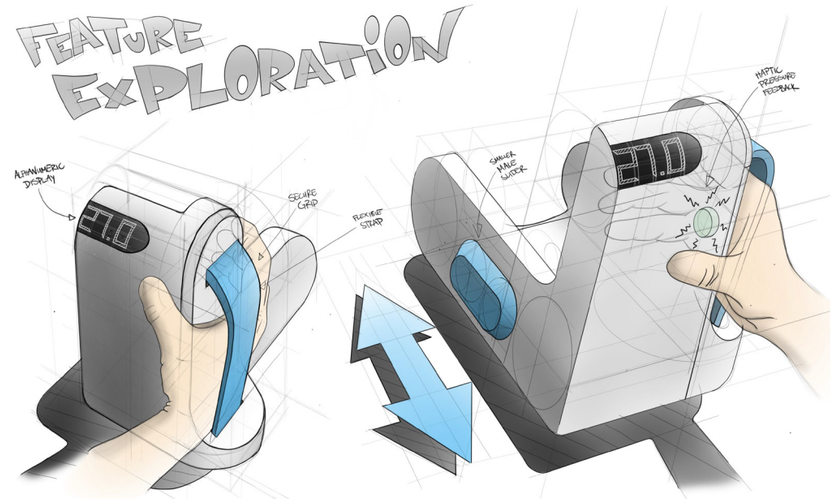
CONCEPT



CONCEPTUALISATION

30.10.2020

CONCEPT



Questions?

Appendix F
PoC Codes

magnetoPot_Smoothing

```
/*
  Smoothing

  Reads repeatedly from an analog input, calculating a running average and
  printing it to the computer. Keeps ten readings in an array and continually
  averages them.

  The circuit:
  - analog sensor (potentiometer will do) attached to analog input 0

  created 22 Apr 2007
  by David A. Mellis  <dam@mellis.org>
  modified 9 Apr 2012
  by Tom Igoe

  This example code is in the public domain.

  http://www.arduino.cc/en/Tutorial/Smoothing
*/

// Define the number of samples to keep track of. The higher the number, the
// more the readings will be smoothed, but the slower the output will respond to
// the input. Using a constant rather than a normal variable lets us use this
// value to determine the size of the readings array.
const int numReadings = 10;

int readings[numReadings];      // the readings from the analog input
int readIndex = 0;              // the index of the current reading
int total = 0;                  // the running total
int average = 0;                // the average

int inputPin = A0;

void setup() {
  // initialize serial communication with computer:
  Serial.begin(9600);
  // initialize all the readings to 0:
  for (int thisReading = 0; thisReading < numReadings; thisReading++) {
    readings[thisReading] = 0;
  }
}

void loop() {
  // subtract the last reading:
  total = total - readings[readIndex];
  // read from the sensor:
  readings[readIndex] = analogRead(inputPin);
  // add the reading to the total:
  total = total + readings[readIndex];
  // advance to the next position in the array:
  readIndex = readIndex + 1;

  // if we're at the end of the array...
  if (readIndex >= numReadings) {
    // ...wrap around to the beginning:
    readIndex = 0;
  }

  // calculate the average:
  //average = total / numReadings;
  // send it to the computer as ASCII digits
  //Serial.println(average);
  //int distance = map (average, 20 , 990 , -290 , 210);
  //float distance2 = distance / 10;
  const float distance1 = -25.00;
  const float distance2 = 25.00;
  float distance3 = distance1 + ((distance2 - distance1)* analogRead(inputPin) /1024);
  Serial.println (String(distance3) + "mm");
 //Serial.println(readings[readIndex]);
  delay(100);        // delay in between reads for stability
}
```

double_magnetoPot_Smoothing

```
/*
  Smoothing

  Reads repeatedly from an analog input, calculating a running average and
  printing it to the computer. Keeps ten readings in an array and continually
  averages them.

  The circuit:
  - analog sensor (potentiometer will do) attached to analog input 0

  created 22 Apr 2007
  by David A. Mellis  <dam@mellis.org>
  modified 9 Apr 2012
  by Tom Igoe

  This example code is in the public domain.

  http://www.arduino.cc/en/Tutorial/Smoothing
*/

// Define the number of samples to keep track of. The higher the number, the
// more the readings will be smoothed, but the slower the output will respond to
// the input. Using a constant rather than a normal variable lets us use this
// value to determine the size of the readings array.
const int numReadings1 = 10;
const int numReadings2 = 10;

int readings1[numReadings1];      // the readings from the analog input
int readIndex1 = 0;              // the index of the current reading
int total1 = 0;                  // the running total
int average1 = 0;                // the average
int readings2[numReadings2];      // the readings from the analog input
int readIndex2 = 0;              // the index of the current reading
int total2 = 0;                  // the running total
int average2 = 0;                // the average

int inputPin1 = A0;
int inputPin2 = A1;

void setup() {
  // initialize serial communication with computer:
  Serial.begin(9600);
  // initialize all the readings to 0:
  for (int thisReading1 = 0; thisReading1 < numReadings1; thisReading1++) {
    readings1[thisReading1] = 0;
}

  for (int thisReading2 = 0; thisReading2 < numReadings2; thisReading2++) {
    readings2[thisReading2] = 0;

  }
}

void loop() {
  // subtract the last reading:
  total1 = total1 - readings1[readIndex1];
  // read from the sensor:
  readings1[readIndex1] = analogRead(inputPin1);
  // add the reading to the total:
  total1 = total1 + readings1[readIndex1];
  // advance to the next position in the array:
  readIndex1 = readIndex1 + 1;

  // if we're at the end of the array...
  if (readIndex1 >= numReadings1) {
    // ...wrap around to the beginning:
    readIndex1 = 0;
}

   // subtract the last reading:
  total2 = total2 - readings2[readIndex2];
  // read from the sensor:
  readings2[readIndex2] = analogRead(inputPin2);
  // add the reading to the total:
  total2 = total2 + readings2[readIndex2];
  // advance to the next position in the array:
  readIndex2 = readIndex2 + 1;

  // if we're at the end of the array...
  if (readIndex2 >= numReadings2) {
    // ...wrap around to the beginning:
    readIndex2 = 0;
  }


  // calculate the average:
  average1 = total1 / numReadings1;
  // send it to the computer as ASCII digits
  //Serial.println(average1);
  int distance1 = map (average1, 20 , 990 , 0 , 25);
  Serial.println (String(distance1) + "mm");
 //Serial.println(readings1[readIndex1]);


 // calculate the average:
  average2 = total2 / numReadings2;
  // send it to the computer as ASCII digits
  //Serial.println(average2);
  int distance2 = map (average2, 20 , 990 , 0 , 25);
  Serial.println (String(distance2) + "mm");
 //Serial.println(readings2[readIndex2]);

  delay(100);        // delay in between reads for stability
}
```

Pelvic_tilt_device_code__1

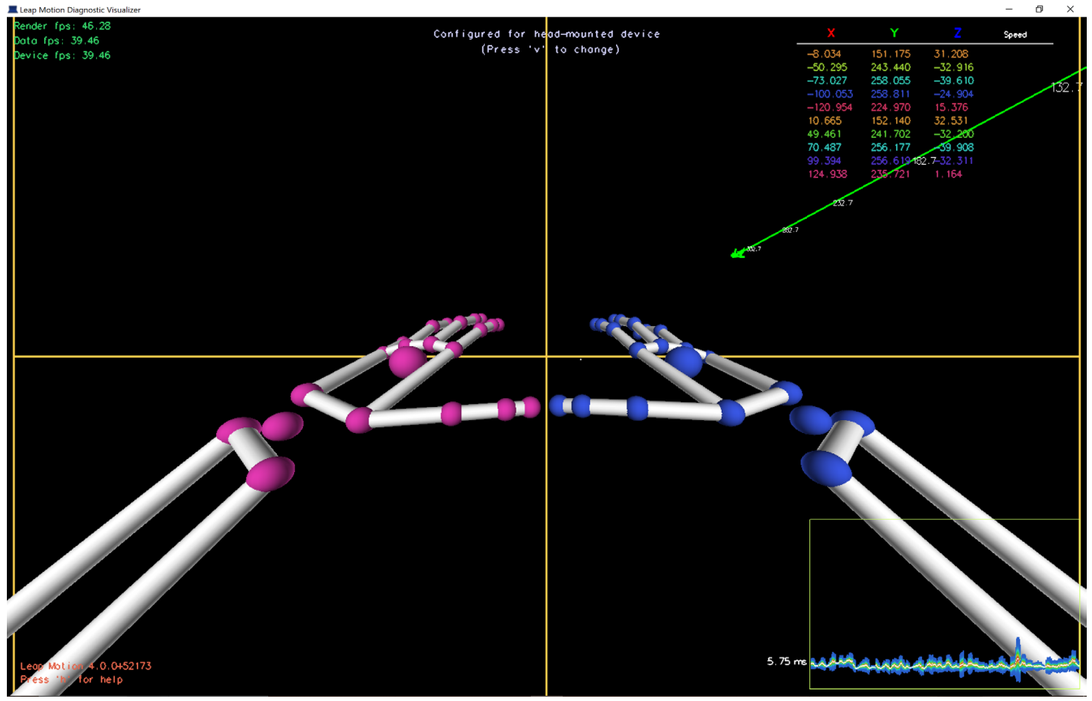
```
#include <Adafruit_NeoPixel.h>

const int flexPin = A0;
#define LED_PIN     6

// How many NeoPixels are attached to the Arduino?
#define LED_COUNT  7

// NeoPixel brightness, 0 (min) to 255 (max)
#define BRIGHTNESS 255

// Declare our NeoPixel strip object:
Adafruit_NeoPixel strip(LED_COUNT, LED_PIN, NEO_GRB + NEO_KHZ800);


void setup()
{
  Serial.begin(9600);

  strip.begin();           // INITIALIZE NeoPixel strip object (REQUIRED)
  strip.show();            // Turn OFF all pixels ASAP
  strip.setBrightness(5); // Set BRIGHTNESS to about 1/5 (max = 255)
}


void loop()
{
  int flexValue;
  flexValue = analogRead(flexPin);
  Serial.print("sensor: ");
  Serial.println(flexValue);
   //colorWipe(strip.Color(  0,   0, 255)     , 50); // Blue
   // pulseBlue(5);


  if (flexValue >= 740) {
    colorWipe(strip.Color(  255,   0, 0)     , 50); // Red
    pulseRed(5);
  }

  else {if (flexValue < 709) {
    colorWipe(strip.Color(  255,   0, 0)     , 50); // Blue
    pulseRed(5);
  }

    else {
    colorWipe(strip.Color(  0,   255, 0)     , 50); // Green
  }
  }
```

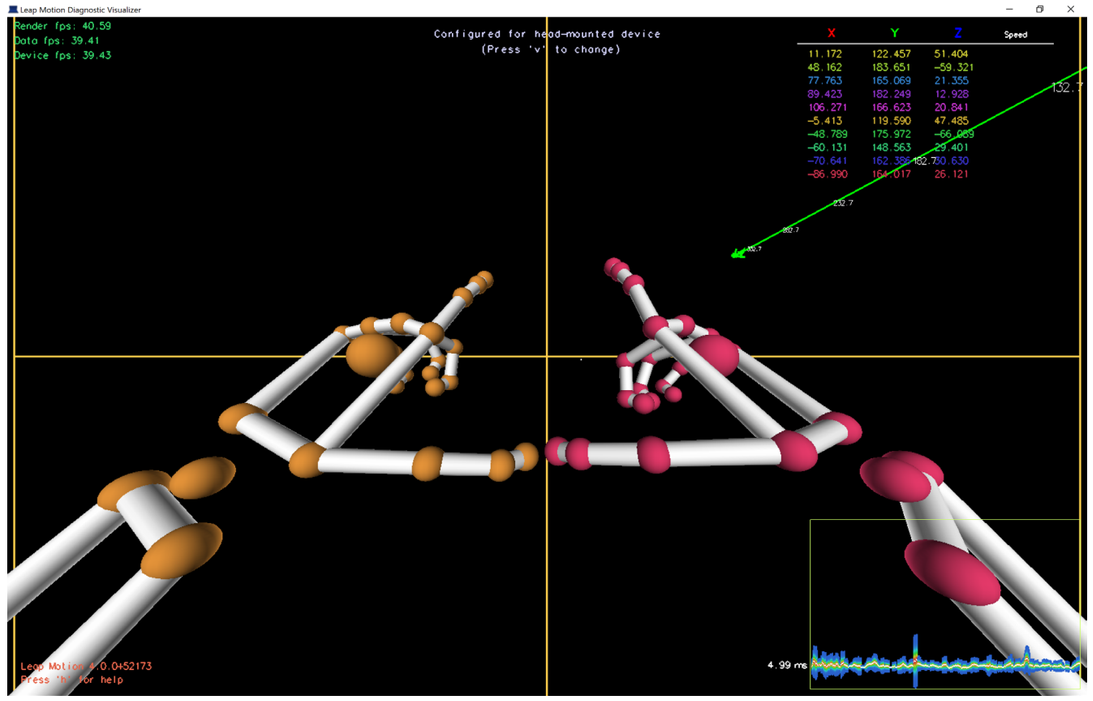
ir_beacon_grayscale_track... | Line: 1, Col: 1

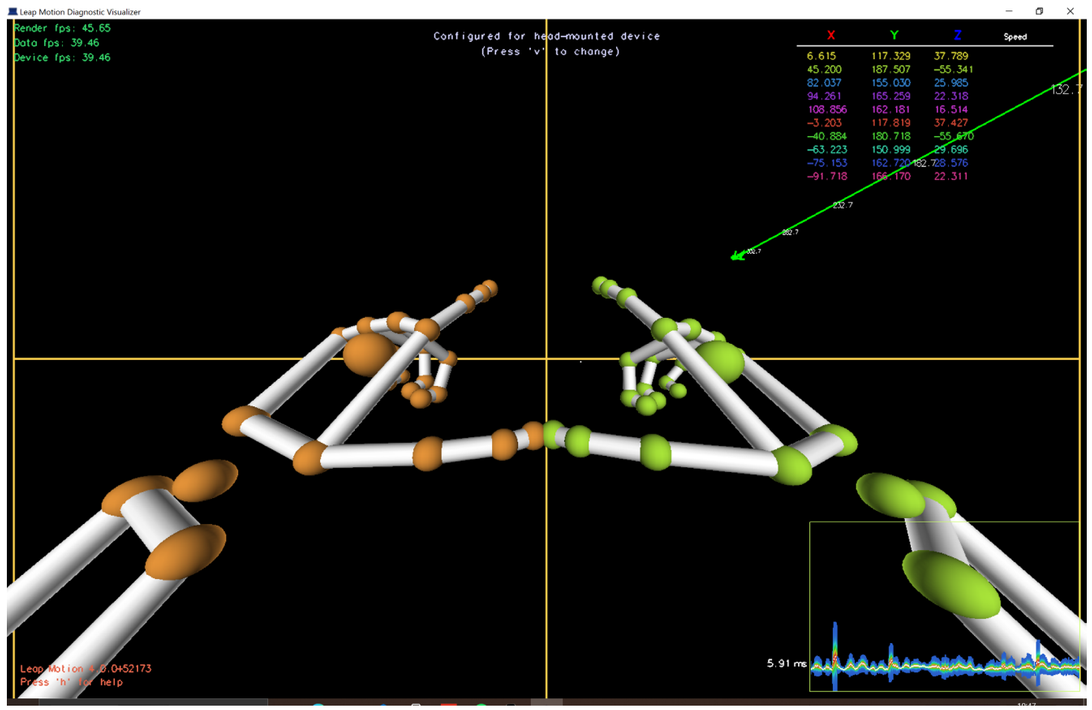
```
# IR Beacon Grayscale Tracking Example
#
# This example shows off IR beacon Grayscale tracking using the OpenMV Cam.

import sensor, image, time

thresholds = (230, 255) # thresholds for bright white light from IR.

sensor.reset()
sensor.set_pixformat(sensor.GRAYSCALE)
sensor.set_framesize(sensor.WQXGA2)
sensor.set_windowing((2592, 1944)) # 2592x1944 center pixels of VGA
sensor.skip_frames(time = 2000)
sensor.set_auto_gain(False) # must be turned off for color tracking
sensor.set_auto_whitebal(False) # must be turned off for color tracking
clock = time.clock()

# Only blobs that with more pixels than "pixel_threshold" and more area than "area_threshold" are
# returned by "find_blobs" below. Change "pixels_threshold" and "area_threshold" if you change the
# camera resolution. "merge=True" merges all overlapping blobs in the image.

while(True):
    clock.tick()
    img = sensor.snapshot()
    for blob in img.find_blobs([thresholds], pixels_threshold=1000, area_threshold=1000, merge=True):
        ratio = blob.w() / blob.h()
        if (ratio >= 0.8) and (ratio <= 1.2): # filter out non-squarish blobs
            img.draw_rectangle(blob.rect(), color=(255,255,255))
            img.draw_cross(blob.cx(), blob.cy())

            print("x:", blob.cx(), end='')
            print(" y:", blob.cy())
```

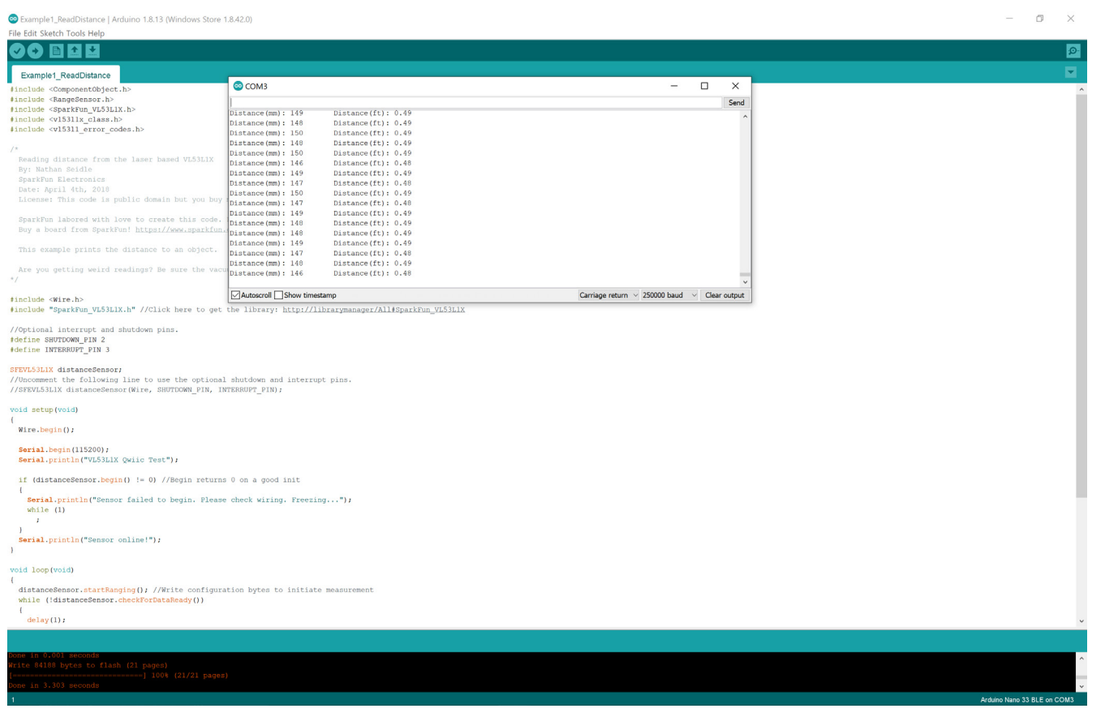
Appendix G

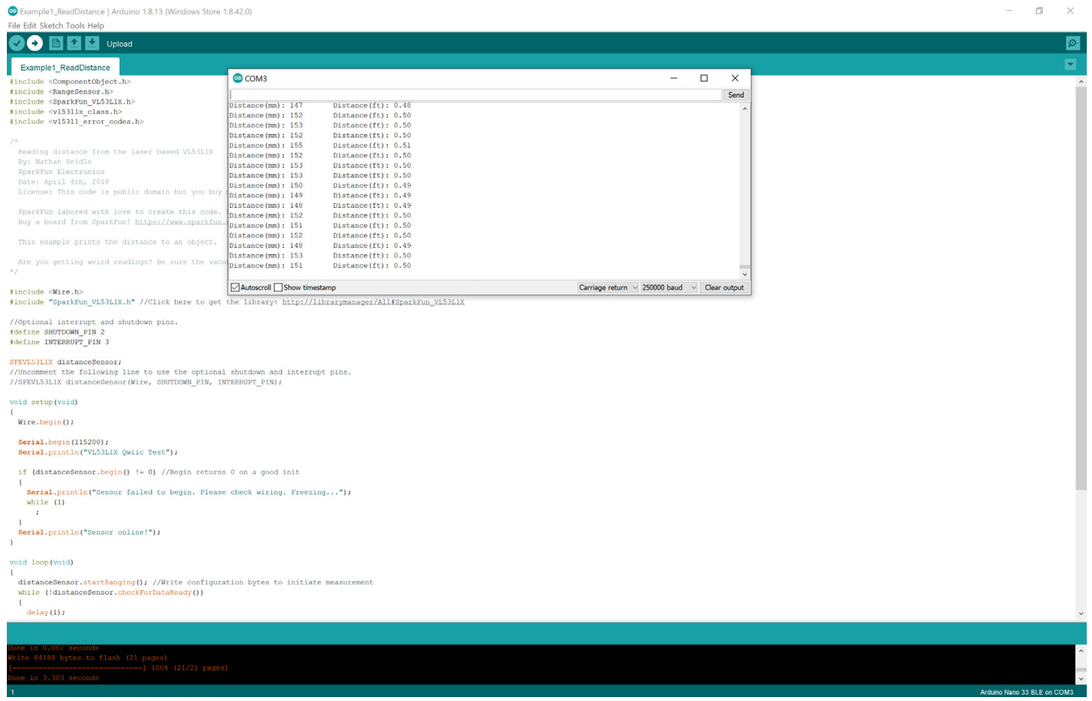
PoC Pictures


Leap Motion Diagnostic Visualizer
Render fps: 46.28
Data fps: 39.46
Device fps: 39.46
Configured for head-mounted device
(Press 'v' to change)
X Y Z Speed
-8.034 151.175 31.208
-50.295 243.440 -32.916
-73.027 258.055 -39.610
-100.053 258.811 -24.904
-120.954 224.970 15.376
10.665 152.140 32.531
49.461 241.702 -32.300
70.487 256.177 -39.908
99.394 256.619 -32.311
124.938 236.721 1.164
132.7
232.7
82.7
5.75 ms
Leap Motion 4.0.0+52173
Press 'h' for help


Leap Motion Diagnostic Visualizer
Render fps: 40.59
Data fps: 39.41
Device fps: 39.43
Configured for head-mounted device
(Press 'v' to change)
X Y Z Speed
11.172 122.457 51.404
48.162 183.651 -59.321
77.763 165.069 21.355
89.423 182.249 12.928
106.271 166.623 20.841
-5.413 119.590 47.485
-48.789 175.972 -66.089
-60.131 148.563 29.401
-70.641 162.386 50.630
-86.990 164.017 26.121
132.7
232.7
82.7
4.99 ms
Leap Motion 4.0.0+52173
Press 'h' for help


Leap Motion Diagnostic Visualizer
Render fps: 45.65
Data fps: 39.46
Device fps: 39.46
Configured for head-mounted device
(Press 'v' to change)
X Y Z Speed
6.615 117.329 37.789
45.200 187.507 -55.341
82.037 155.030 25.985
94.261 165.259 22.318
108.856 162.181 16.514
-3.203 117.819 37.427
-40.884 180.718 -55.670
-63.223 150.999 29.696
-75.153 162.720 28.576
-91.718 166.170 22.311
132.7
232.7
82.7
5.91 ms
Leap Motion 4.0.0+52173
Press 'h' for help


Example1_ReadDistance | Arduino 1.8.13 (Windows Store 1.8.42.0)
File Edit Sketch Tools Help
Example1_ReadDistance
COM3
Send
Distance(mm): 149 Distance(ft): 0.49
Distance(mm): 148 Distance(ft): 0.49
Distance(mm): 150 Distance(ft): 0.49
Distance(mm): 148 Distance(ft): 0.49
Distance(mm): 150 Distance(ft): 0.49
Distance(mm): 146 Distance(ft): 0.48
Distance(mm): 149 Distance(ft): 0.49
Distance(mm): 147 Distance(ft): 0.48
Distance(mm): 150 Distance(ft): 0.49
Distance(mm): 147 Distance(ft): 0.48
Distance(mm): 149 Distance(ft): 0.49
Distance(mm): 148 Distance(ft): 0.49
Distance(mm): 148 Distance(ft): 0.49
Distance(mm): 149 Distance(ft): 0.49
Distance(mm): 147 Distance(ft): 0.48
Distance(mm): 140 Distance(ft): 0.49
Distance(mm): 146 Distance(ft): 0.48
Autoscroll
Show timestamp
Carriage return
250000 baud
Clear output
#include <ComponentObject.h>
#include <RangeSensor.h>
#include <SparkFun_VL53L1X.h>
#include <vl53l1x_class.h>
#include <vl53l1_error_codes.h>
/*
Reading distance from the laser based VL53L1X
By: Nathan Seidle
SparkFun Electronics
Date: April 4th, 2018
License: This code is public domain but you buy
SparkFun labored with love to create this code.
Buy a board from SparkFun! https://www.sparkfun.
This example prints the distance to an object.
Are you getting weird readings? Be sure the vacu
*/
#include <Wire.h>
#include "SparkFun_VL53L1X.h" //Click here to get the library: http://librarymanager/All#SparkFun_VL53L1X
//Optional interrupt and shutdown pins.
#define SHUTDOWN_PIN 2
#define INTERRUPT_PIN 3
SFEVL53L1X distanceSensor;
//Uncomment the following line to use the optional shutdown and interrupt pins.
//SFEVL53L1X distanceSensor(Wire, SHUTDOWN_PIN, INTERRUPT_PIN);
void setup(void)
{
Wire.begin();
Serial.begin(115200);
Serial.println("VL53L1X Qwiic Test");
if (distanceSensor.begin() != 0) //Begin returns 0 on a good init
{
Serial.println("Sensor failed to begin. Please check wiring. Freezing...");
while (1)
;
}
Serial.println("Sensor online!");
}
void loop(void)
{
distanceSensor.startRanging(); //Write configuration bytes to initiate measurement
while (!distanceSensor.checkForDataReady())
{
delay(1);
Done in 0.601 seconds
Write 84188 bytes to flash (21 pages)
[==========] 100% (21/21 pages)
Done in 3.303 seconds
1
Arduino Nano 33 BLE on COM3


Example1_ReadDistance | Arduino 1.8.13 (Windows Store 1.8.42.0)
File Edit Sketch Tools Help
Upload
Example1_ReadDistance
#include <ComponentObject.h>
#include <RangeSensor.h>
#include <SparkFun_VL53L1X.h>
#include <vl53l1x_class.h>
#include <vl53l1_error_codes.h>
/*
Reading distance from the laser based VL53L1X
By: Nathan Seidle
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Date: April 4th, 2018
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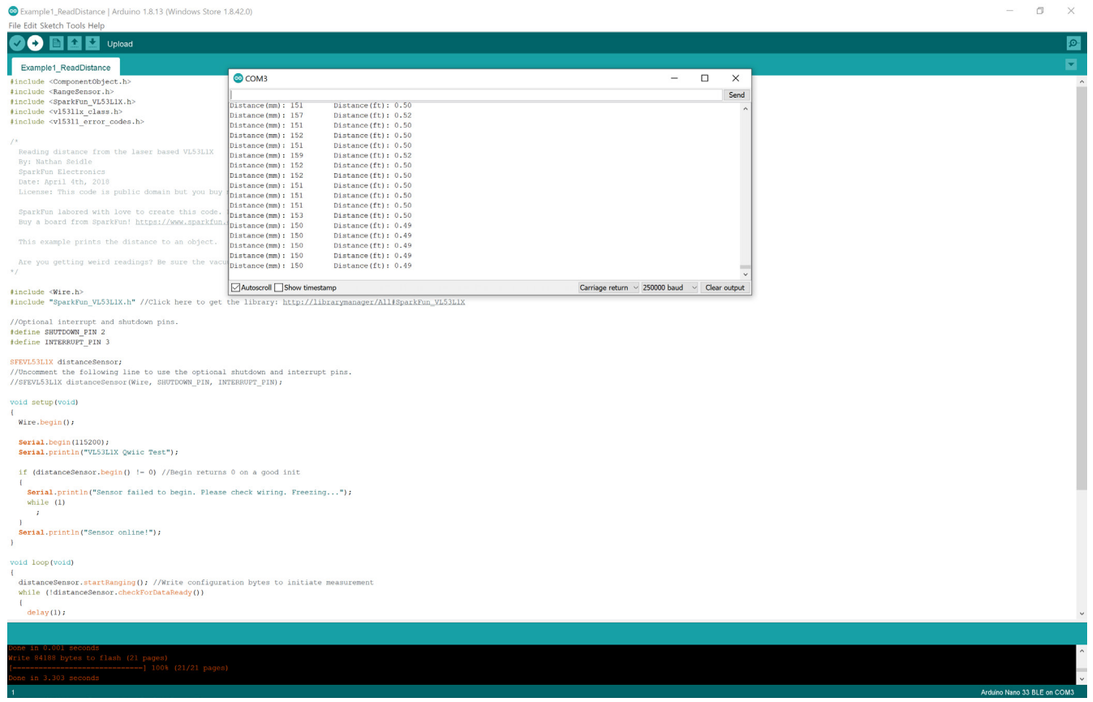
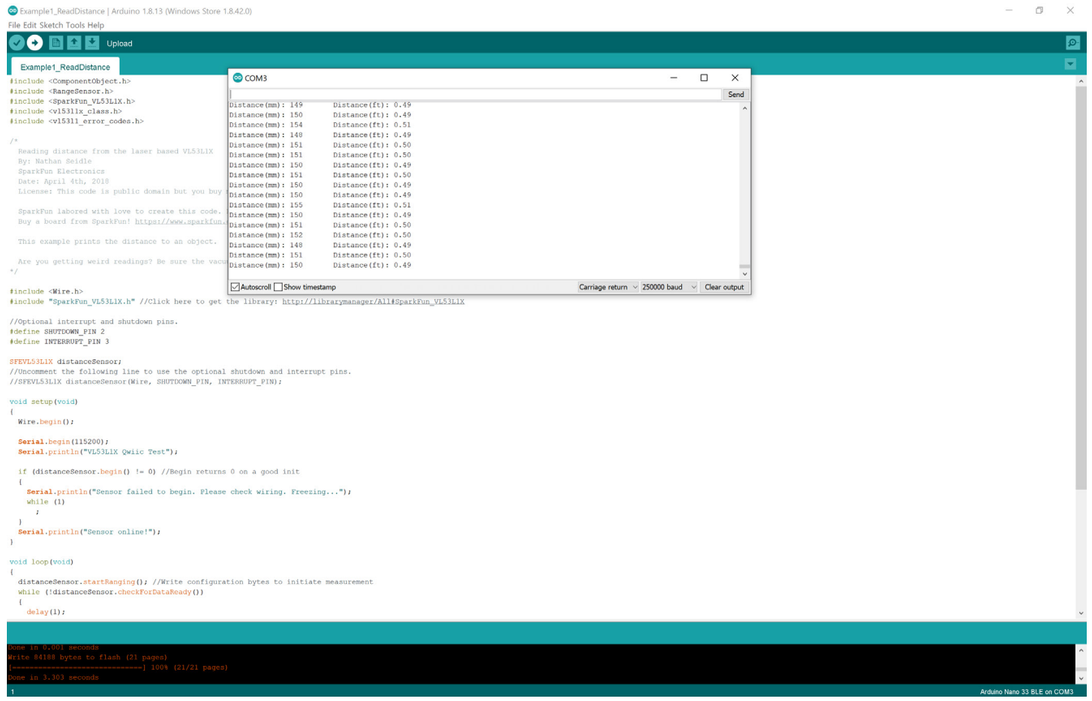
SparkFun labored with love to create this code.
Buy a board from SparkFun! https://www.sparkfun.
This example prints the distance to an object.
Are you getting weird readings? Be sure the vacu
*/
#include <Wire.h>
#include "SparkFun_VL53L1X.h" //Click here to get the library: http://librarymanager/All#SparkFun_VL53L1X
//Optional interrupt and shutdown pins.
#define SHUTDOWN_PIN 2
#define INTERRUPT_PIN 3
SFEVL53L1X distanceSensor;
//Uncomment the following line to use the optional shutdown and interrupt pins.
//SFEVL53L1X distanceSensor(Wire, SHUTDOWN_PIN, INTERRUPT_PIN);
void setup(void)
{
Wire.begin();
Serial.begin(115200);
Serial.println("VL53L1X Qwiic Test");
if (distanceSensor.begin() != 0) //Begin returns 0 on a good init
{
Serial.println("Sensor failed to begin. Please check wiring. Freezing...");
while (1)
;
}
Serial.println("Sensor online!");
}
void loop(void)
{
distanceSensor.startRanging(); //Write configuration bytes to initiate measurement
while (!distanceSensor.checkForDataReady())
{
delay(1);
COM3
Send
Distance(mm): 147 Distance(ft): 0.48
Distance(mm): 152 Distance(ft): 0.50
Distance(mm): 153 Distance(ft): 0.50
Distance(mm): 152 Distance(ft): 0.50
Distance(mm): 155 Distance(ft): 0.51
Distance(mm): 152 Distance(ft): 0.50
Distance(mm): 153 Distance(ft): 0.50
Distance(mm): 153 Distance(ft): 0.50
Distance(mm): 150 Distance(ft): 0.49
Distance(mm): 149 Distance(ft): 0.49
Distance(mm): 148 Distance(ft): 0.49
Distance(mm): 152 Distance(ft): 0.50
Distance(mm): 151 Distance(ft): 0.50
Distance(mm): 152 Distance(ft): 0.50
Distance(mm): 148 Distance(ft): 0.49
Distance(mm): 153 Distance(ft): 0.50
Distance(mm): 151 Distance(ft): 0.50
Autoscroll
Show timestamp
Carriage return
250000 baud
Clear output
Done in 0.001 seconds
Write 84188 bytes to flash (21 pages)
[============================] 100% (21/21 pages)
Done in 3.303 seconds
1
Arduino Nano 33 BLE on COM3


Example1_ReadDistance | Arduino 1.8.13 (Windows Store 1.8.42.0)
File Edit Sketch Tools Help
Upload
Example1_ReadDistance
#include <ComponentObject.h>
#include <RangeSensor.h>
#include <SparkFun_VL53L1X.h>
#include <vl53l1x_class.h>
#include <vl53l1_error_codes.h>
/*
Reading distance from the laser based VL53L1X
By: Nathan Seidle
SparkFun Electronics
Date: April 4th, 2018
License: This code is public domain but you buy
SparkFun labored with love to create this code.
Buy a board from SparkFun! https://www.sparkfun.
This example prints the distance to an object.
Are you getting weird readings? Be sure the vacu
*/
#include <Wire.h>
#include "SparkFun_VL53L1X.h" //Click here to get the library: http://librarymanager/All#SparkFun_VL53L1X
//Optional interrupt and shutdown pins.
#define SHUTDOWN_PIN 2
#define INTERRUPT_PIN 3
SFEVL53L1X distanceSensor;
//Uncomment the following line to use the optional shutdown and interrupt pins.
//SFEVL53L1X distanceSensor(Wire, SHUTDOWN_PIN, INTERRUPT_PIN);
void setup(void)
{
Wire.begin();
Serial.begin(115200);
Serial.println("VL53L1X Qwiic Test");
if (distanceSensor.begin() != 0) //Begin returns 0 on a good init
{
Serial.println("Sensor failed to begin. Please check wiring. Freezing...");
while (1)
;
}
Serial.println("Sensor online!");
}
void loop(void)
{
distanceSensor.startRanging(); //Write configuration bytes to initiate measurement
while (!distanceSensor.checkForDataReady())
{
delay(1);
COM3
Send
Distance(mm): 151 Distance(ft): 0.50
Distance(mm): 157 Distance(ft): 0.52
Distance(mm): 151 Distance(ft): 0.50
Distance(mm): 152 Distance(ft): 0.50
Distance(mm): 151 Distance(ft): 0.50
Distance(mm): 159 Distance(ft): 0.52
Distance(mm): 152 Distance(ft): 0.50
Distance(mm): 152 Distance(ft): 0.50
Distance(mm): 151 Distance(ft): 0.50
Distance(mm): 151 Distance(ft): 0.50
Distance(mm): 153 Distance(ft): 0.50
Distance(mm): 150 Distance(ft): 0.49
Distance(mm): 150 Distance(ft): 0.49
Distance(mm): 150 Distance(ft): 0.49
Autoscroll
Show timestamp
Carriage return
250000 baud
Clear output
Done in 0.001 seconds
Write 84188 bytes to flash (21 pages)
[============================] 100% (21/21 pages)
Done in 3.303 seconds
1
Arduino Nano 33 BLE on COM3


Example1_ReadDistance | Arduino 1.8.13 (Windows Store 1.8.42.0)
File Edit Sketch Tools Help
Upload
Example1_ReadDistance
#include <ComponentObject.h>
#include <RangeSensor.h>
#include <SparkFun_VL53L1X.h>
#include <vl53l1x_class.h>
#include <vl53l1_error_codes.h>
/*
Reading distance from the laser based VL53L1X
By: Nathan Seidle
SparkFun Electronics
Date: April 4th, 2018
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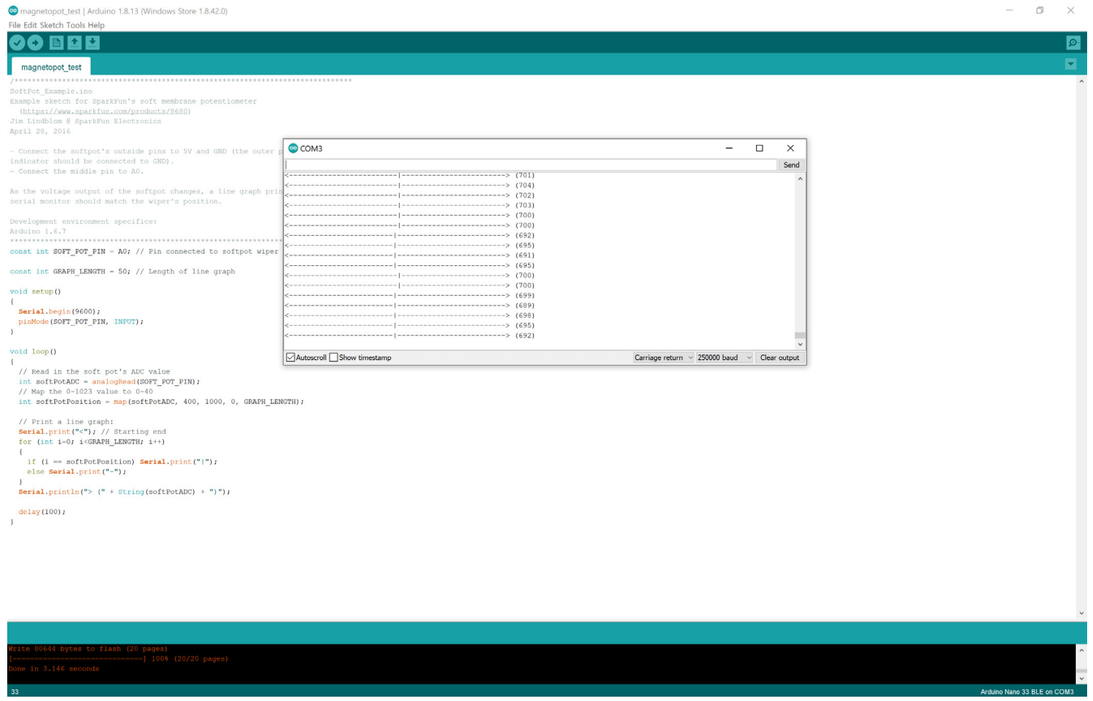
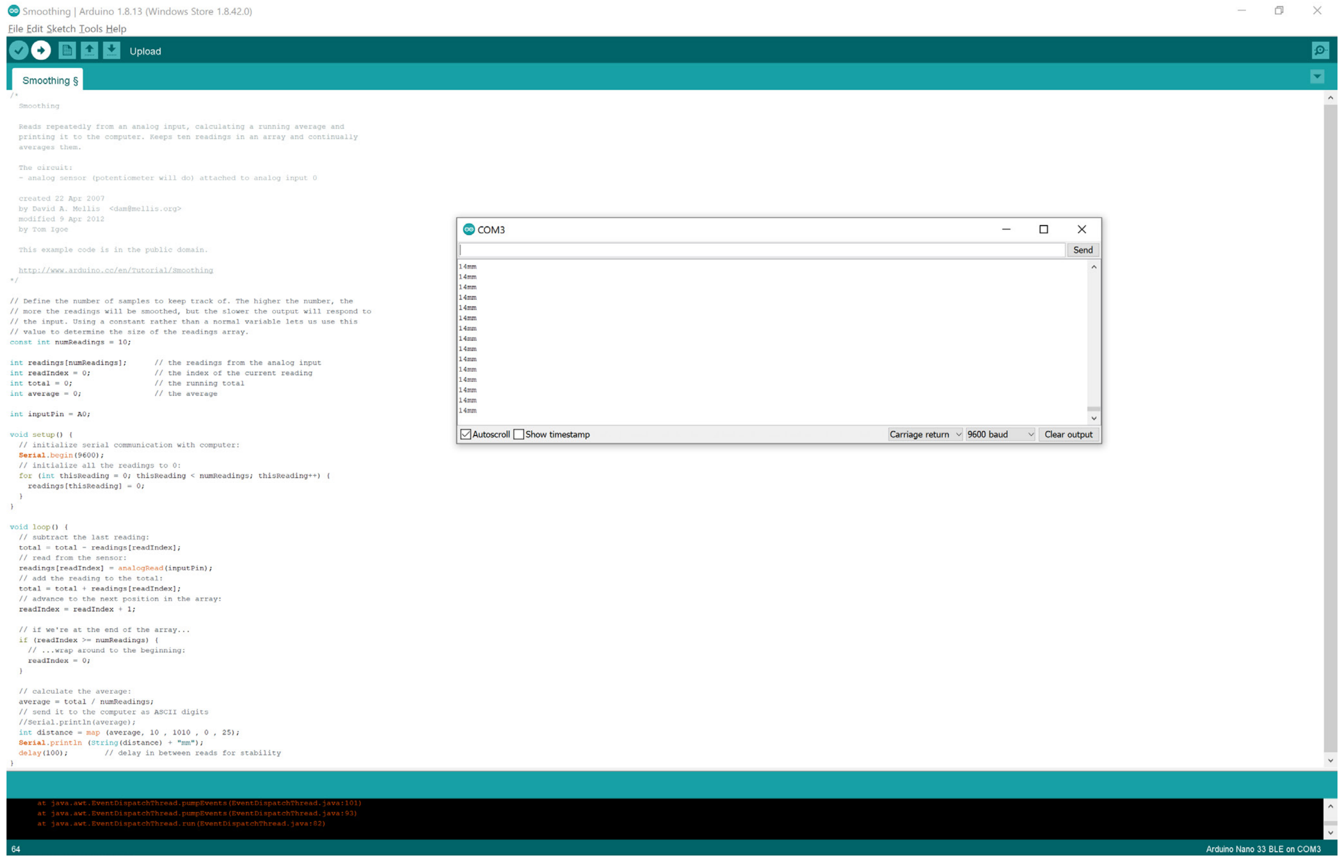
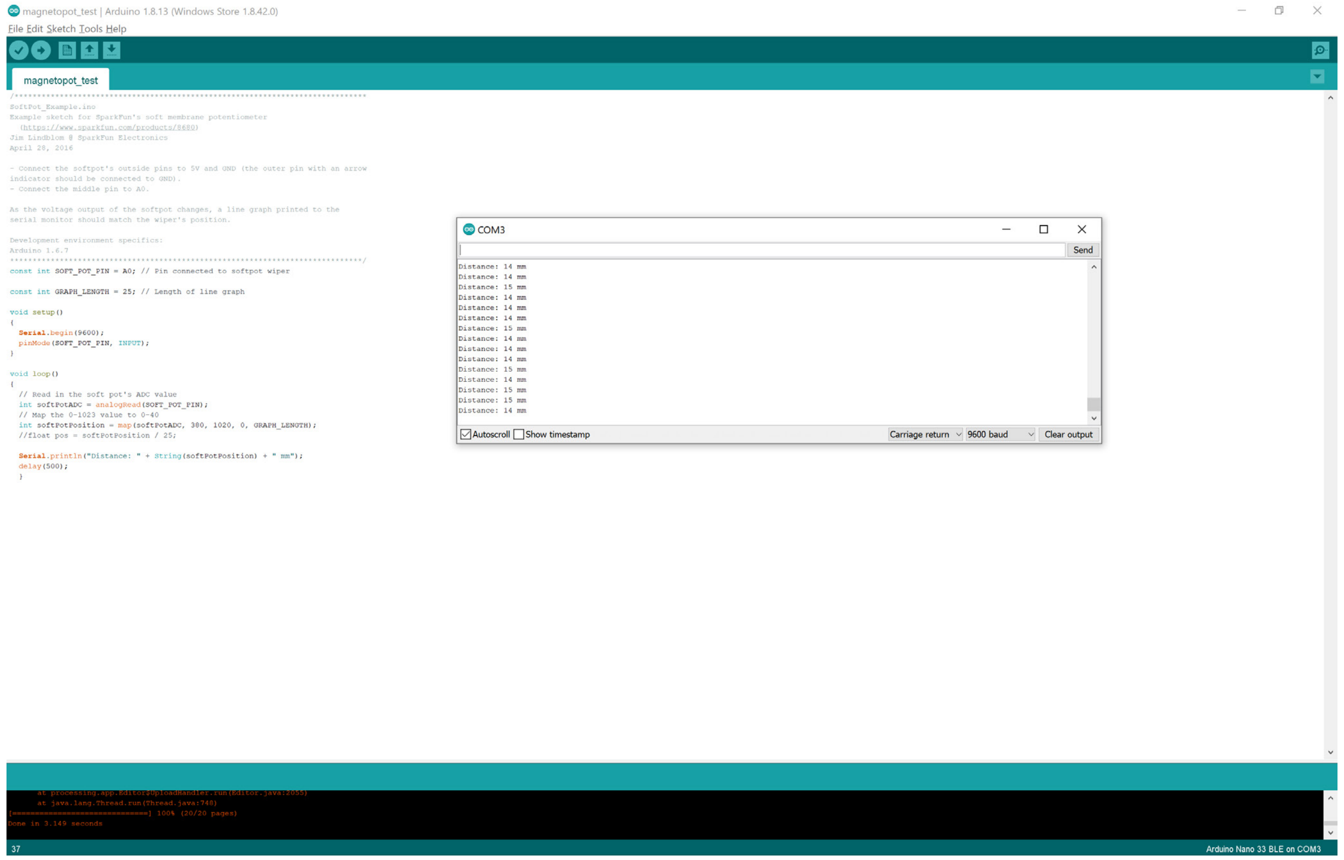
SparkFun labored with love to create this code.
Buy a board from SparkFun! https://www.sparkfun.
This example prints the distance to an object.
Are you getting weird readings? Be sure the vacu
*/
#include <Wire.h>
#include "SparkFun_VL53L1X.h" //Click here to get the library: http://librarymanager/All#SparkFun_VL53L1X
//Optional interrupt and shutdown pins.
#define SHUTDOWN_PIN 2
#define INTERRUPT_PIN 3
SFEVL53L1X distanceSensor;
//Uncomment the following line to use the optional shutdown and interrupt pins.
//SFEVL53L1X distanceSensor(Wire, SHUTDOWN_PIN, INTERRUPT_PIN);
void setup(void)
{
Wire.begin();
Serial.begin(115200);
Serial.println("VL53L1X Qwiic Test");
if (distanceSensor.begin() != 0) //Begin returns 0 on a good init
{
Serial.println("Sensor failed to begin. Please check wiring. Freezing...");
while (1)
;
}
Serial.println("Sensor online!");
}
void loop(void)
{
distanceSensor.startRanging(); //Write configuration bytes to initiate measurement
while (!distanceSensor.checkForDataReady())
{
delay(1);
COM3
Send
Distance(mm): 149 Distance(ft): 0.49
Distance(mm): 150 Distance(ft): 0.49
Distance(mm): 154 Distance(ft): 0.51
Distance(mm): 148 Distance(ft): 0.49
Distance(mm): 151 Distance(ft): 0.50
Distance(mm): 151 Distance(ft): 0.50
Distance(mm): 150 Distance(ft): 0.49
Distance(mm): 151 Distance(ft): 0.50
Distance(mm): 150 Distance(ft): 0.49
Distance(mm): 150 Distance(ft): 0.49
Distance(mm): 155 Distance(ft): 0.51
Distance(mm): 150 Distance(ft): 0.49
Distance(mm): 151 Distance(ft): 0.50
Distance(mm): 152 Distance(ft): 0.50
Distance(mm): 148 Distance(ft): 0.49
Distance(mm): 151 Distance(ft): 0.50
Distance(mm): 150 Distance(ft): 0.49
Autoscroll
Show timestamp
Carriage return
250000 baud
Clear output
Done in 0.001 seconds
Write 84188 bytes to flash (21 pages)
[============================] 100% (21/21 pages)
Done in 3.303 seconds
1
Arduino Nano 33 BLE on COM3

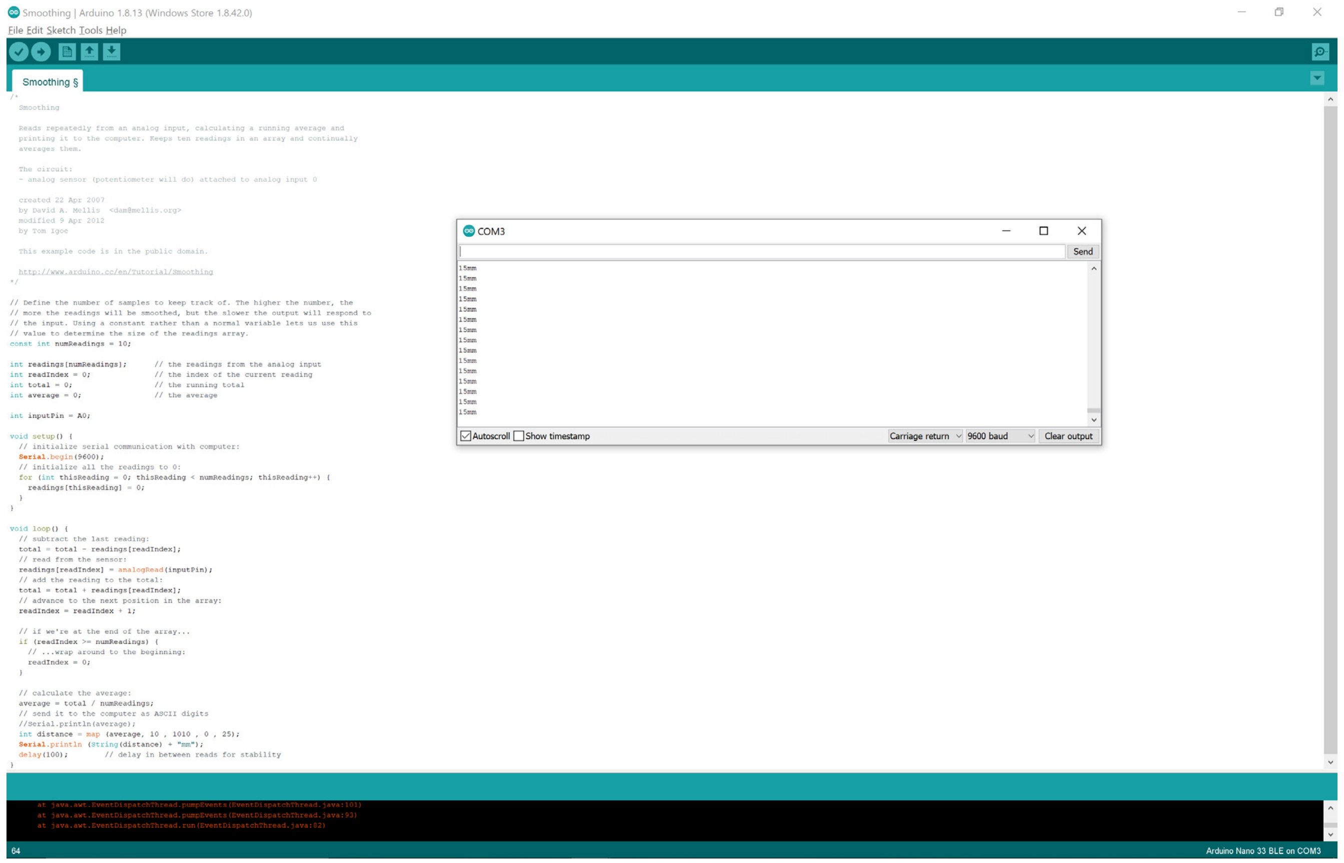

magnetopot_test | Arduino 1.8.13 (Windows Store 1.8.42.0)
File Edit Sketch Tools Help
magnetopot_test
/**
SoftPot_Example.ino
Example sketch for SparkFun's soft membrane potentiometer
(https://www.sparkfun.com/products/8680)
Jim Lindblom @ SparkFun Electronics
April 26, 2016
- Connect the softpot's outside pins to 5V and GND (the outer
indicator should be connected to GND).
- Connect the middle pin to A0.
As the voltage output of the softpot changes, a line graph prin
serial monitor should match the wiper's position.
Development environment specifics:
Arduino 1.6.7
**/
const int SOFT_POT_PIN = A0; // Pin connected to softpot wiper
const int GRAPH_LENGTH = 50; // Length of line graph
void setup()
{
Serial.begin(9600);
pinMode(SOFT_POT_PIN, INPUT);
}
void loop()
{
// Read in the soft pot's ADC value
int softPotADC = analogRead(SOFT_POT_PIN);
// Map the 0-1023 value to 0-40
int softPotPosition = map(softPotADC, 400, 1000, 0, GRAPH_LENGTH);
// Print a line graph:
Serial.print("<"); // Starting end
for (int i=0; i<GRAPH_LENGTH; i++)
{
if (i == softPotPosition) Serial.print("|");
else Serial.print("-");
}
Serial.println("> (" + String(softPotADC) + ")");
delay(100);
}
COM3
Send
<----------|----------> (701)
<----------|----------> (704)
<----------|----------> (702)
<----------|----------> (703)
<----------|----------> (700)
<----------|----------> (700)
<----------|----------> (692)
<----------|----------> (695)
<----------|----------> (691)
<----------|----------> (695)
<----------|----------> (700)
<----------|----------> (700)
<----------|----------> (699)
<----------|----------> (699)
<----------|----------> (698)
<----------|----------> (695)
<----------|----------> (692)
Autoscroll
Show timestamp
Carriage return
250000 baud
Clear output
Write 80644 bytes to flash (20 pages)
[============================] 100% (20/20 pages)
Done in 3.146 seconds
33
Arduino Nano 33 BLE on COM3

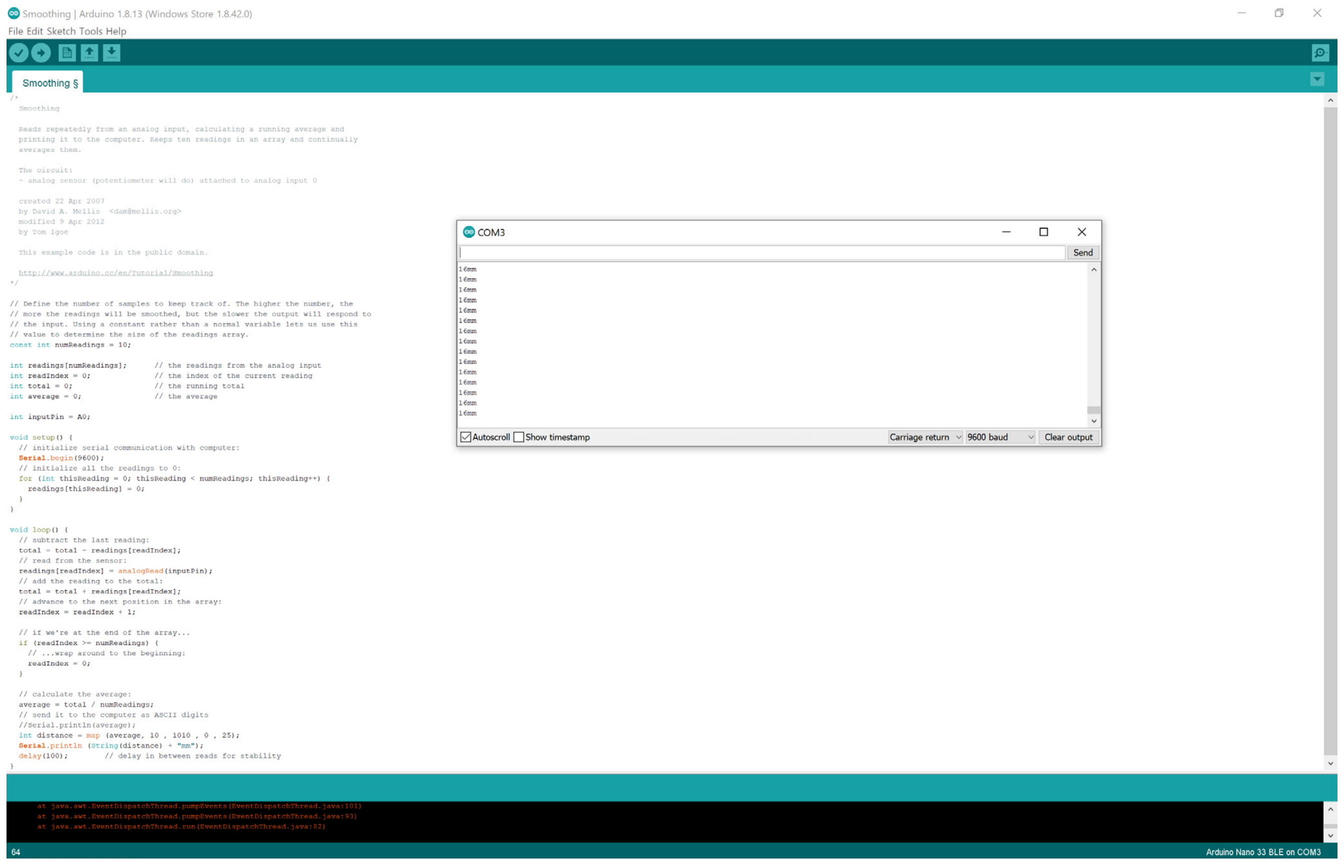


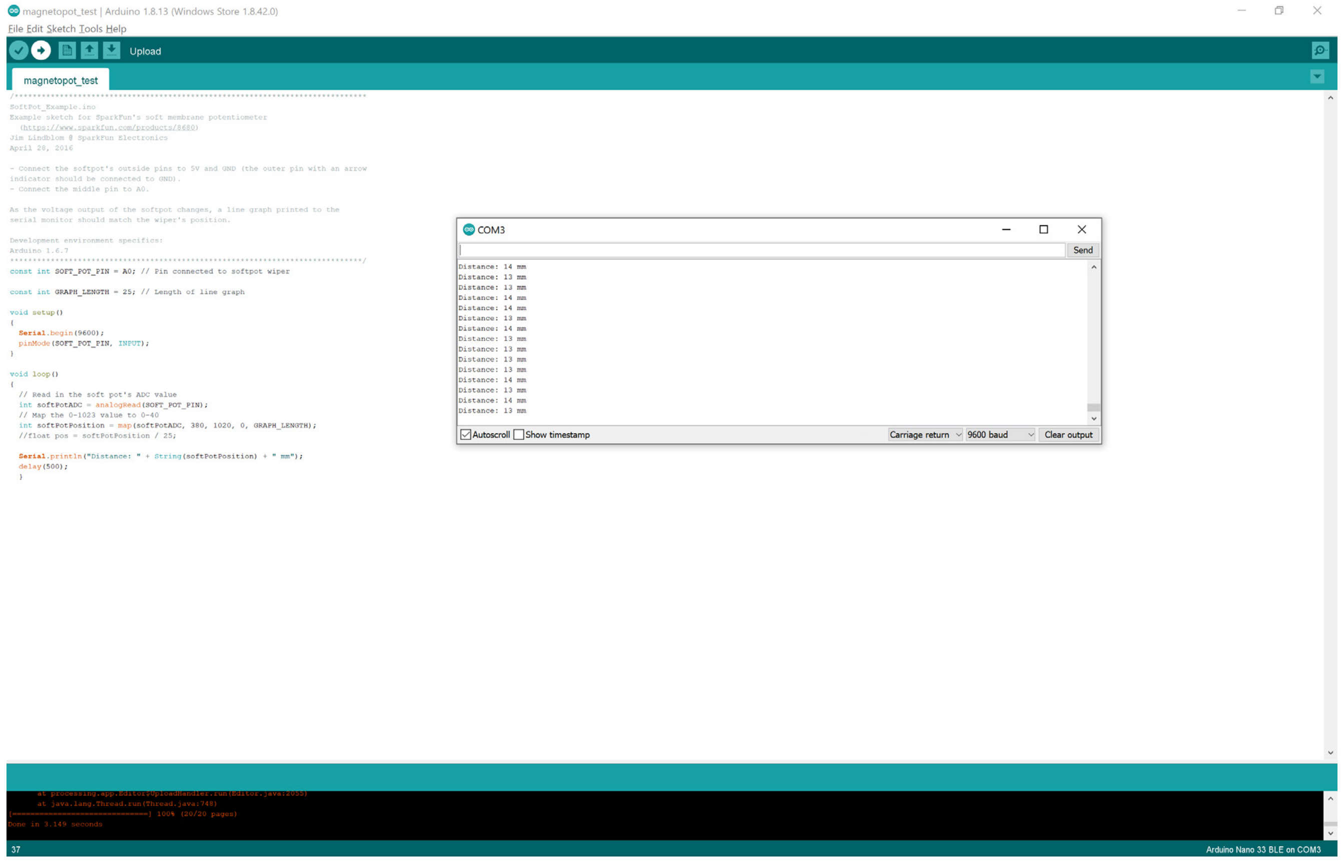

```
/*
  Smoothing

  Reads repeatedly from an analog input, calculating a running average and
  printing it to the computer. Keeps ten readings in an array and continually
  averages them.

  The circuit:
  - analog sensor (potentiometer will do) attached to analog input 0

  created 22 Apr 2007
  by David A. Mellis  <dam@mellis.org>
  modified 9 Apr 2012
  by Tom Igoe

  This example code is in the public domain.

  http://www.arduino.cc/en/Tutorial/Smoothing
*/

// Define the number of samples to keep track of. The higher the number, the
// more the readings will be smoothed, but the slower the output will respond to
// the input. Using a constant rather than a normal variable lets us use this
// value to determine the size of the readings array.
const int numReadings = 10;

int readings[numReadings];      // the readings from the analog input
int readIndex = 0;              // the index of the current reading
int total = 0;                  // the running total
int average = 0;                // the average

int inputPin = A0;

void setup() {
  // initialize serial communication with computer:
  Serial.begin(9600);
  // initialize all the readings to 0:
  for (int thisReading = 0; thisReading < numReadings; thisReading++) {
    readings[thisReading] = 0;
  }
}

void loop() {
  // subtract the last reading:
  total = total - readings[readIndex];
  // read from the sensor:
  readings[readIndex] = analogRead(inputPin);
  // add the reading to the total:
  total = total + readings[readIndex];
  // advance to the next position in the array:
  readIndex = readIndex + 1;

  // if we're at the end of the array...
  if (readIndex >= numReadings) {
    // ...wrap around to the beginning:
    readIndex = 0;
  }

  // calculate the average:
  average = total / numReadings;
  // send it to the computer as ASCII digits
  //Serial.println(average);
  int distance = map (average, 10 , 1010 , 0 , 25);
  Serial.println (String(distance) + "mm");
  delay(100);        // delay in between reads for stability
}
```

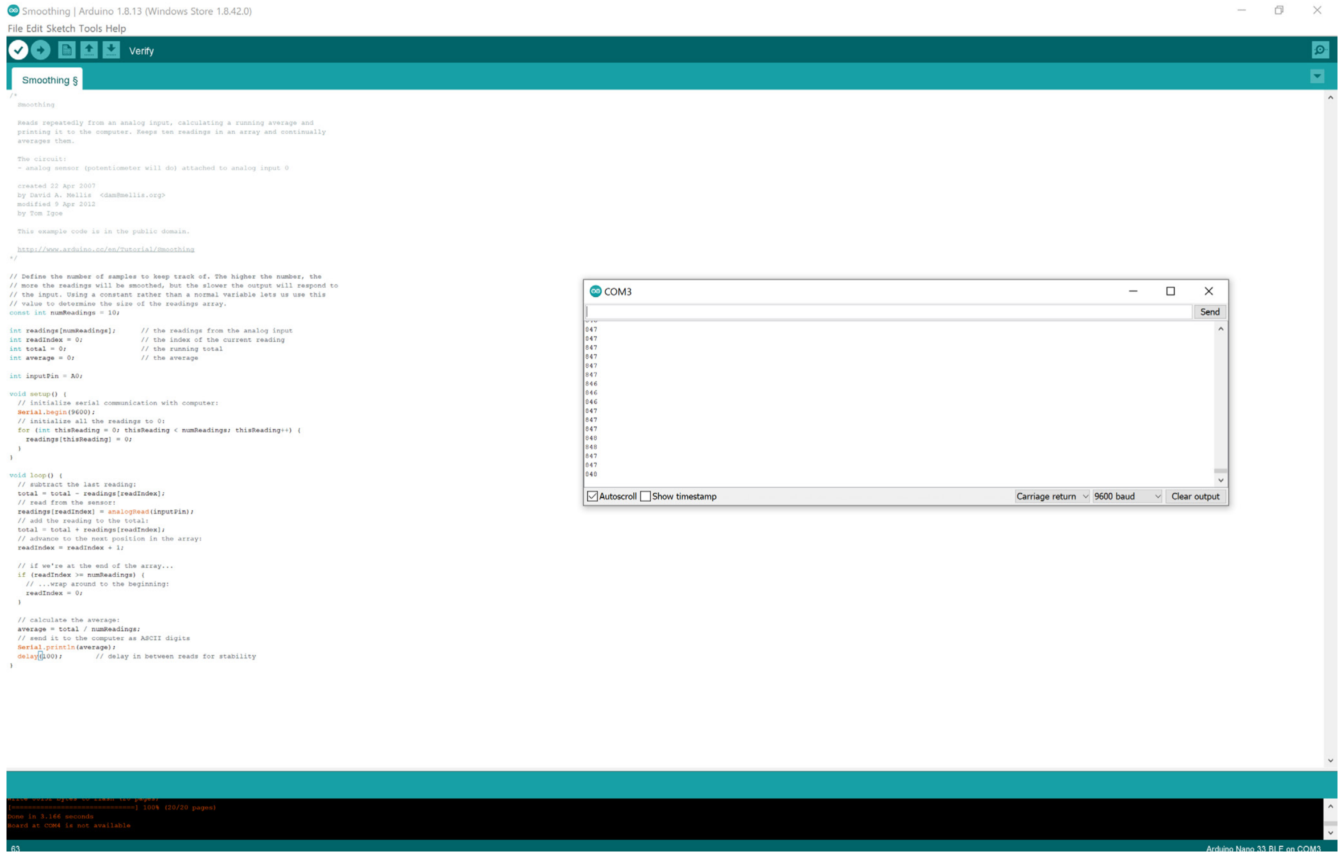


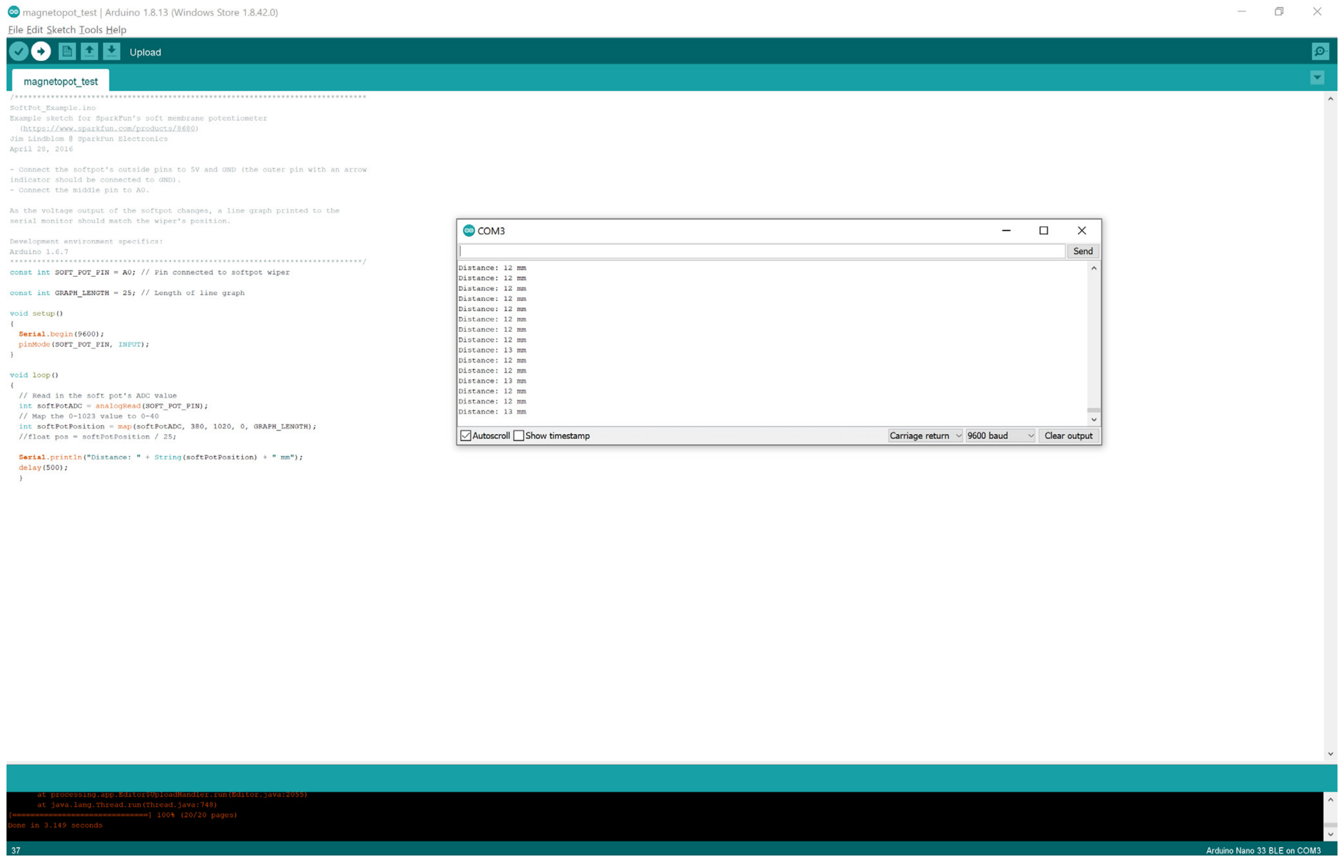

```
/******************************************************************************
SoftPot_Example.ino
Example sketch for SparkFun's soft membrane potentiometer
  (https://www.sparkfun.com/products/8680)
Jim Lindblom @ SparkFun Electronics
April 28, 2016

- Connect the softpot's outside pins to 5V and GND (the outer pin with an arrow
indicator should be connected to GND).
- Connect the middle pin to A0.

As the voltage output of the softpot changes, a line graph printed to the
serial monitor should match the wiper's position.

Development environment specifics:
Arduino 1.6.7
******************************************************************************/
const int SOFT_POT_PIN = A0; // Pin connected to softpot wiper

const int GRAPH_LENGTH = 25; // Length of line graph

void setup()
{
  Serial.begin(9600);
  pinMode(SOFT_POT_PIN, INPUT);
}

void loop()
{
  // Read in the soft pot's ADC value
  int softPotADC = analogRead(SOFT_POT_PIN);
  // Map the 0-1023 value to 0-40
  int softPotPosition = map(softPotADC, 380, 1020, 0, GRAPH_LENGTH);
  //float pos = softPotPosition / 25;

  Serial.println("Distance: " + String(softPotPosition) + " mm");
  delay(500);
  }
```






magnetopot_test | Arduino 1.8.13 (Windows Store 1.8.42.0)
File Edit Sketch Tools Help
Upload
magnetopot_test
COM3
Send
Autoscroll
Show timestamp
Carriage return
9600 baud
Clear output
Arduino Nano 33 BLE on COM3


Smoothing | Arduino 1.8.13 (Windows Store 1.8.42.0)
File Edit Sketch Tools Help
Verify
Smoothing §
COM3
Send
Autoscroll
Show timestamp
Carriage return
9600 baud
Clear output
Arduino Nano 33 BLE on COM3


magnetopot_test | Arduino 1.8.13 (Windows Store 1.8.42.0)
File Edit Sketch Tools Help
Upload
magnetopot_test
COM3
Send
Autoscroll
Show timestamp
Carriage return
9600 baud
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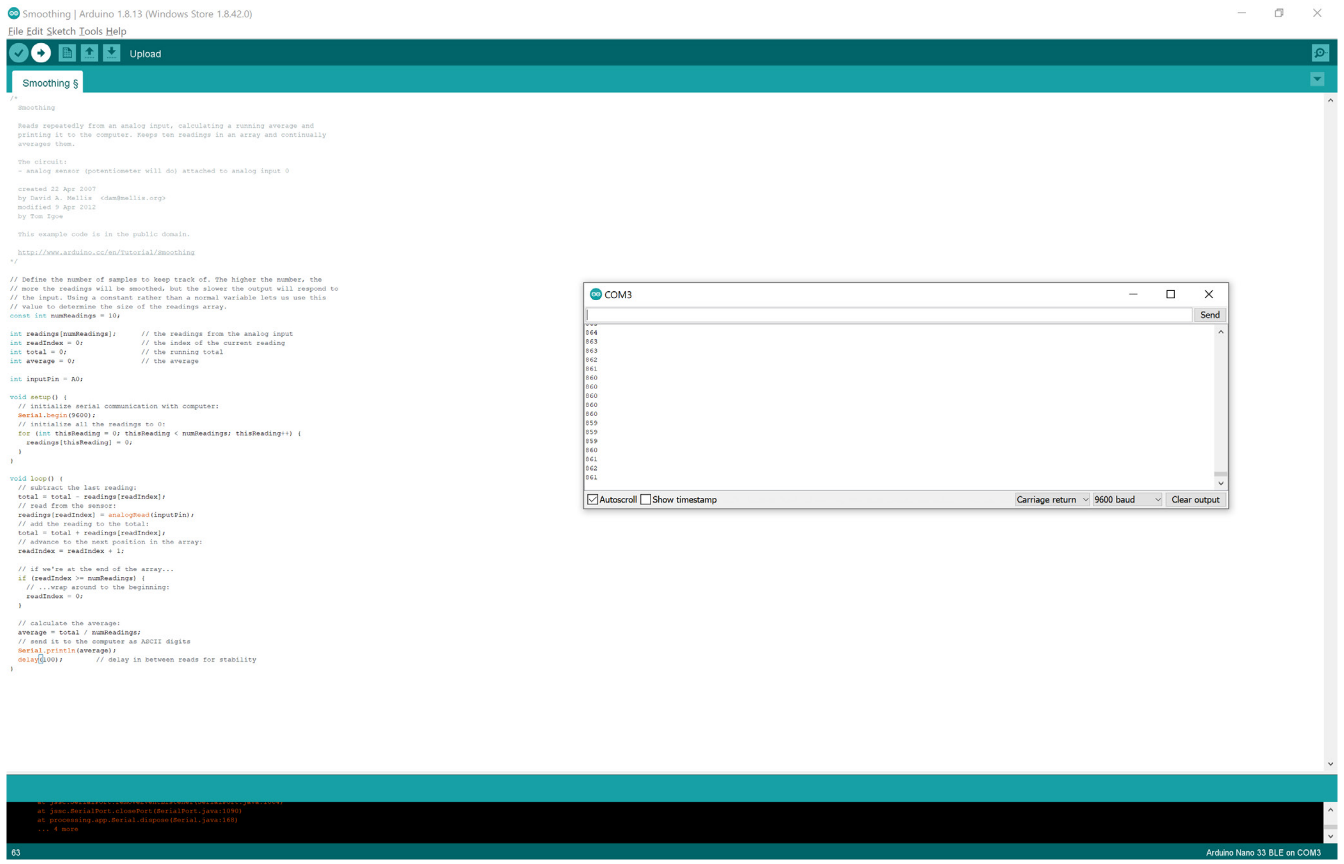
Smoothing | Arduino 1.8.13 (Windows Store 1.8.42.0)
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Upload
Smoothing §
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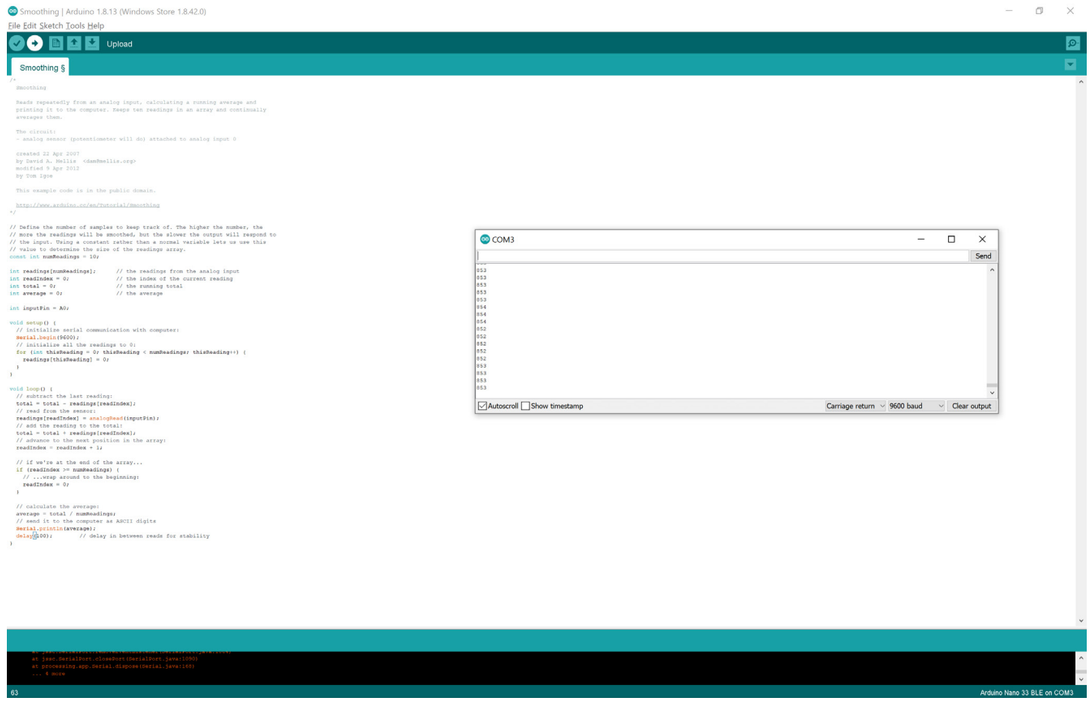
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Clear output
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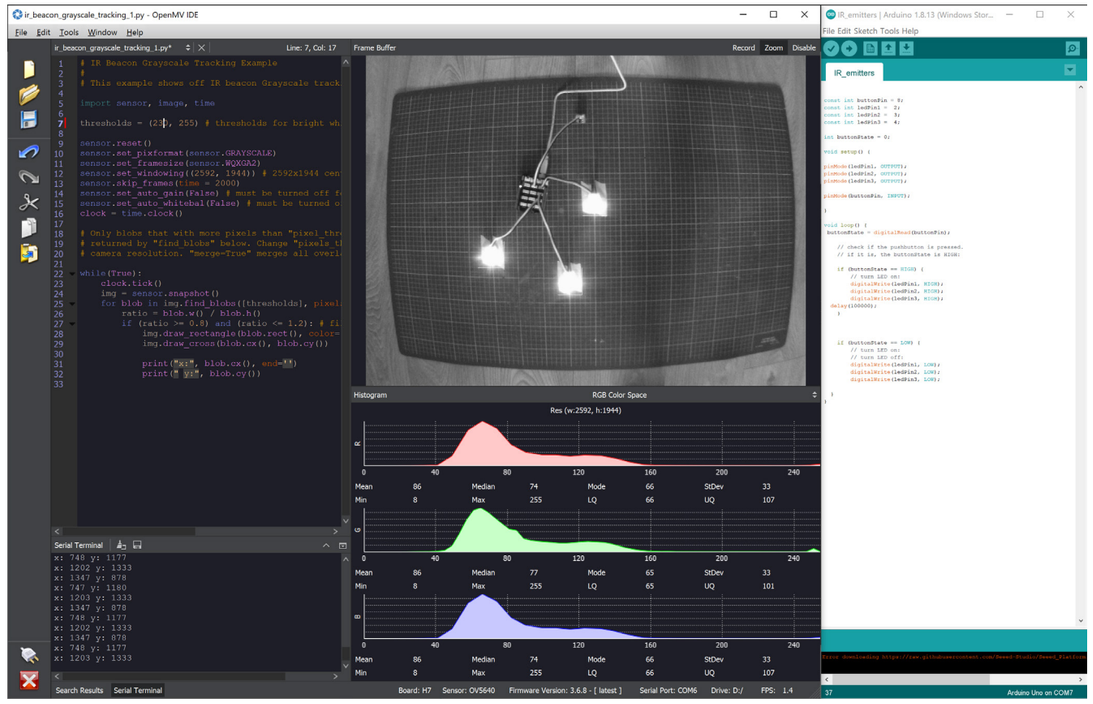
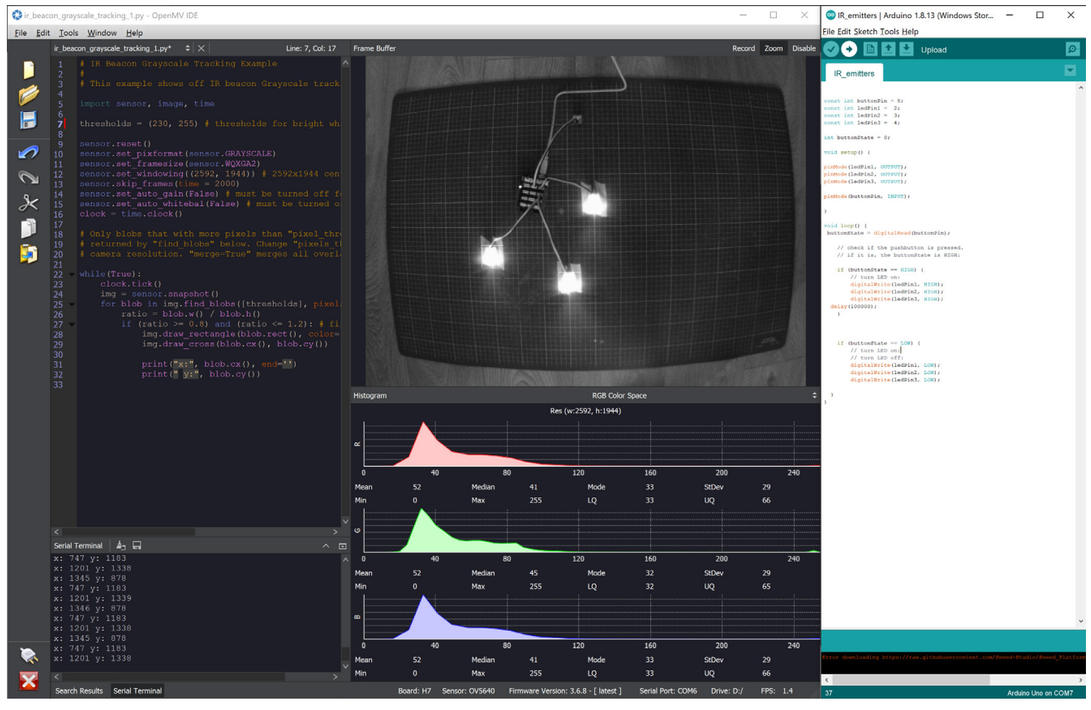
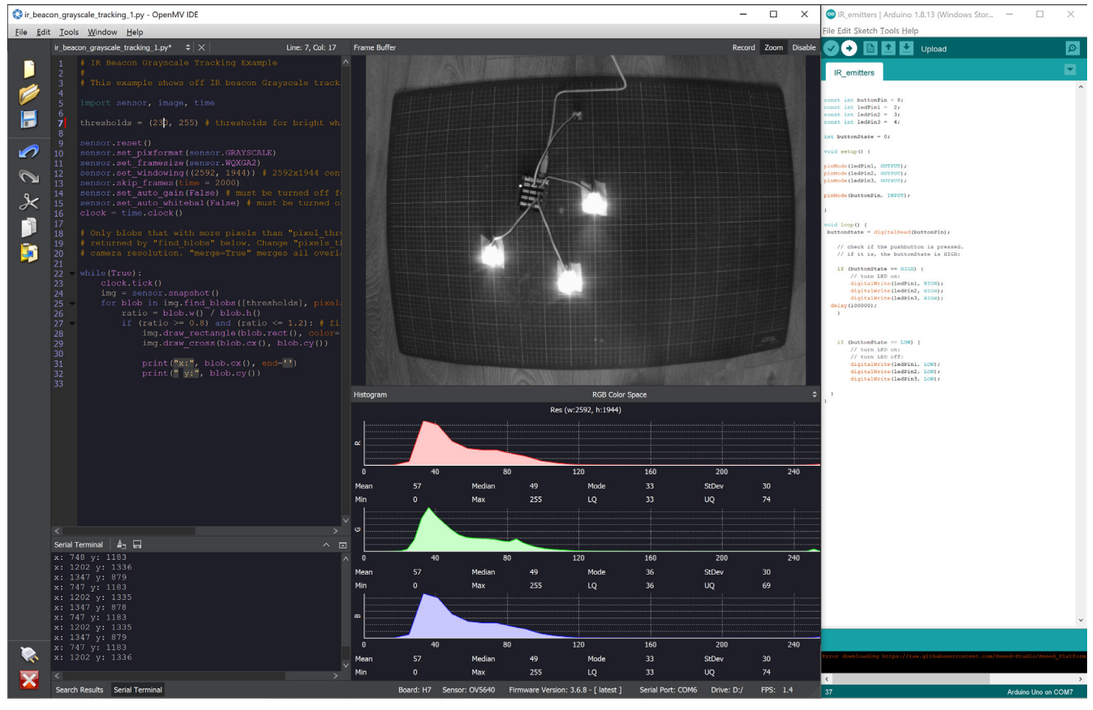
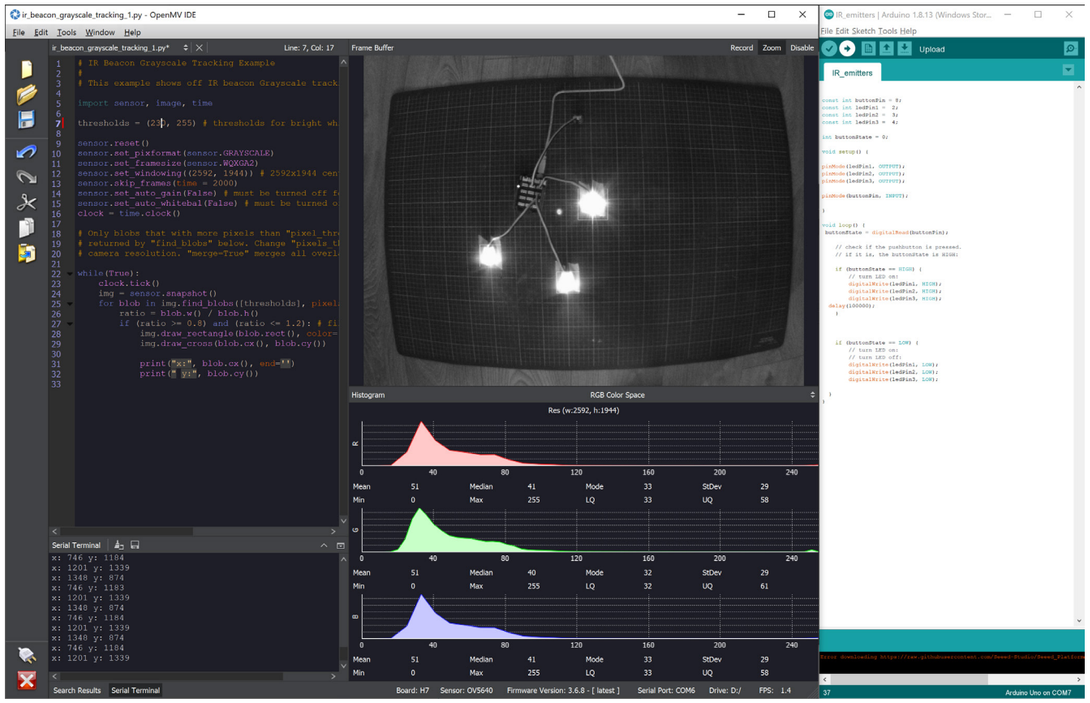
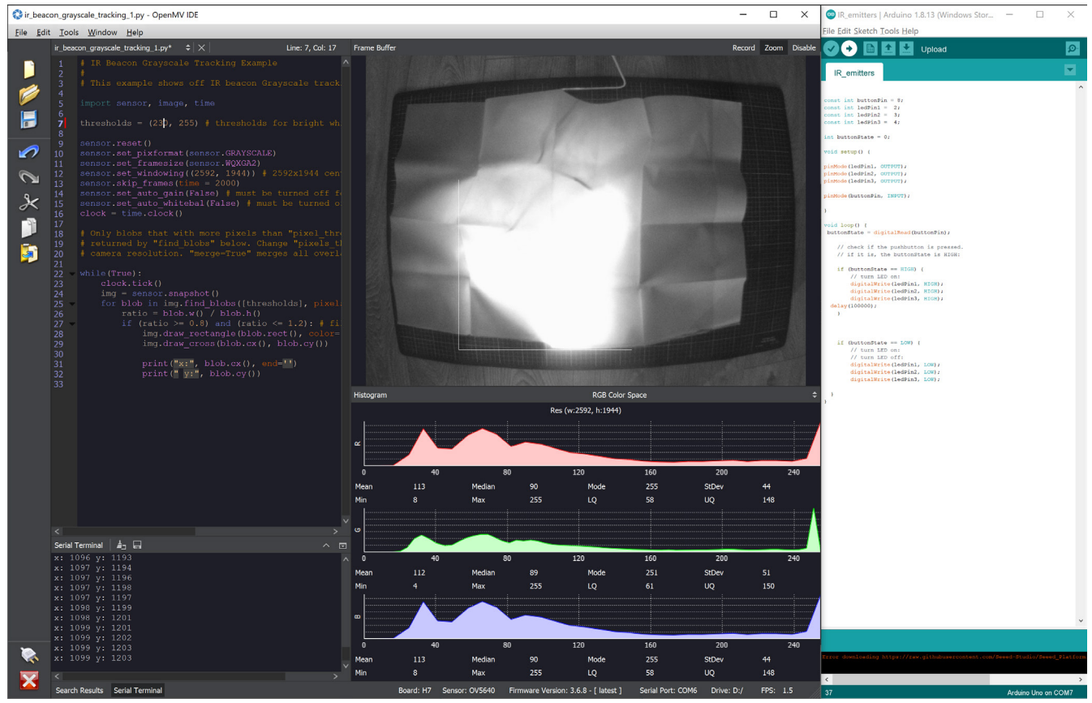

ir_beacon_grayscale_tracking_1.py - OpenMV IDE
File Edit Tools Window Help
Frame Buffer
Record
Zoom
Disable
Histogram
RGB Color Space
Res (w:2592, h:1944)
Serial Terminal
Search Results
Board: H7
Sensor: OV5640
Firmware Version: 3.6.8 - [latest]
Serial Port: COM6
Drive: D:/
FPS: 1.4
IR_emitters | Arduino 1.8.13 (Windows Stor...
IR_emitters
Arduino Uno on COM7


ir_beacon_grayscale_tracking_1.py - OpenMV IDE
IR_emitters | Arduino 1.8.13 (Windows Stor...
Arduino Nano 33 BLE on COM3


ir_beacon_grayscale_tracking_1.py - OpenMV IDE
IR_emitters | Arduino 1.8.13 (Windows Stor...
Arduino Uno on COM7


ir_beacon_grayscale_tracking_1.py - OpenMV IDE
File Edit Tools Window Help
ir_beacon_grayscale_tracking_1.py*
Line: 7, Col: 17
Frame Buffer
Record Zoom Disable
# IR Beacon Grayscale Tracking Example
# This example shows off IR beacon Grayscale track
import sensor, image, time
thresholds = (230, 255) # thresholds for bright wh
sensor.reset()
sensor.set_pixformat(sensor.GRAYSCALE)
sensor.set_framesize(sensor.WQXGA2)
sensor.set_windowing((2592, 1944)) # 2592x1944 cen
sensor.skip_frames(time = 2000)
sensor.set_auto_gain(False) # must be turned off f
sensor.set_auto_whitebal(False) # must be turned o
clock = time.clock()
# Only blobs that with more pixels than "pixel_thre
# returned by "find_blobs" below. Change "pixels_t
# camera resolution. "merge=True" merges all overl
while(True):
clock.tick()
img = sensor.snapshot()
for blob in img.find_blobs([thresholds], pixel
ratio = blob.w() / blob.h()
if (ratio >= 0.8) and (ratio <= 1.2): # fi
img.draw_rectangle(blob.rect(), color=
img.draw_cross(blob.cx(), blob.cy())
print("x:", blob.cx(), end='')
print(" y:", blob.cy())
Serial Terminal
x: 746 y: 1184
x: 1201 y: 1339
x: 1348 y: 874
x: 746 y: 1183
x: 1201 y: 1339
x: 1348 y: 874
x: 746 y: 1184
x: 1201 y: 1339
x: 1348 y: 874
x: 746 y: 1184
x: 1201 y: 1339
Histogram
RGB Color Space
Res (w:2592, h:1944)
R
Mean 51 Median 41 Mode 33 StDev 29
Min 0 Max 255 LQ 33 UQ 58
G
Mean 51 Median 40 Mode 32 StDev 29
Min 0 Max 255 LQ 32 UQ 61
B
Mean 51 Median 41 Mode 33 StDev 29
Min 0 Max 255 LQ 33 UQ 58
Search Results
Serial Terminal
Board: H7 Sensor: OV5640 Firmware Version: 3.6.8 - [latest] Serial Port: COM6 Drive: D:/ FPS: 1.4
IR_emitters | Arduino 1.8.13 (Windows Stor...
File Edit Sketch Tools Help
Upload
IR_emitters
const int buttonPin = 9;
const int ledPin1 = 2;
const int ledPin2 = 3;
const int ledPin3 = 4;
int buttonState = 0;
void setup() {
pinMode(ledPin1, OUTPUT);
pinMode(ledPin2, OUTPUT);
pinMode(ledPin3, OUTPUT);
pinMode(buttonPin, INPUT);
}
void loop() {
buttonState = digitalRead(buttonPin);
// check if the pushbutton is pressed.
// if it is, the buttonState is HIGH:
if (buttonState == HIGH) {
// turn LED on:
digitalWrite(ledPin1, HIGH);
digitalWrite(ledPin2, HIGH);
digitalWrite(ledPin3, HIGH);
delay(100000);
}
if (buttonState == LOW) {
// turn LED on:
// turn LED off:
digitalWrite(ledPin1, LOW);
digitalWrite(ledPin2, LOW);
digitalWrite(ledPin3, LOW);
}
}
Error downloading https://raw.githubusercontent.com/Seeed-Studio/Seeed_Platform
37
Arduino Uno on COM7


ir_beacon_grayscale_tracking_1.py - OpenMV IDE
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sensor.set_framesize(sensor.WQXGA2)
sensor.set_windowing((2592, 1944)) # 2592x1944 cen
sensor.skip_frames(time = 2000)
sensor.set_auto_gain(False) # must be turned off f
sensor.set_auto_whitebal(False) # must be turned o
clock = time.clock()
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for blob in img.find_blobs([thresholds], pixel
ratio = blob.w() / blob.h()
if (ratio >= 0.8) and (ratio <= 1.2): # fi
img.draw_rectangle(blob.rect(), color=
img.draw_cross(blob.cx(), blob.cy())
print("x:", blob.cx(), end='')
print(" y:", blob.cy())
Serial Terminal
x: 1096 y: 1193
x: 1097 y: 1194
x: 1097 y: 1196
x: 1097 y: 1198
x: 1097 y: 1197
x: 1098 y: 1199
x: 1098 y: 1201
x: 1099 y: 1201
x: 1099 y: 1202
x: 1099 y: 1203
x: 1099 y: 1203
Histogram
RGB Color Space
Res (w:2592, h:1944)
R
Mean 113 Median 90 Mode 255 StDev 44
Min 8 Max 255 LQ 58 UQ 148
G
Mean 112 Median 89 Mode 251 StDev 51
Min 4 Max 255 LQ 61 UQ 150
B
Mean 113 Median 90 Mode 255 StDev 44
Min 8 Max 255 LQ 58 UQ 148
Search Results
Serial Terminal
Board: H7 Sensor: OV5640 Firmware Version: 3.6.8 - [latest] Serial Port: COM6 Drive: D:/ FPS: 1.5
IR_emitters | Arduino 1.8.13 (Windows Stor...
File Edit Sketch Tools Help
Upload
IR_emitters
const int buttonPin = 9;
const int ledPin1 = 2;
const int ledPin2 = 3;
const int ledPin3 = 4;
int buttonState = 0;
void setup() {
pinMode(ledPin1, OUTPUT);
pinMode(ledPin2, OUTPUT);
pinMode(ledPin3, OUTPUT);
pinMode(buttonPin, INPUT);
}
void loop() {
buttonState = digitalRead(buttonPin);
// check if the pushbutton is pressed.
// if it is, the buttonState is HIGH:
if (buttonState == HIGH) {
// turn LED on:
digitalWrite(ledPin1, HIGH);
digitalWrite(ledPin2, HIGH);
digitalWrite(ledPin3, HIGH);
delay(100000);
}
if (buttonState == LOW) {
// turn LED on:
// turn LED off:
digitalWrite(ledPin1, LOW);
digitalWrite(ledPin2, LOW);
digitalWrite(ledPin3, LOW);
}
}
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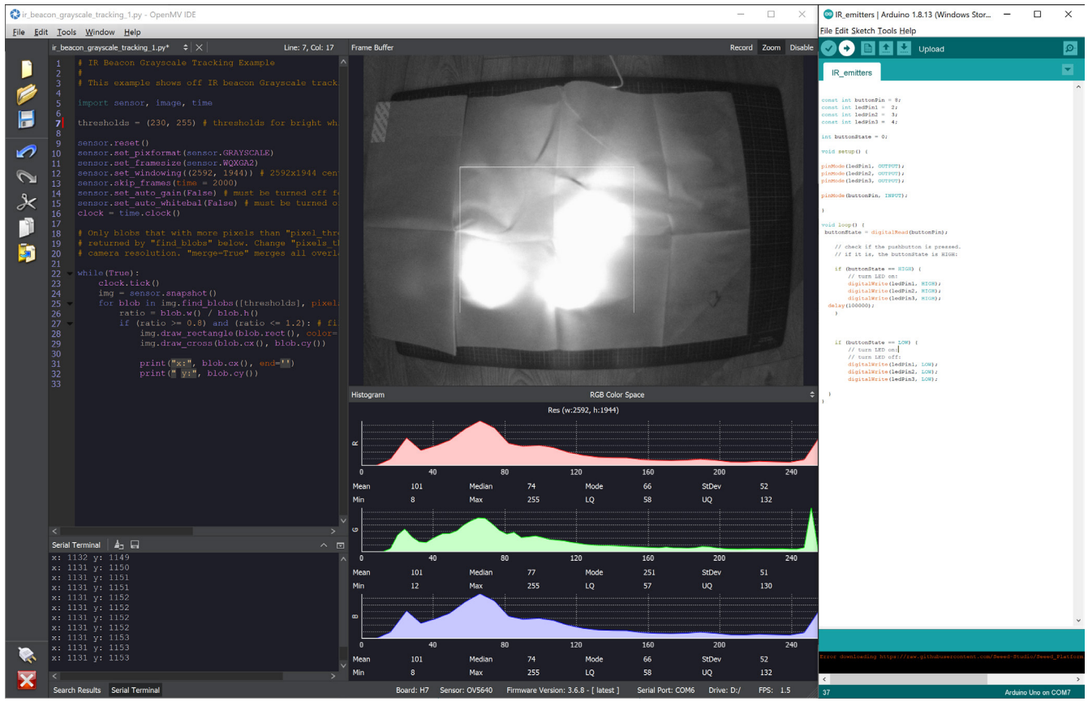
Arduino Uno on COM7


ir_beacon_grayscale_tracking_1.py - OpenMV IDE
File Edit Tools Window Help
ir_beacon_grayscale_tracking_1.py*
Line: 7, Col: 17
Frame Buffer
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sensor.set_framesize(sensor.WQXGA2)
sensor.set_windowing((2592, 1944)) # 2592x1944 cen
sensor.skip_frames(time = 2000)
sensor.set_auto_gain(False) # must be turned off f
sensor.set_auto_whitebal(False) # must be turned o
clock = time.clock()
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# returned by "find_blobs" below. Change "pixels_t
# camera resolution. "merge=True" merges all overl
while(True):
clock.tick()
img = sensor.snapshot()
for blob in img.find_blobs([thresholds], pixel
ratio = blob.w() / blob.h()
if (ratio >= 0.8) and (ratio <= 1.2): # fi
img.draw_rectangle(blob.rect(), color=
img.draw_cross(blob.cx(), blob.cy())
print("x:", blob.cx(), end='')
print(" y:", blob.cy())
Serial Terminal
x: 1132 y: 1149
x: 1131 y: 1150
x: 1131 y: 1151
x: 1131 y: 1151
x: 1131 y: 1152
x: 1131 y: 1152
x: 1131 y: 1152
x: 1131 y: 1152
x: 1131 y: 1153
x: 1131 y: 1153
x: 1131 y: 1153
Histogram
RGB Color Space
Res (w:2592, h:1944)
R
Mean 101 Median 74 Mode 66 StDev 52
Min 8 Max 255 LQ 58 UQ 132
G
Mean 101 Median 77 Mode 251 StDev 51
Min 12 Max 255 LQ 57 UQ 130
B
Mean 101 Median 74 Mode 66 StDev 52
Min 8 Max 255 LQ 58 UQ 132
Search Results
Serial Terminal
Board: H7 Sensor: OV5640 Firmware Version: 3.6.8 - [latest] Serial Port: COM6 Drive: D:/ FPS: 1.5
IR_emitters | Arduino 1.8.13 (Windows Stor...
File Edit Sketch Tools Help
Upload
IR_emitters
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const int ledPin1 = 2;
const int ledPin2 = 3;
const int ledPin3 = 4;
int buttonState = 0;
void setup() {
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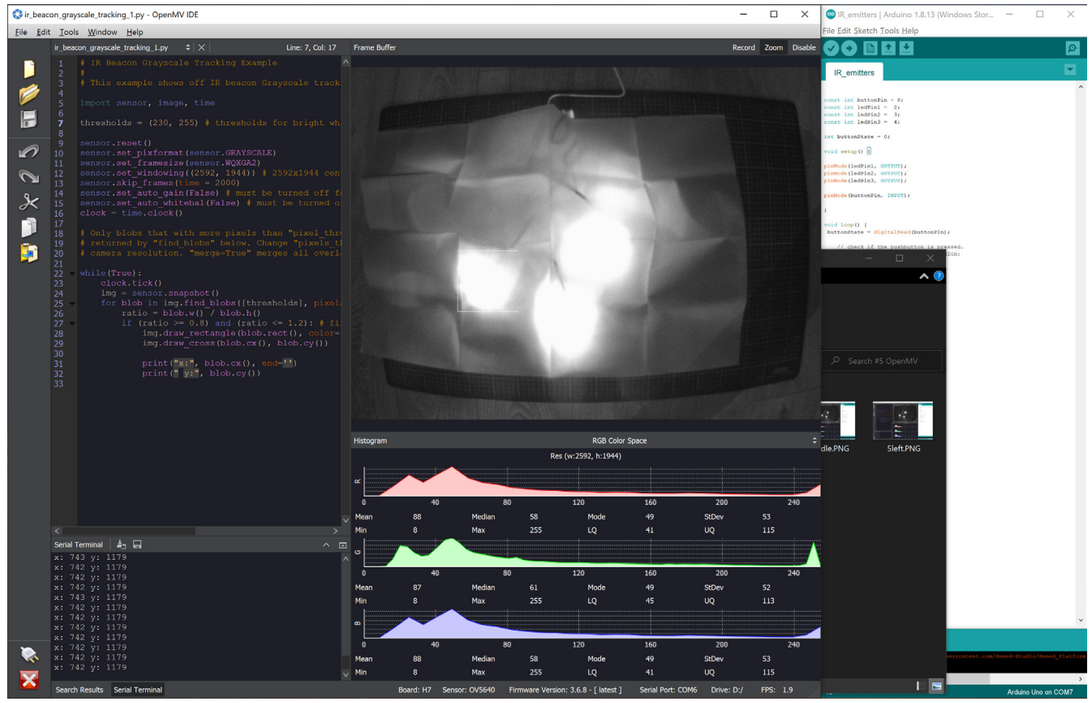
pinMode(ledPin2, OUTPUT);
pinMode(ledPin3, OUTPUT);
pinMode(buttonPin, INPUT);
}
void loop() {
buttonState = digitalRead(buttonPin);
// check if the pushbutton is pressed.
// if it is, the buttonState is HIGH:
if (buttonState == HIGH) {
// turn LED on:
digitalWrite(ledPin1, HIGH);
digitalWrite(ledPin2, HIGH);
digitalWrite(ledPin3, HIGH);
delay(100000);
}
if (buttonState == LOW) {
// turn LED on:
// turn LED off:
digitalWrite(ledPin1, LOW);
digitalWrite(ledPin2, LOW);
digitalWrite(ledPin3, LOW);
}
}
Error downloading https://raw.githubusercontent.com/Seeed-Studio/Seeed_Platform
37
Arduino Uno on COM7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sensor.skip_frames(time = 2000)
sensor.set_auto_gain(False) # must be turned off f
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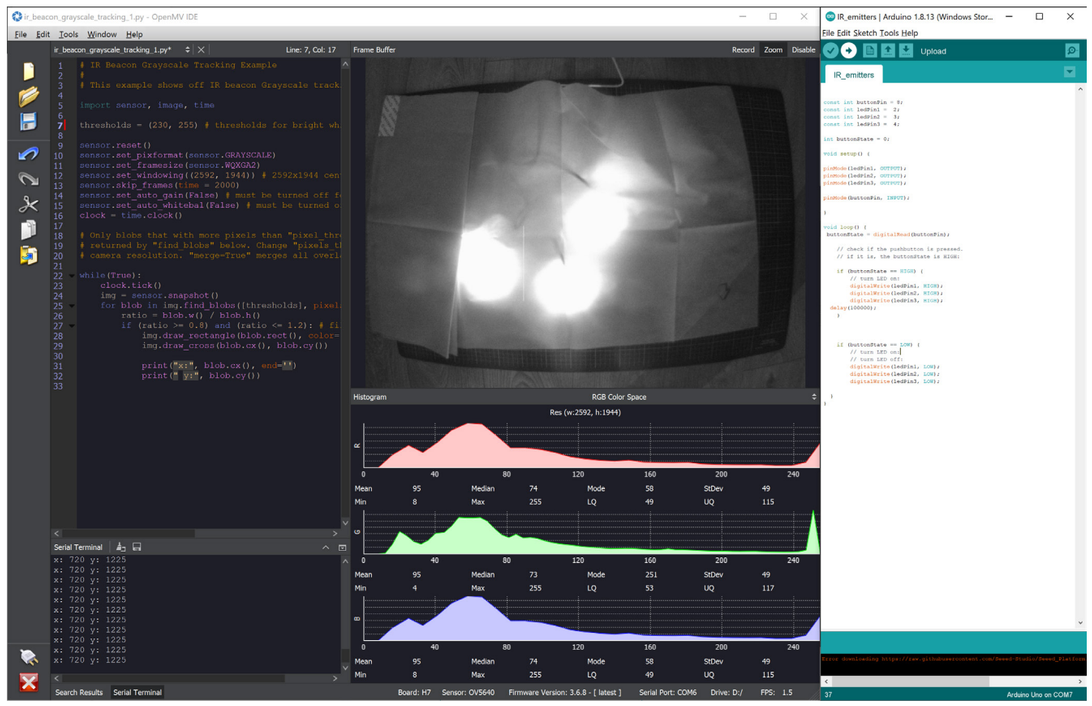
ratio = blob.w() / blob.h()
if (ratio >= 0.8) and (ratio <= 1.2): # fi
img.draw_rectangle(blob.rect(), color=
img.draw_cross(blob.cx(), blob.cy())
print("x:", blob.cx(), end='')
print(" y:", blob.cy())
Serial Terminal
x: 743 y: 1179
x: 742 y: 1179
x: 742 y: 1179
x: 742 y: 1179
x: 743 y: 1179
x: 742 y: 1179
x: 742 y: 1179
x: 742 y: 1179
x: 742 y: 1179
x: 742 y: 1179
x: 742 y: 1179
Histogram
RGB Color Space
Res (w:2592, h:1944)
R
Mean 88 Median 58 Mode 49 StDev 53
Min 8 Max 255 LQ 41 UQ 115
G
Mean 87 Median 61 Mode 49 StDev 52
Min 8 Max 255 LQ 45 UQ 113
B
Mean 88 Median 58 Mode 49 StDev 53
Min 8 Max 255 LQ 41 UQ 115
Search Results
Serial Terminal
Board: H7 Sensor: OV5640 Firmware Version: 3.6.8 - [latest] Serial Port: COM6 Drive: D:/ FPS: 1.9
IR_emitters | Arduino 1.8.13 (Windows Stor...
File Edit Sketch Tools Help
Upload
IR_emitters
Search #5 OpenMV
dle.PNG
Sleft.PNG
Arduino Uno on COM7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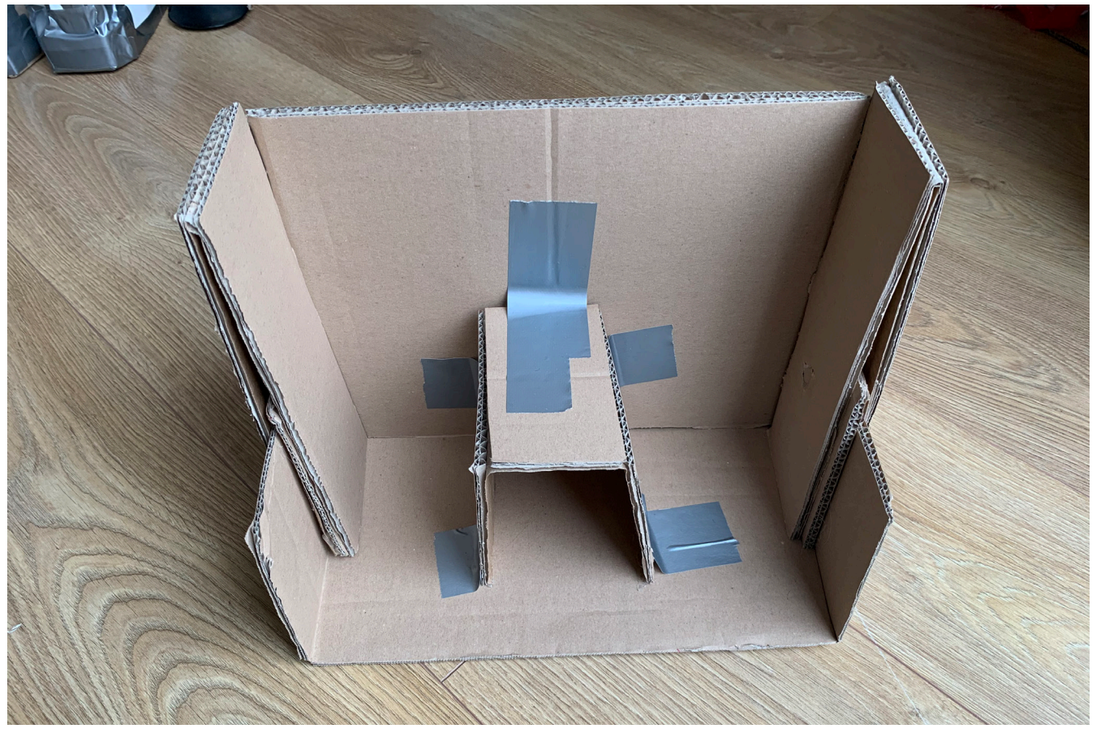
sensor.set_framesize(sensor.WQXGA2)
sensor.set_windowing((2592, 1944)) # 2592x1944 cen
sensor.skip_frames(time = 2000)
sensor.set_auto_gain(False) # must be turned off f
sensor.set_auto_whitebal(False) # must be turned o
clock = time.clock()
# Only blobs that with more pixels than "pixel_thre
# returned by "find_blobs" below. Change "pixels_t
# camera resolution. "merge=True" merges all overl
while(True):
clock.tick()
img = sensor.snapshot()
for blob in img.find_blobs([thresholds], pixel
ratio = blob.w() / blob.h()
if (ratio >= 0.8) and (ratio <= 1.2): # fi
img.draw_rectangle(blob.rect(), color=
img.draw_cross(blob.cx(), blob.cy())
print("x:", blob.cx(), end="")
print(" y:", blob.cy())
Frame Buffer
Record
Zoom
Disable
Histogram
RGB Color Space
Res (w:2592, h:1944)
Mean 95 Median 74 Mode 58 StDev 49
Min 8 Max 255 LQ 49 UQ 115
Mean 95 Median 73 Mode 251 StDev 49
Min 4 Max 255 LQ 53 UQ 117
Mean 95 Median 74 Mode 58 StDev 49
Min 8 Max 255 LQ 49 UQ 115
Serial Terminal
x: 720 y: 1225
Search Results
Serial Terminal
Board: H7
Sensor: OV5640
Firmware Version: 3.6.8 - [latest]
Serial Port: COM6
Drive: D:/
FPS: 1.5
IR_emitters | Arduino 1.8.13 (Windows Stor...
File Edit Sketch Tools Help
Upload
IR_emitters
const int buttonPin = 0;
const int ledPin1 = 2;
const int ledPin2 = 3;
const int ledPin3 = 4;
int buttonState = 0;
void setup() {
pinMode(ledPin1, OUTPUT);
pinMode(ledPin2, OUTPUT);
pinMode(ledPin3, OUTPUT);
pinMode(buttonPin, INPUT);
}
void loop() {
buttonState = digitalRead(buttonPin);
// check if the pushbutton is pressed.
// If it is, the buttonState is HIGH:
if (buttonState == HIGH) {
// turn LED on:
digitalWrite(ledPin1, HIGH);
digitalWrite(ledPin2, HIGH);
digitalWrite(ledPin3, HIGH);
delay(100000);
}
if (buttonState == LOW) {
// turn LED on:
// turn LED off:
digitalWrite(ledPin1, LOW);
digitalWrite(ledPin2, LOW);
digitalWrite(ledPin3, LOW);
}
}
Arduino Uno on COM7


Elegance
2.2L
KOFFER
WEEGSCHAAL
Digitaal
60 KGS MAX




KOFFER
WEEGSCHAAL

Appendix H

Cable Concept Renders

The Concept

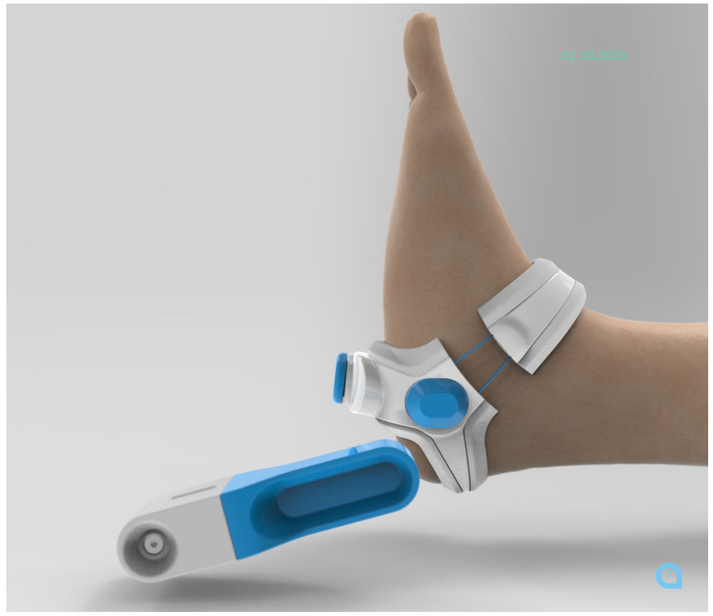
TU Delft

GREEN LIGHT MEETING

CURRENT

Concept Introduction

- Wearable design
  - Waterproof
  - Sterilisable
- Minimal surfaces fit

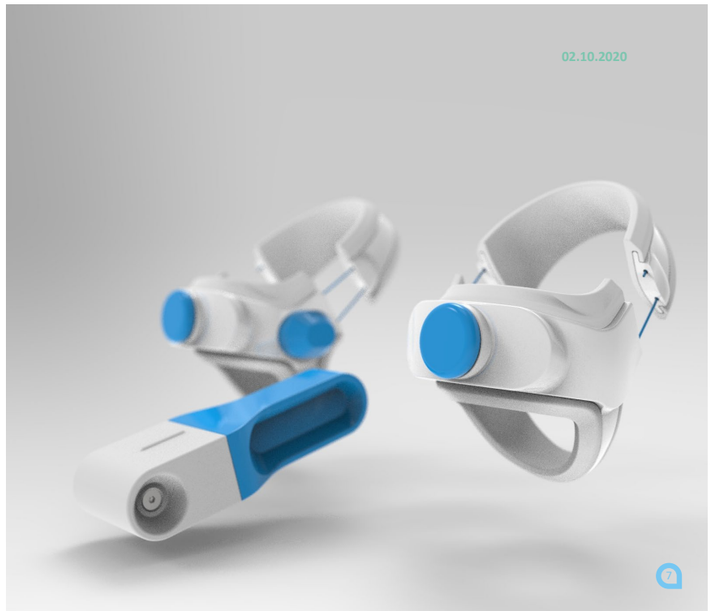


GREEN LIGHT MEETING

CURRENT

Concept Introduction

- Wearable design
  - Waterproof
  - Sterilisable
- Minimal surfaces fit

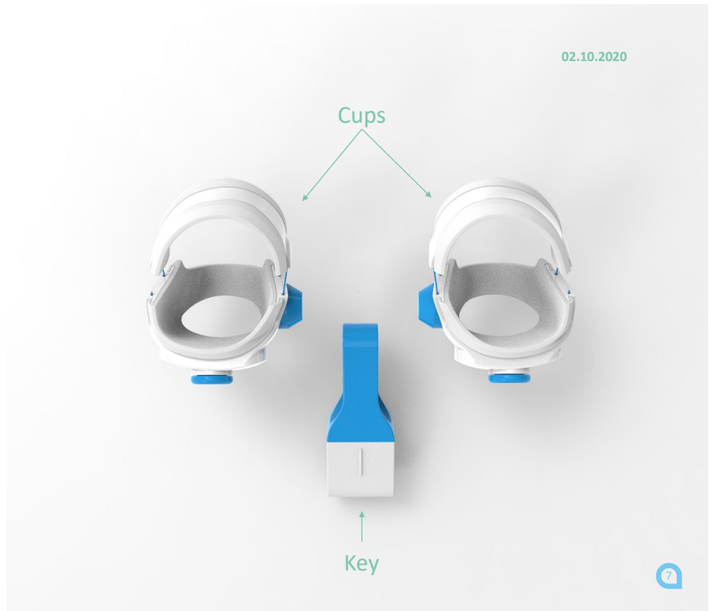


GREEN LIGHT MEETING

CURRENT

Concept Introduction

- Wearable design
  - Waterproof
  - Sterilisable
- Minimal surfaces fit
- Maximum workflow flexibility

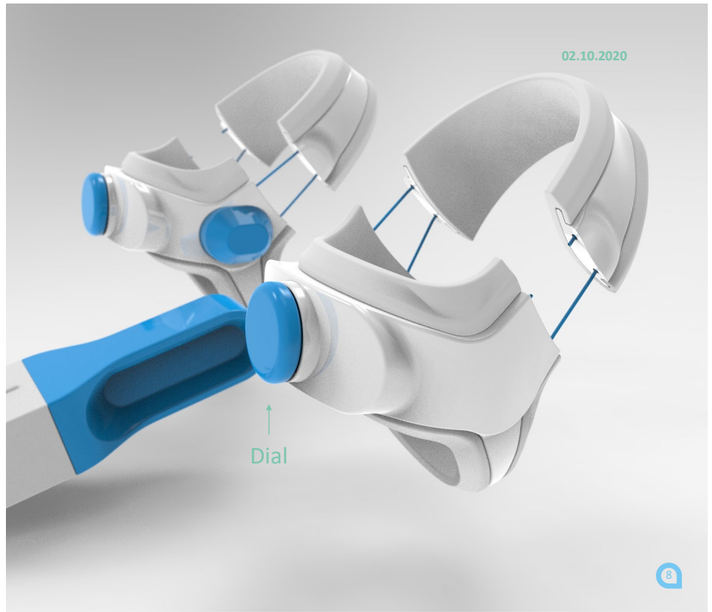


GREEN LIGHT MEETING

CURRENT

Cup Breakdown

- Cable closure system

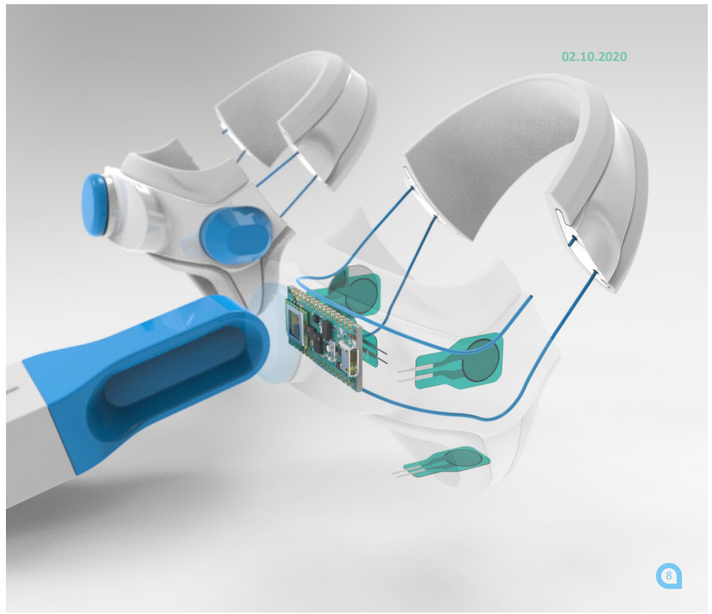


GREEN LIGHT MEETING

CURRENT

Cup Breakdown

- Cable closure system
- Arduino Nano 33 BLE
- Pressure sensors



GREEN LIGHT MEETING

CURRENT

Cup Breakdown

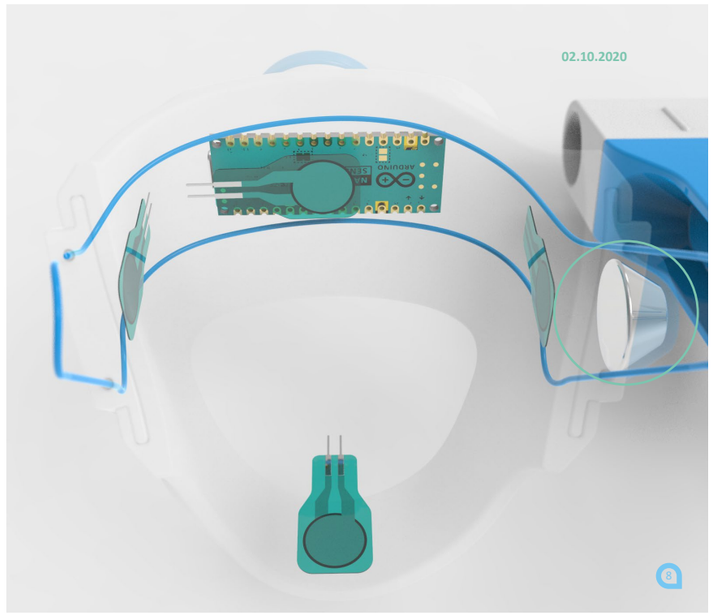
- Cable closure system
- Arduino Nano 33 BLE
- Pressure sensors
  - 3x Fit control
  - 1x Heel pressure control

GREEN LIGHT MEETING

CURRENT

Cup Breakdown

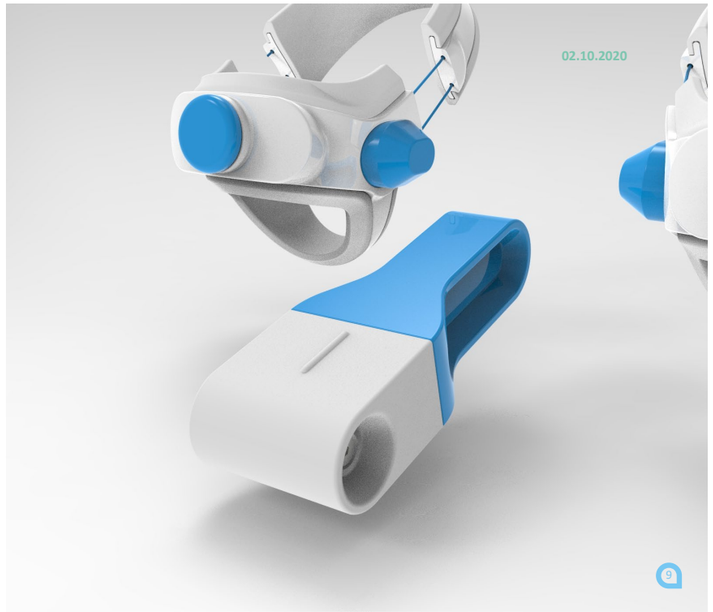
- Cable closure system
- Arduino Nano 33 BLE
- Pressure sensors
  - 3x Fit control
  - 1x Heel pressure control
- Positioning Magnet



GREEN LIGHT MEETING

CURRENT

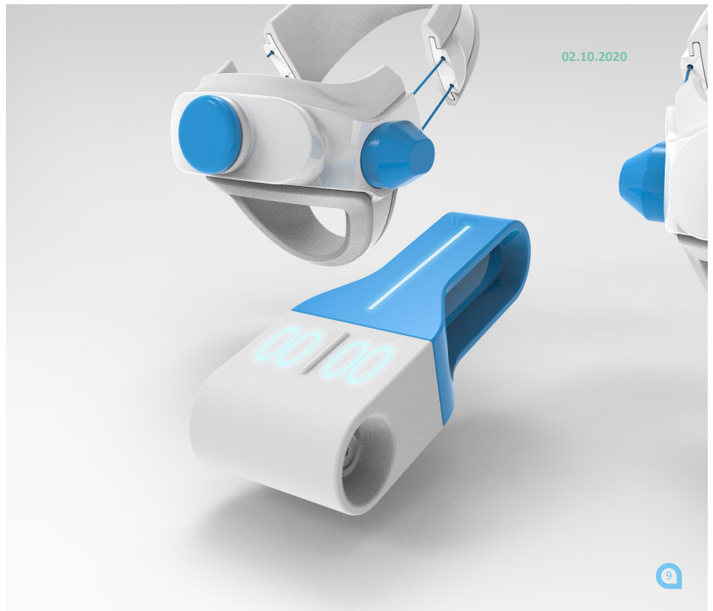
Key Breakdown



GREEN LIGHT MEETING

CURRENT

Key Breakdown

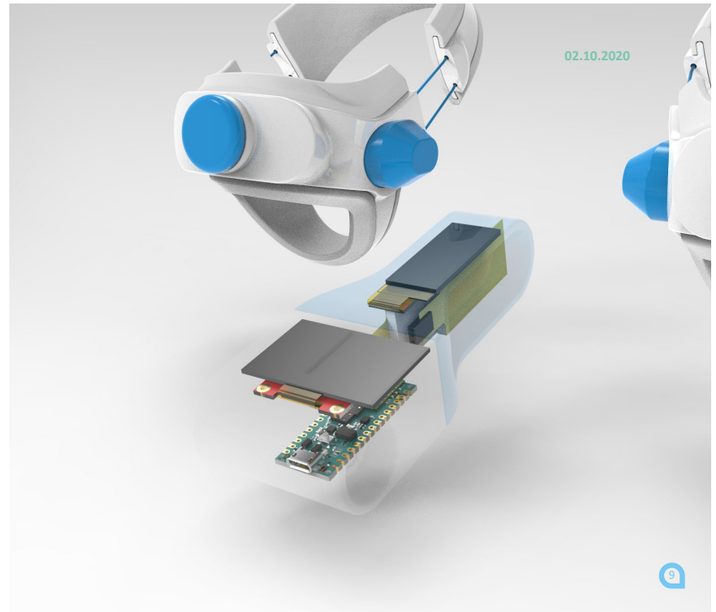


GREEN LIGHT MEETING

CURRENT

Key Breakdown

- Oled Screens
  - Grayscale Oled
  - Blue Oled
- Arduino Nano 33 BLE

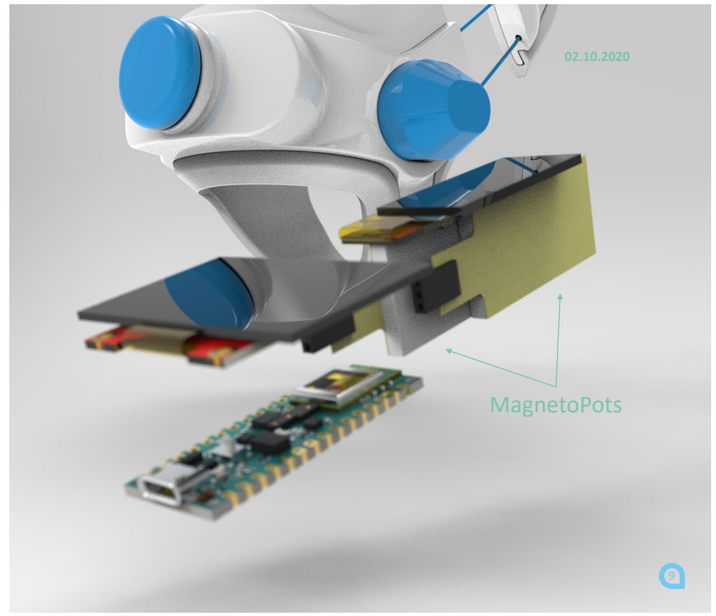


GREEN LIGHT MEETING

CURRENT

Key Breakdown

- Oled Screens
  - Grayscale Oled
  - Blue Oled
- Arduino Nano 33 BLE
- MagnetoPot Position Sensing
  - Independent heel positioning
  - Visual communication

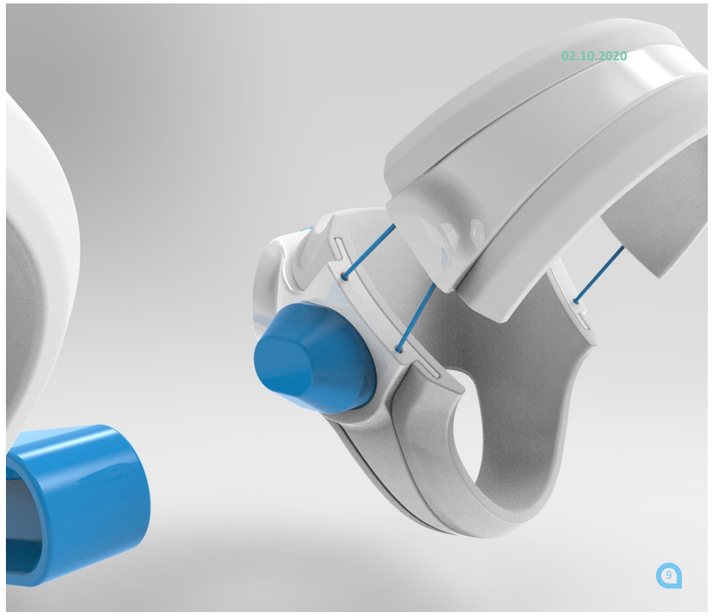


GREEN LIGHT MEETING

CURRENT

Key Breakdown

- Oled Screens
  - Grayscale Oled
  - Blue Oled
- Arduino Nano 33 BLE
- MagnetoPot Position Sensing
  - Independent heel positioning
  - Visual communication
- Magnet Activation

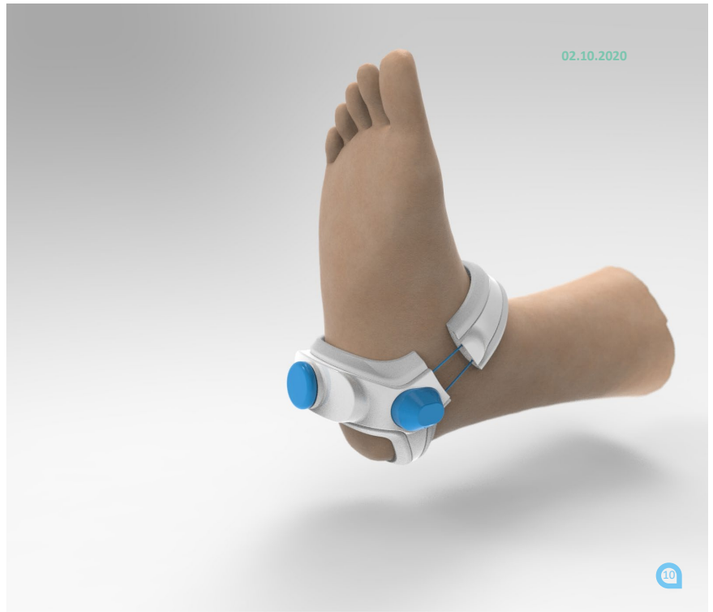


GREEN LIGHT MEETING

CURRENT

Usage Breakdown

- Shape embodied intelligence
  - Self aligning

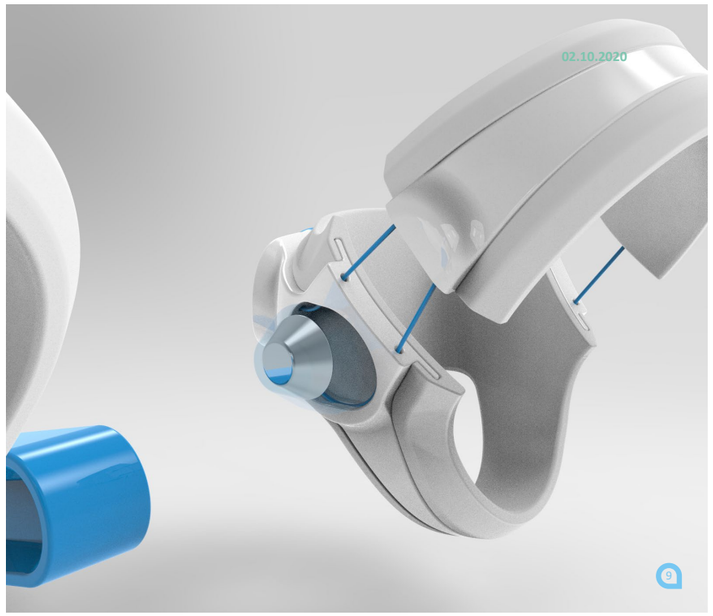


GREEN LIGHT MEETING

CURRENT

Key Breakdown

- Oled Screens
  - Grayscale Oled
  - Blue Oled
- Arduino Nano 33 BLE
- MagnetoPot Position Sensing
  - Independent heel positioning
  - Visual communication
- Magnet Activation

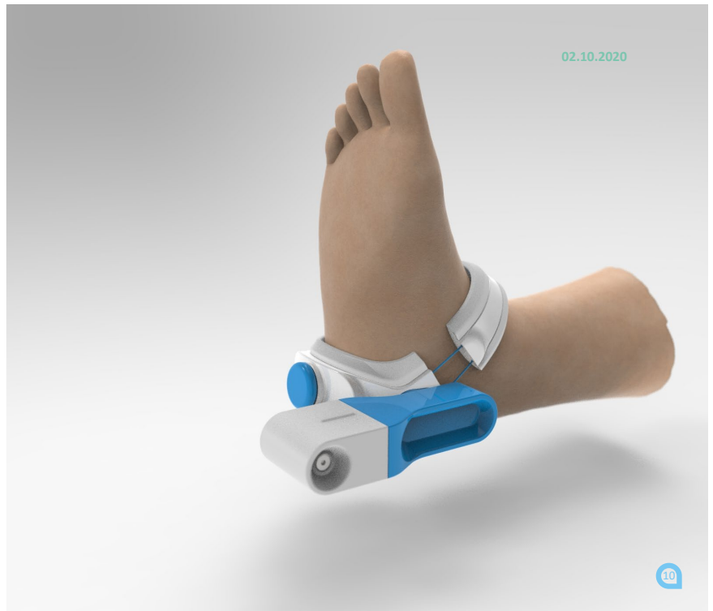


GREEN LIGHT MEETING

CURRENT

Usage Breakdown

- Shape embodied intelligence
  - Self aligning
  - Perpendicularity ensured

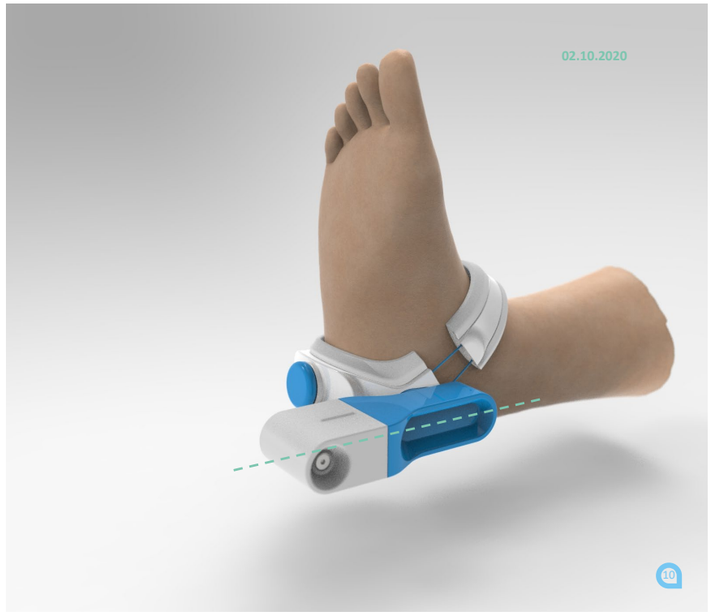


GREEN LIGHT MEETING

CURRENT

Usage Breakdown

- Shape embodied intelligence
  - Self aligning
  - Perpendicularity ensured

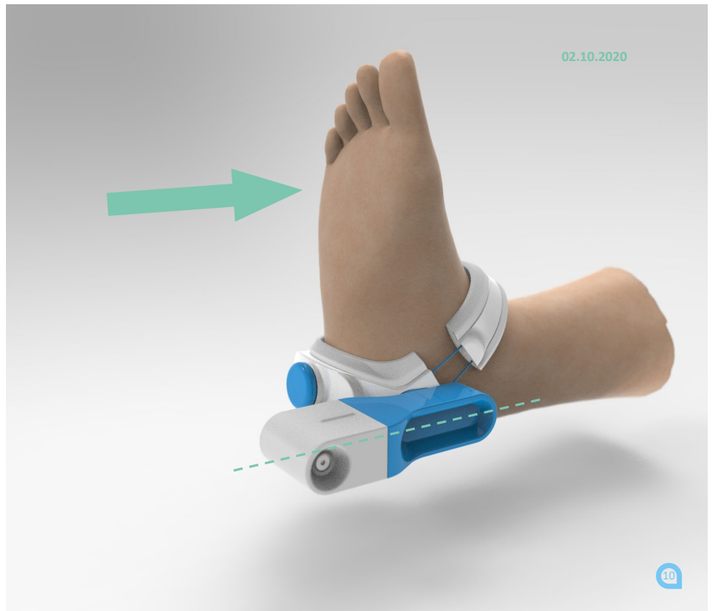


GREEN LIGHT MEETING

CURRENT

Usage Breakdown

- Shape embodied intelligence
  - Self aligning
  - Perpendicularity ensured
- Precision Mode
  - Activated by sliding



GREEN LIGHT MEETING

CURRENT

Usage Breakdown

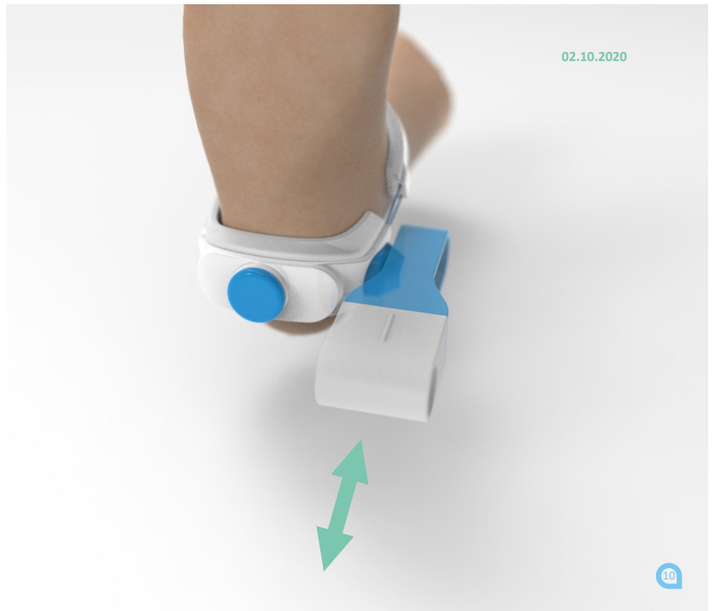
- Shape embodied intelligence
  - Self aligning
  - Perpendicularity ensured

GREEN LIGHT MEETING

CURRENT

Usage Breakdown

- Shape embodied intelligence
  - Self aligning
  - Perpendicularity ensured
- Precision Mode
  - Activated by sliding

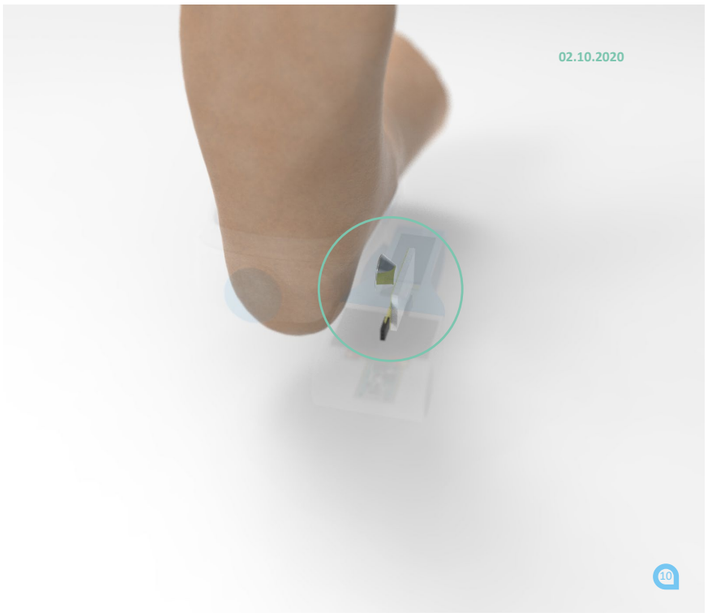


GREEN LIGHT MEETING

CURRENT

Usage Breakdown

- Shape embodied intelligence
  - Self aligning
  - Perpendicularity ensured
- Precision Mode
  - Activated by sliding
- MagnetoPot Position Sensing
  - Independent heel positioning
  - Visual communication

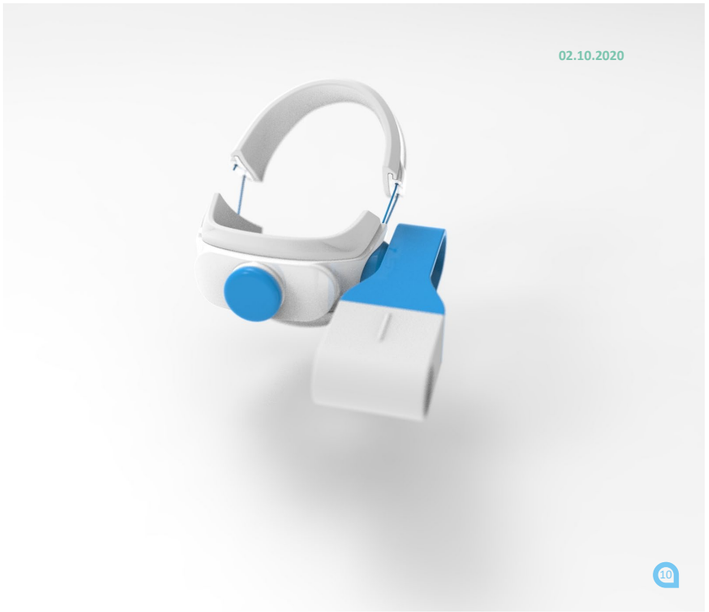


GREEN LIGHT MEETING

CURRENT

Usage Breakdown

- Shape embodied intelligence
  - Self aligning
  - Perpendicularity ensured
- Precision Mode
  - Activated by sliding
- MagnetoPot Position Sensing
  - Independent heel positioning
  - Visual communication

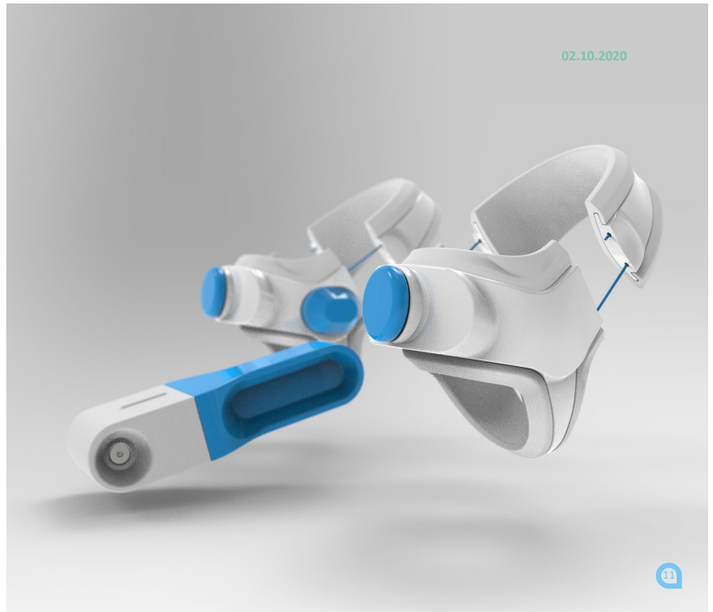


GREEN LIGHT MEETING

NEXT

To be done

- 3D Modelling (!)
- Final Prototype
- Testing & Evaluating

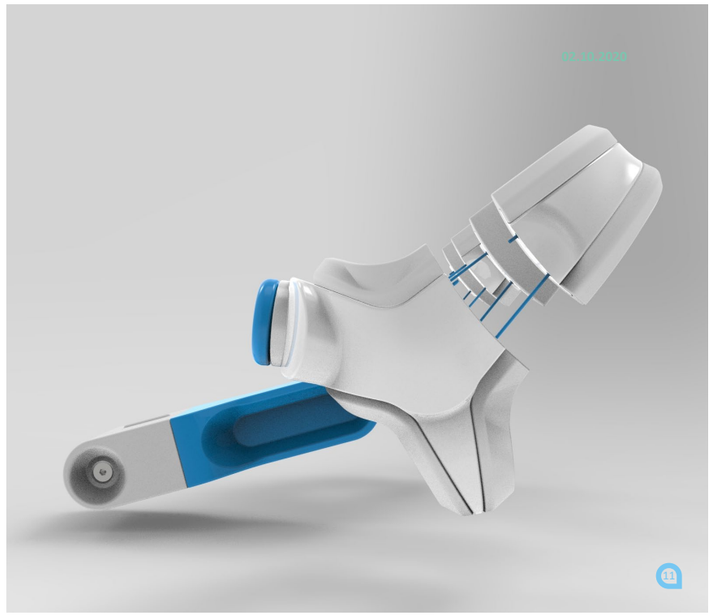


GREEN LIGHT MEETING

NEXT

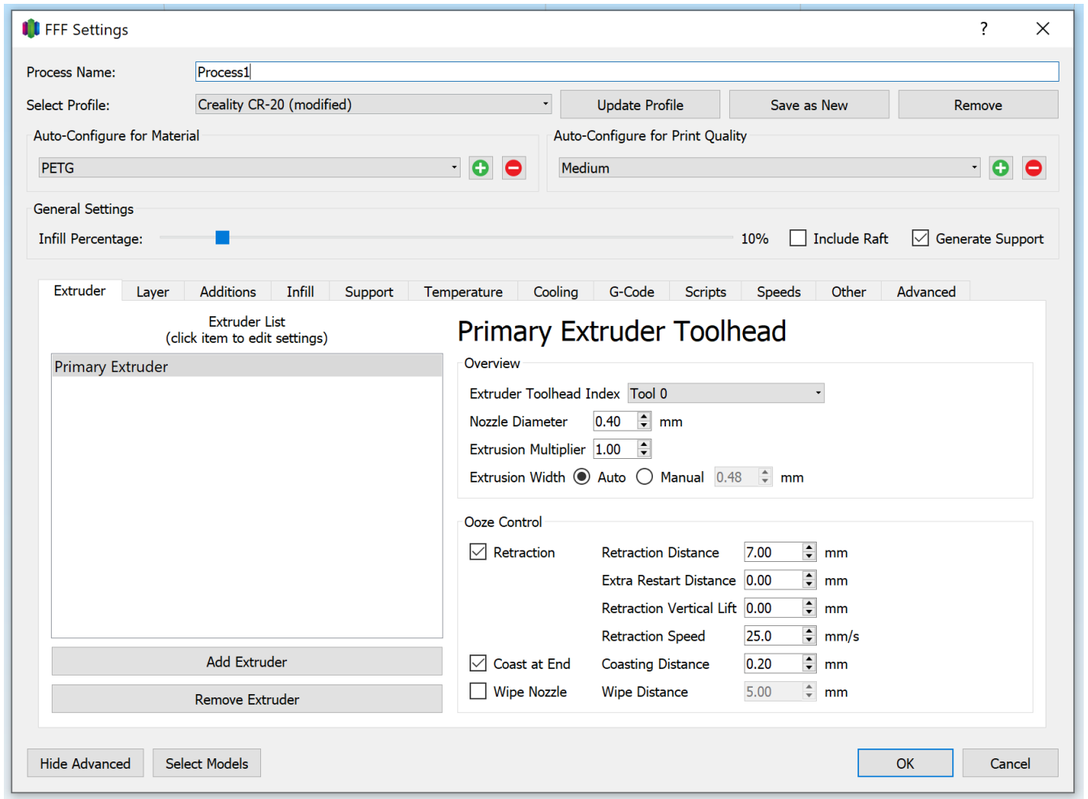
To be done

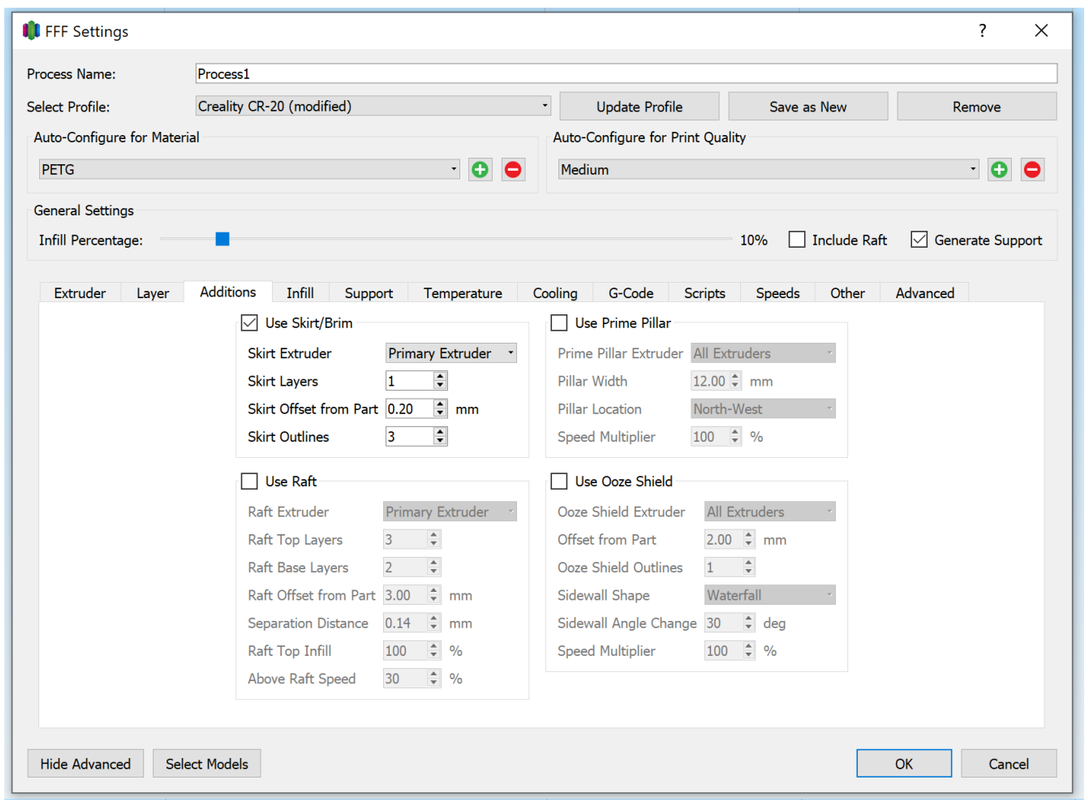
- 3D Modelling (!)
- Final Prototype
- Testing & Evaluating
- Report
- Report Visuals
- Appendix
- Video

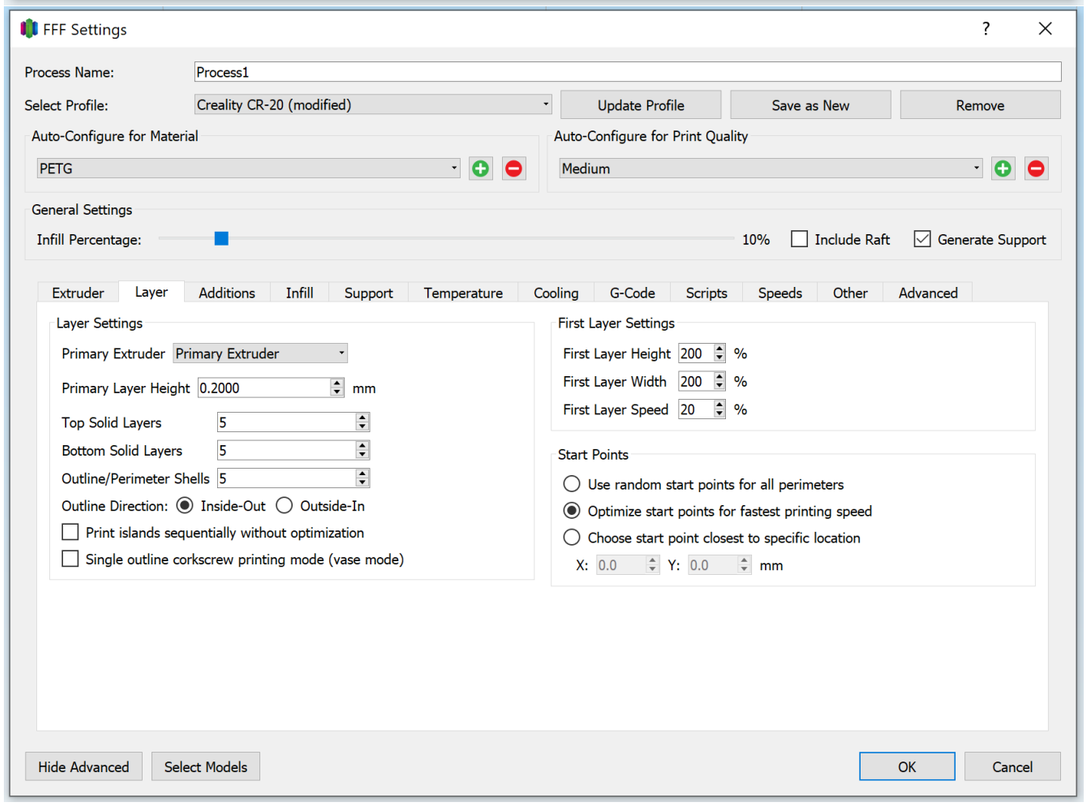


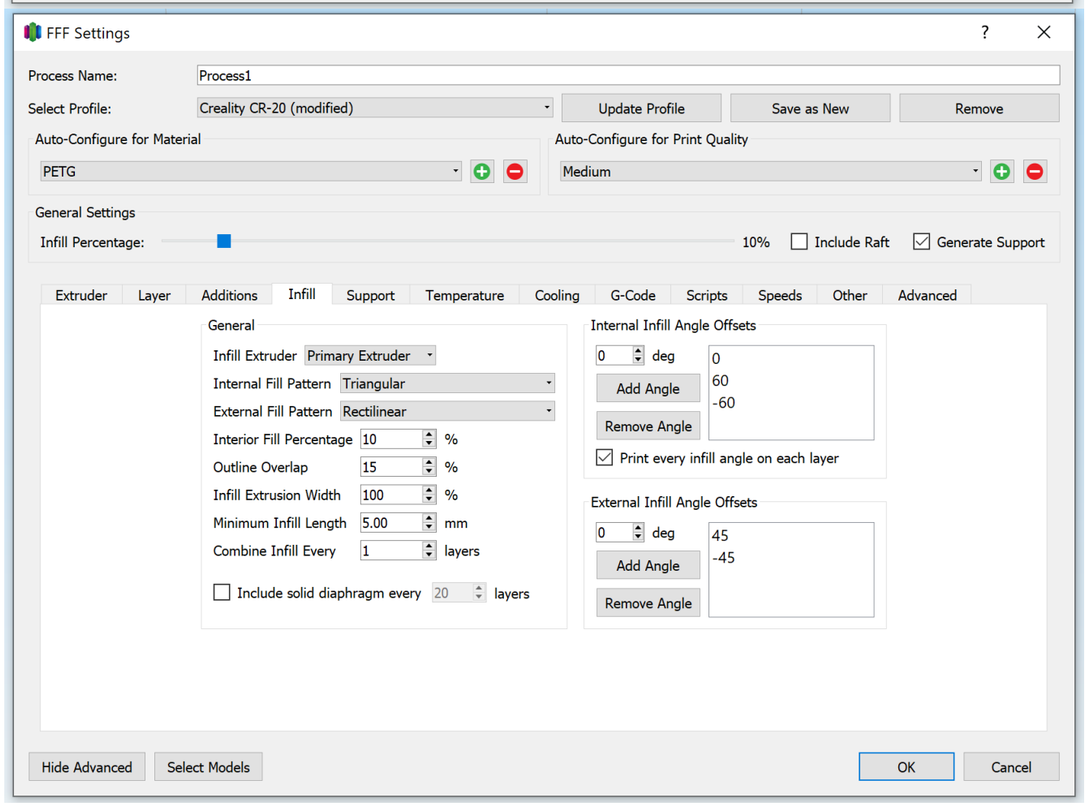
Appendix I

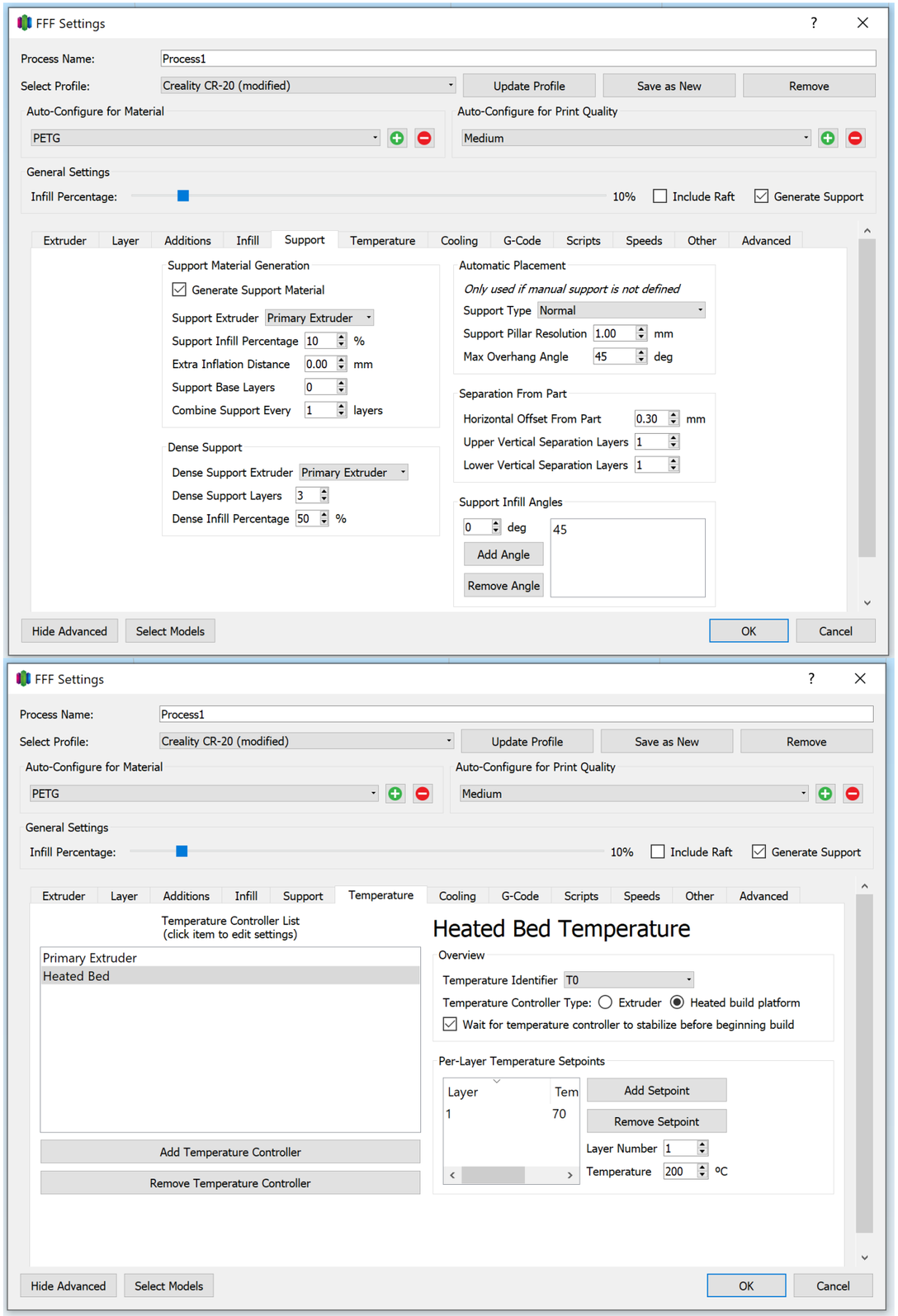
S3D Slicing Profiles


FFF Settings
Process Name: Process1
Select Profile: Creality CR-20 (modified)
Update Profile
Save as New
Remove
Auto-Configure for Material
PETG
Auto-Configure for Print Quality
Medium
General Settings
Infill Percentage: 10%
Include Raft
Generate Support
Extruder Layer Additions Infill Support Temperature Cooling G-Code Scripts Speeds Other Advanced
Extruder List
(click item to edit settings)
Primary Extruder
Add Extruder
Remove Extruder
Primary Extruder Toolhead
Overview
Extruder Toolhead Index Tool 0
Nozzle Diameter 0.40 mm
Extrusion Multiplier 1.00
Extrusion Width Auto Manual 0.48 mm
Ooze Control
Retraction
Retraction Distance 7.00 mm
Extra Restart Distance 0.00 mm
Retraction Vertical Lift 0.00 mm
Retraction Speed 25.0 mm/s
Coast at End
Coasting Distance 0.20 mm
Wipe Nozzle
Wipe Distance 5.00 mm
Hide Advanced
Select Models
OK
Cancel

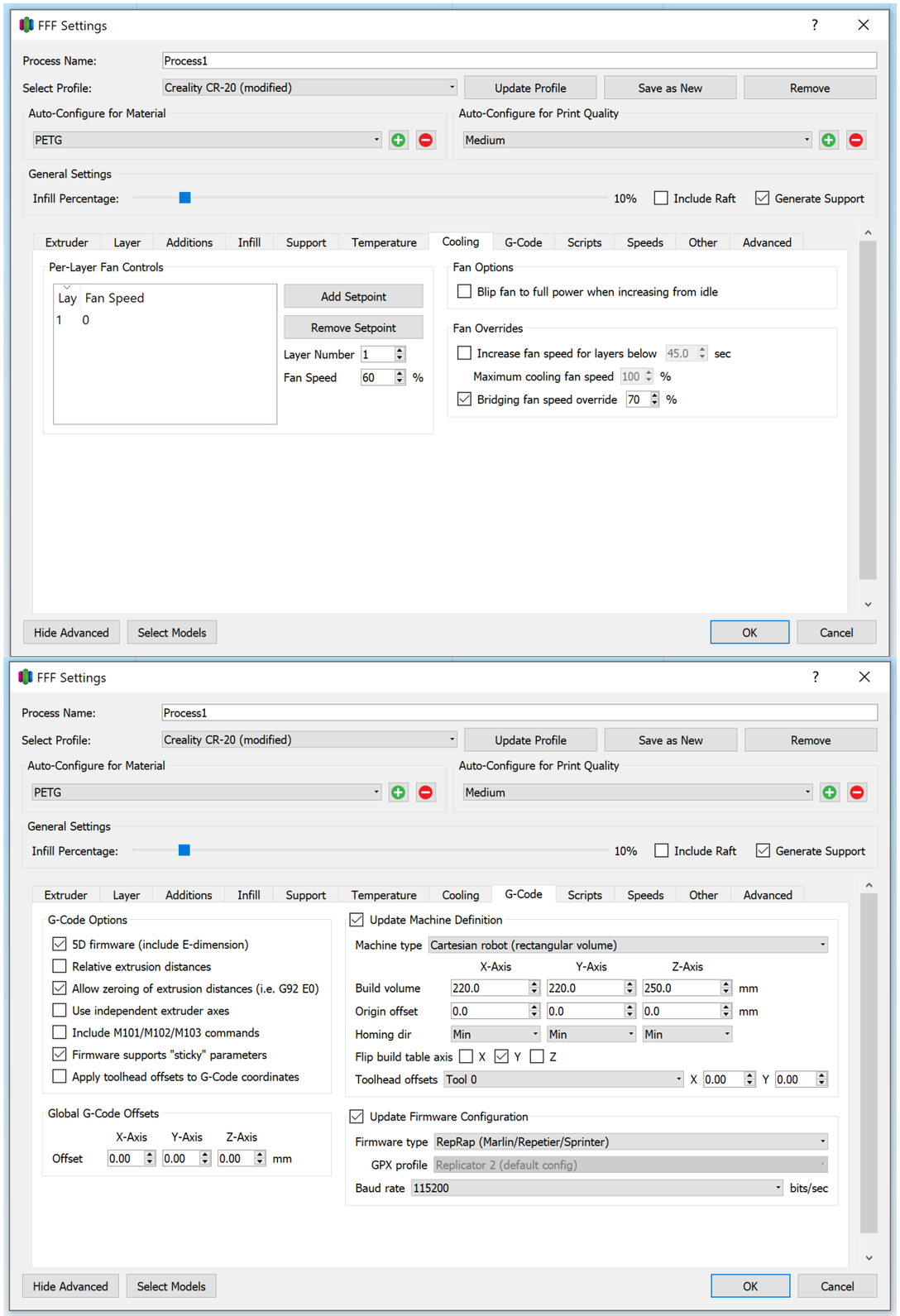

FFF Settings
Process Name: Process1
Select Profile: Creality CR-20 (modified)
Update Profile
Save as New
Remove
Auto-Configure for Material
PETG
Auto-Configure for Print Quality
Medium
General Settings
Infill Percentage: 10%
Include Raft
Generate Support
Extruder Layer Additions Infill Support Temperature Cooling G-Code Scripts Speeds Other Advanced
Use Skirt/Brim
Skirt Extruder Primary Extruder
Skirt Layers 1
Skirt Offset from Part 0.20 mm
Skirt Outlines 3
Use Raft
Raft Extruder Primary Extruder
Raft Top Layers 3
Raft Base Layers 2
Raft Offset from Part 3.00 mm
Separation Distance 0.14 mm
Raft Top Infill 100 %
Above Raft Speed 30 %
Use Prime Pillar
Prime Pillar Extruder All Extruders
Pillar Width 12.00 mm
Pillar Location North-West
Speed Multiplier 100 %
Use Ooze Shield
Ooze Shield Extruder All Extruders
Offset from Part 2.00 mm
Ooze Shield Outlines 1
Sidewall Shape Waterfall
Sidewall Angle Change 30 deg
Speed Multiplier 100 %
Hide Advanced
Select Models
OK
Cancel


FFF Settings
Process Name: Process1
Select Profile: Creality CR-20 (modified)
Update Profile
Save as New
Remove
Auto-Configure for Material
PETG
Auto-Configure for Print Quality
Medium
General Settings
Infill Percentage: 10%
Include Raft
Generate Support
Extruder Layer Additions Infill Support Temperature Cooling G-Code Scripts Speeds Other Advanced
Layer Settings
Primary Extruder Primary Extruder
Primary Layer Height 0.2000 mm
Top Solid Layers 5
Bottom Solid Layers 5
Outline/Perimeter Shells 5
Outline Direction: Inside-Out Outside-In
Print islands sequentially without optimization
Single outline corkscrew printing mode (vase mode)
First Layer Settings
First Layer Height 200 %
First Layer Width 200 %
First Layer Speed 20 %
Start Points
Use random start points for all perimeters
Optimize start points for fastest printing speed
Choose start point closest to specific location
X: 0.0 Y: 0.0 mm
Hide Advanced
Select Models
OK
Cancel

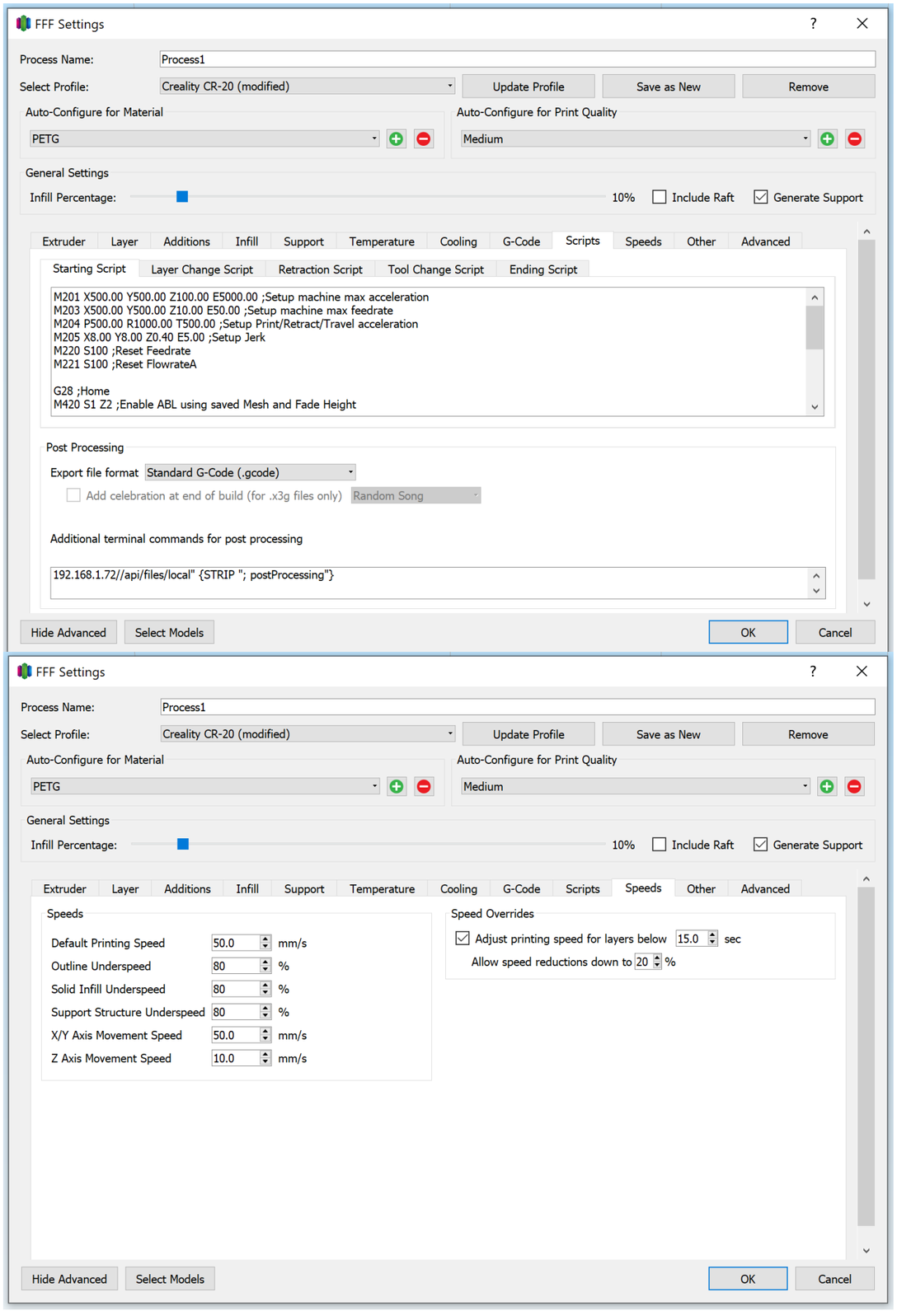

FFF Settings
Process Name: Process1
Select Profile: Creality CR-20 (modified)
Update Profile
Save as New
Remove
Auto-Configure for Material
PETG
Auto-Configure for Print Quality
Medium
General Settings
Infill Percentage: 10%
Include Raft
Generate Support
Extruder Layer Additions Infill Support Temperature Cooling G-Code Scripts Speeds Other Advanced
General
Infill Extruder Primary Extruder
Internal Fill Pattern Triangular
External Fill Pattern Rectilinear
Interior Fill Percentage 10 %
Outline Overlap 15 %
Infill Extrusion Width 100 %
Minimum Infill Length 5.00 mm
Combine Infill Every 1 layers
Include solid diaphragm every 20 layers
Internal Infill Angle Offsets
0 deg
Add Angle
Remove Angle
0
60
-60
Print every infill angle on each layer
External Infill Angle Offsets
0 deg
Add Angle
Remove Angle
45
-45
Hide Advanced
Select Models
OK
Cancel


FFF Settings
Process Name: Process1
Select Profile: Creality CR-20 (modified)
Update Profile
Save as New
Remove
Auto-Configure for Material
PETG
Auto-Configure for Print Quality
Medium
General Settings
Infill Percentage: 10%
Include Raft
Generate Support
Extruder Layer Additions Infill Support Temperature Cooling G-Code Scripts Speeds Other Advanced
Support Material Generation
Generate Support Material
Support Extruder Primary Extruder
Support Infill Percentage 10 %
Extra Inflation Distance 0.00 mm
Support Base Layers 0
Combine Support Every 1 layers
Dense Support
Dense Support Extruder Primary Extruder
Dense Support Layers 3
Dense Infill Percentage 50 %
Automatic Placement
Only used if manual support is not defined
Support Type Normal
Support Pillar Resolution 1.00 mm
Max Overhang Angle 45 deg
Separation From Part
Horizontal Offset From Part 0.30 mm
Upper Vertical Separation Layers 1
Lower Vertical Separation Layers 1
Support Infill Angles
0 deg
Add Angle
Remove Angle
45
Hide Advanced
Select Models
OK
Cancel

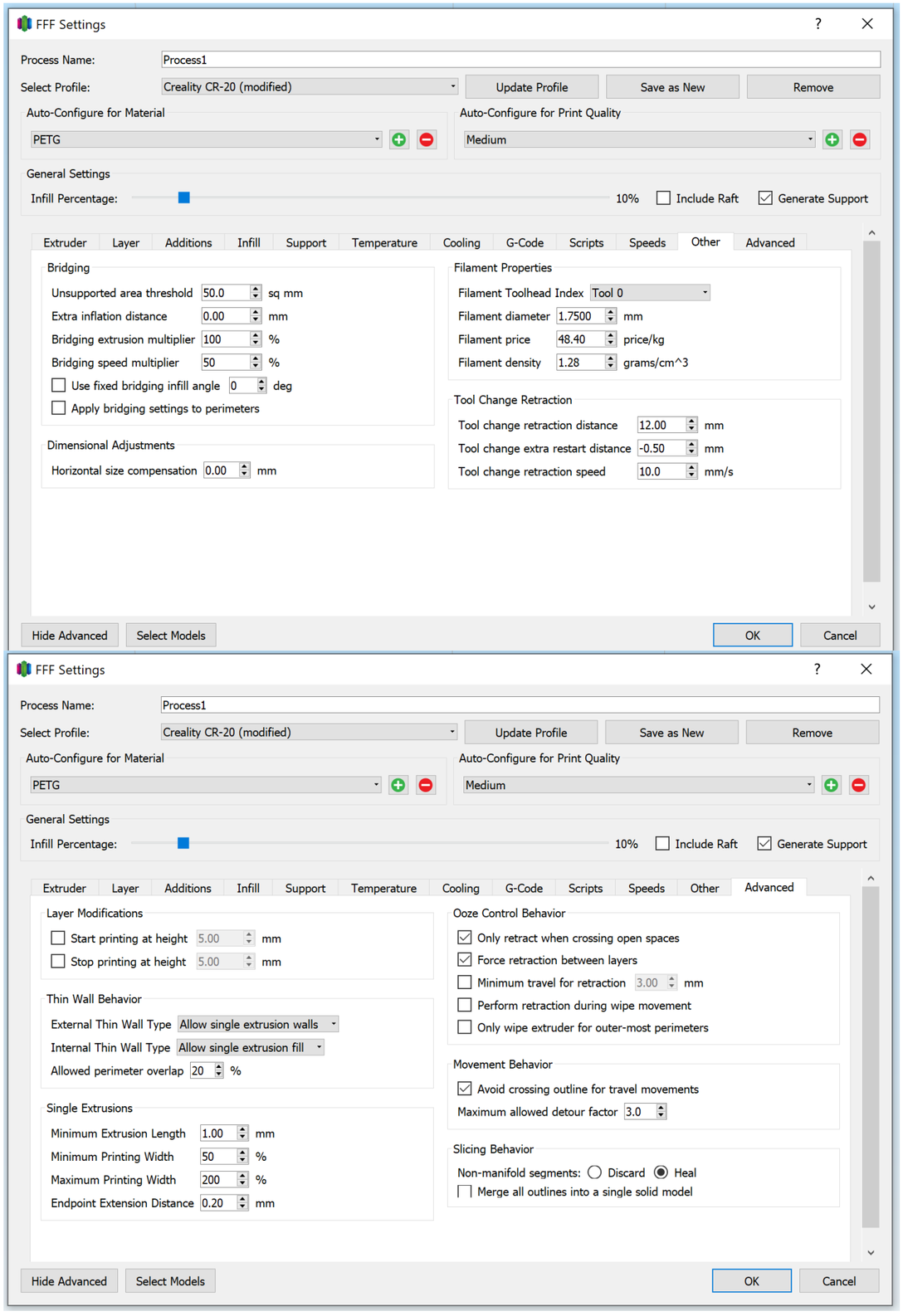
FFF Settings
Process Name: Process1
Select Profile: Creality CR-20 (modified)
Update Profile
Save as New
Remove
Auto-Configure for Material
PETG
Auto-Configure for Print Quality
Medium
General Settings
Infill Percentage: 10%
Include Raft
Generate Support
Extruder Layer Additions Infill Support Temperature Cooling G-Code Scripts Speeds Other Advanced
Temperature Controller List
(click item to edit settings)
Primary Extruder
Heated Bed
Add Temperature Controller
Remove Temperature Controller
Heated Bed Temperature
Overview
Temperature Identifier T0
Temperature Controller Type: Extruder Heated build platform
Wait for temperature controller to stabilize before beginning build
Per-Layer Temperature Setpoints
Layer Tem
1 70
Add Setpoint
Remove Setpoint
Layer Number 1
Temperature 200 °C
Hide Advanced
Select Models
OK
Cancel


FFF Settings
Process Name: Process1
Select Profile: Creality CR-20 (modified)
Update Profile
Save as New
Remove
Auto-Configure for Material
PETG
Auto-Configure for Print Quality
Medium
General Settings
Infill Percentage: 10%
Include Raft
Generate Support
Extruder Layer Additions Infill Support Temperature Cooling G-Code Scripts Speeds Other Advanced
Per-Layer Fan Controls
Lay Fan Speed
1 0
Add Setpoint
Remove Setpoint
Layer Number 1
Fan Speed 60 %
Fan Options
Blip fan to full power when increasing from idle
Fan Overrides
Increase fan speed for layers below 45.0 sec
Maximum cooling fan speed 100 %
Bridging fan speed override 70 %
Hide Advanced
Select Models
OK
Cancel

FFF Settings
Process Name: Process1
Select Profile: Creality CR-20 (modified)
Update Profile
Save as New
Remove
Auto-Configure for Material
PETG
Auto-Configure for Print Quality
Medium
General Settings
Infill Percentage: 10%
Include Raft
Generate Support
Extruder Layer Additions Infill Support Temperature Cooling G-Code Scripts Speeds Other Advanced
G-Code Options
5D firmware (include E-dimension)
Relative extrusion distances
Allow zeroing of extrusion distances (i.e. G92 E0)
Use independent extruder axes
Include M101/M102/M103 commands
Firmware supports "sticky" parameters
Apply toolhead offsets to G-Code coordinates
Global G-Code Offsets
X-Axis Y-Axis Z-Axis
Offset 0.00 0.00 0.00 mm
Update Machine Definition
Machine type Cartesian robot (rectangular volume)
X-Axis Y-Axis Z-Axis
Build volume 220.0 220.0 250.0 mm
Origin offset 0.0 0.0 0.0 mm
Homing dir Min Min Min
Flip build table axis X Y Z
Toolhead offsets Tool 0 X 0.00 Y 0.00
Update Firmware Configuration
Firmware type RepRap (Marlin/Repetier/Sprinter)
GPX profile Replicator 2 (default config)
Baud rate 115200 bits/sec
Hide Advanced
Select Models
OK
Cancel


FFF Settings
Process Name: Process1
Select Profile: Creality CR-20 (modified)
Update Profile
Save as New
Remove
Auto-Configure for Material
PETG
Auto-Configure for Print Quality
Medium
General Settings
Infill Percentage: 10%
Include Raft
Generate Support
Extruder Layer Additions Infill Support Temperature Cooling G-Code Scripts Speeds Other Advanced
Starting Script
Layer Change Script
Retraction Script
Tool Change Script
Ending Script
M201 X500.00 Y500.00 Z100.00 E5000.00 ;Setup machine max acceleration
M203 X500.00 Y500.00 Z10.00 E50.00 ;Setup machine max feedrate
M204 P500.00 R1000.00 T500.00 ;Setup Print/Retract/Travel acceleration
M205 X8.00 Y8.00 Z0.40 E5.00 ;Setup Jerk
M220 S100 ;Reset Feedrate
M221 S100 ;Reset FlowrateA
G28 ;Home
M420 S1 Z2 ;Enable ABL using saved Mesh and Fade Height
Post Processing
Export file format Standard G-Code (.gcode)
Add celebration at end of build (for .x3g files only)
Random Song
Additional terminal commands for post processing
192.168.1.72//api/files/local" {STRIP "; postProcessing"}
Hide Advanced
Select Models
OK
Cancel

FFF Settings
Process Name: Process1
Select Profile: Creality CR-20 (modified)
Update Profile
Save as New
Remove
Auto-Configure for Material
PETG
Auto-Configure for Print Quality
Medium
General Settings
Infill Percentage: 10%
Include Raft
Generate Support
Extruder Layer Additions Infill Support Temperature Cooling G-Code Scripts Speeds Other Advanced
Speeds
Default Printing Speed 50.0 mm/s
Outline Underspeed 80 %
Solid Infill Underspeed 80 %
Support Structure Underspeed 80 %
X/Y Axis Movement Speed 50.0 mm/s
Z Axis Movement Speed 10.0 mm/s
Speed Overrides
Adjust printing speed for layers below 15.0 sec
Allow speed reductions down to 20 %
Hide Advanced
Select Models
OK
Cancel


FFF Settings
Process Name: Process1
Select Profile: Creality CR-20 (modified)
Update Profile
Save as New
Remove
Auto-Configure for Material
PETG
Auto-Configure for Print Quality
Medium
General Settings
Infill Percentage: 10%
Include Raft
Generate Support
Extruder Layer Additions Infill Support Temperature Cooling G-Code Scripts Speeds Other Advanced
Bridging
Unsupported area threshold 50.0 sq mm
Extra inflation distance 0.00 mm
Bridging extrusion multiplier 100 %
Bridging speed multiplier 50 %
Use fixed bridging infill angle 0 deg
Apply bridging settings to perimeters
Dimensional Adjustments
Horizontal size compensation 0.00 mm
Filament Properties
Filament Toolhead Index Tool 0
Filament diameter 1.7500 mm
Filament price 48.40 price/kg
Filament density 1.28 grams/cm^3
Tool Change Retraction
Tool change retraction distance 12.00 mm
Tool change extra restart distance -0.50 mm
Tool change retraction speed 10.0 mm/s
Hide Advanced
Select Models
OK
Cancel

FFF Settings
Process Name: Process1
Select Profile: Creality CR-20 (modified)
Update Profile
Save as New
Remove
Auto-Configure for Material
PETG
Auto-Configure for Print Quality
Medium
General Settings
Infill Percentage: 10%
Include Raft
Generate Support
Extruder Layer Additions Infill Support Temperature Cooling G-Code Scripts Speeds Other Advanced
Layer Modifications
Start printing at height 5.00 mm
Stop printing at height 5.00 mm
Thin Wall Behavior
External Thin Wall Type Allow single extrusion walls
Internal Thin Wall Type Allow single extrusion fill
Allowed perimeter overlap 20 %
Single Extrusions
Minimum Extrusion Length 1.00 mm
Minimum Printing Width 50 %
Maximum Printing Width 200 %
Endpoint Extension Distance 0.20 mm
Ooze Control Behavior
Only retract when crossing open spaces
Force retraction between layers
Minimum travel for retraction 3.00 mm
Perform retraction during wipe movement
Only wipe extruder for outer-most perimeters
Movement Behavior
Avoid crossing outline for travel movements
Maximum allowed detour factor 3.0
Slicing Behavior
Non-manifold segments: Discard Heal
Merge all outlines into a single solid model
Hide Advanced
Select Models
OK
Cancel

Appendix J

Magnetopot
Datasheet

spectrasymbol

MagnetoPot MP1

Features

- Contactless Linear Sensor
- IP64 Debris Proof, Splash Proof
- Ideal for Hydraulic and Pneumatic Position Sensing
- Liquid Level Capability
- Upon request
  - Male or Female Nicomatic Connectors
  - Corresponding Exterior Magnet

Mechanical Specifications

-Life Cycle: >1 million
-Height: ≤3.50mm (0.138")
-Actuation Force: 18 grams pull force from exterior magnet or ferromagnet

Environmental Specifications

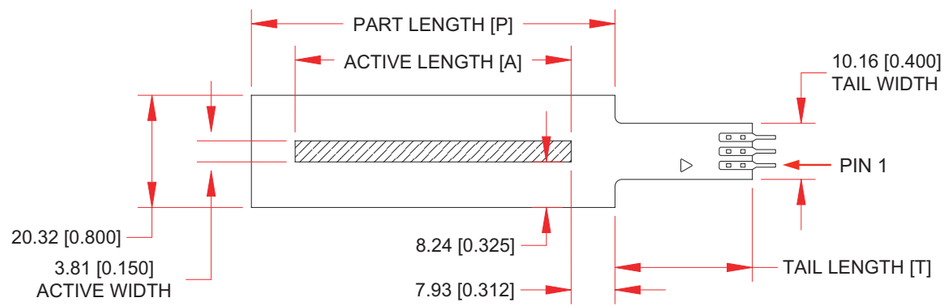
-Operating Temperature: up to +85°C
-IP Rating of Active Area: IP64

Electrical Specifications

-Resistance - Standard: 10k Ohms (lengths >300mm = 20k Ohms)
-Resistance - Custom: 5k to 500k Ohms
-Resistance Tolerance: ±20%
-Effective Electrical Travel: 8 to 1200mm
-Resolution: Depends on the exterior magnet strength and distance to the MagnetoPot
-Power Rating: 0.50 Watt continuous, 1 Watt Peak
-Dielectric Value: No affect @ 500VAC for 1 minute
-Independant Linearity: ±5% (±1% available)
-Hysteresis: 3mm*

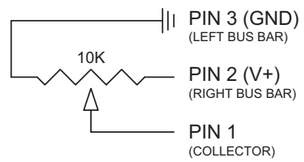
***Please note** that the hysteresis is directly affected by the drive magnet size, strength, and distance from the internal magnet.*

Dimensional Diagram - Stock Linear MagnetoPots

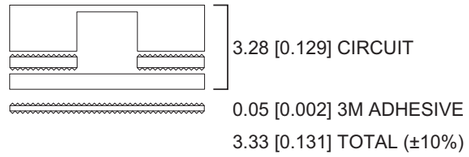


A	12.50mm 0.492"	25.00mm 0.984"	50.00mm 1.969"	100.00mm 3.937"	150.00mm 5.906"	171.89mm 6.768"	200.00mm 7.874"	300.00mm 11.811"	400.00mm 15.748"	500.00mm 19.685"	750.00mm 29.528"	1000.00mm 39.370"
P	28.36mm 1.117"	40.86mm 1.609"	65.86mm 2.593"	115.86mm 4.562"	165.86mm 6.531"	185.86mm 7.318"	215.86mm 8.499"	315.86mm 12.436"	415.86mm 16.373"	515.86mm 20.310"	765.86mm 30.153"	1015.86mm 39.995"
T	12.70mm 0.500"		24.89mm 0.980"									

Electrical Schematic



Material Cross-Section



How to Order - MagnetoPots

MP1 — L — 0050 — 103 — 5% — ST

Series
MP1 = MagnetoPot

Model
L = Linear

Active Length
0012 = 12,5mm
0025 = 25mm
0050 = 50mm
0100 = 100mm
0150 = 150mm
0172 = 172mm
0200 = 200mm
0300 = 300mm
0400 = 400mm
0500 = 500mm
0750 = 750mm
1000 = 1000mm

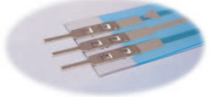
Resistance
Active Lengths ≤ 300mm
103 = 10 KOhm
Active Lengths > 300mm
203 = 20 KOhm

Ind. Linearity
5% = ±5%

Connectors
ST = Solder Tab
MP = Male Pins
RH = Receptacles w/Plain Housing
RL = Receptacles w/Latch* Housing
RD = Receptacles w/Detent* Housing

* Please note that the RL and RD style connectors are only available with the latch or detent downward.

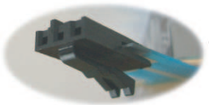
Standard Connector Options



Crimpflex Solder Tab (ST)

Crimpflex Short Male Pins (MP)

Crimpflex Female Receptacles with a Plain Housing (RH)



Crimpflex Female Receptacles with a Latch Housing (RL)
**only available with the latch oriented downward*

Crimpflex Female Receptacles with a Detent Housing (RD)
**only available with the detent oriented downward*

Customization

Customize the size and shape. Such custom requests, for example, can be: custom lengths 10mm-1200mm; custom rotary diameters, etc. Spectra Symbol would be glad to quote your custom application, just contact us at sales@spectrasymbol.com or (888)795-2283.

How It Works

The MagnetoPot is simple, yet elegant in its ability to track motion in a contactless manner. A magnet on the inside of a cylinder, or a magnet on the opposing side of a motion device will guide the built-in magnetics of the MagnetoPot for position location through a potentiometric output.

The MagnetoPot is a sealed potentiometer, in the membrane potentiometer tradition, yet it does not require a wiper/actuator to connect the collector and the resistor. Instead, the MagnetoPot is controlled by an outside magnet, which attracts the magnetic forces within the MagnetoPot to connect to the linear resistor and give linear potentiometer feedback.

The wiper inside the sealed pot is magnetic or ferromagnetic, and will only perform if connected with an exterior magnet.

As opposed to a magnetically-based Reed Switch, which gives simply “open” or “close” signals, the MagnetoPot gives the full linear travel of a hydraulic or pneumatic cylinder.

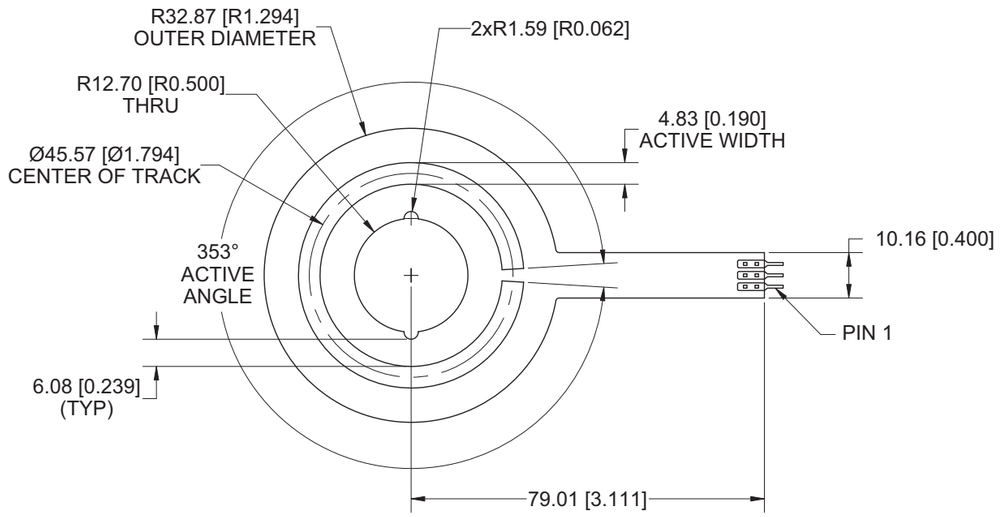
In liquid level applications, the MagnetoPot can attach to the outside of a liquid tank and give position of the magnet inside the float. No water ingress, no wearing of the part by environment, because the MagnetoPot is outside of the tank.

Design and Contruction

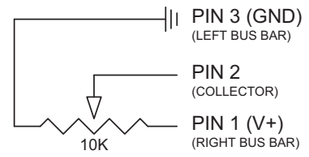
The MagnetoPot is made of polyester, fiberglass and kapton, depending on the specification required. It functions as a voltage divider, a resistor or rheostat, as desired by the end-user. By bringing the exterior magnet into a proximity necessary to connect with the internal magnetic attractors, the operator can obtain linear position sensing based on the location of the exterior magnet. As the exterior magnet moves, so does the electrical output of the MagnetoPot.

The MagnetoPot should not be mounted to a ferromagnetic surface.

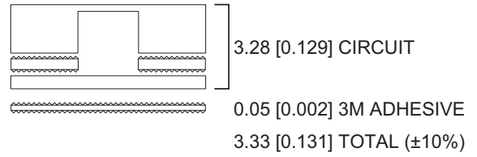
Diagram - Stock Rotary MagnetoPot



Electrical Schematic



Material Cross-Section



How to Order - Rotary MagnetoPot

MP1 — R — 0046 / 0353 — 103 — 5% — ST

Series	Model	Center of Active Track	Active Angle	Resistance	Ind. Linearity	Connectors
MP1 = MagnetoPot	R = Rotary	0046 = 45.57mm	0353 = 353°	103 = 10 KOhm	5% = ±5%	ST = Solder Tab MP = Male Pins RH = Receptacles w/Plain Housing RL = Receptacles w/Latch Housing RD = Receptacles w/Detent Housing

Appendix K
Final Code

Left_unit__user_Button_start_combine____load_cell___motor_small

```
#include "Arduino.h"
#include <Wire.h>
#include <Adafruit_GFX.h>
#include "Adafruit_LEDBackpack.h"


#include "Adafruit_DRV2605.h"
Adafruit_DRV2605 drv;

#include "SparkFun_Qwiic_Scale_NAU7802_Arduino_Library.h" // Click here to get the library: http://librarymanager/All#SparkFun_NAU7802
NAU7802 myScale; //Create instance of the NAU7802 class


//LED DEFINITION
#define LED_MODE   1

const int ledPin = 5;      // the number of the LED pin, D3
const int buttonPin = 3;    // the number of the pushbutton pin, D4
const boolean breathMode = true;  // if or not the led lights as breath mode when it's on

// Variables will change:
int ledState = HIGH;         // the current state of the output pin
int ledFadeValue = 0;
int ledFadeStep = 10;
int ledFadeInterval = 100;   //milliseconds
int buttonState;             // the current reading from the input pin
int lastButtonState = 0;   // the previous reading from the input pin

unsigned long lastDebounceTime = 0;  // the last time the output pin was toggled
unsigned long debounceDelay = 70;    // the debounce time; increase if the output flickers
unsigned long lastLedFadeTime = 0;


//DISPLAY DEFINITION
Adafruit_AlphaNum4 alpha4 = Adafruit_AlphaNum4();

//MAGNETOPOT DEFINITION
const int numReadings = 10;
int readings[numReadings];      // the readings from the analog input
int readIndex = 0;              // the index of the current reading
int total = 0;                  // the running total
int average = 0;                // the average

int inputPin = A0;


void setup() {

  //BUTTON SETUP
  // initialize the LED pin as an output:
  pinMode(ledPin, OUTPUT);
  // initialize the pushbutton pin as an input:
  pinMode(buttonPin, INPUT);

 //MAGNETOPOT SETUP
  for (int thisReading = 0; thisReading < numReadings; thisReading++) {
    readings[thisReading] = 0;
  }

 //DISPLAY SETUP
  alpha4.begin(0x70);  // pass in the address

  alpha4.writeDigitRaw(3, 0x0);
  alpha4.writeDigitAscii(3, '+');
  alpha4.writeDisplay();
  delay(200);

  alpha4.writeDigitRaw(3, 0x0);
  alpha4.writeDigitAscii(2, '+');
  alpha4.writeDisplay();
  delay(200);

  alpha4.writeDigitRaw(3, 0x0);
  alpha4.writeDigitAscii(1, '+');
  alpha4.writeDigitAscii(2, 'P');
  alpha4.writeDigitAscii(3, 'L');
  alpha4.writeDisplay();
  delay(200);

 alpha4.writeDigitRaw(3, 0x0);
 alpha4.writeDigitAscii(0, '+');
 alpha4.writeDigitAscii(1, 'P');
 alpha4.writeDigitAscii(2, 'L');
 alpha4.writeDigitAscii(3, 'U');
 alpha4.writeDisplay();
 delay(3000);

 alpha4.clear();
 alpha4.writeDisplay();



 //CELL SETUP
Serial.begin(9600);
  Serial.println("Qwiic Scale Example");

  Wire.begin();

  if (myScale.begin() == false)
  {
    Serial.println("Scale not detected. Please check wiring. Freezing...");
    while (1);
  }
  Serial.println("Scale detected!");


  //MOTOR SETUP
  drv.begin();


  // I2C trigger by sending 'go' command
 drv.setMode(DRV2605_MODE_INTTRIG); // default, internal trigger when sending GO command

    drv.selectLibrary(1);
    drv.setWaveform(0, 119);  // Smooth hum 1 - 50%
    drv.go();
    delay(100);


}



char displaybuffer[4] = {' ', ' ', ' ', ' '};



void loop() {
  // read the state of the pushbutton value:
  buttonState = digitalRead(buttonPin);

  // check if the pushbutton is pressed. If it is, the buttonState is HIGH:
  if (buttonState == LOW) {
    // turn LED on:
    digitalWrite(ledPin, HIGH);
```

```
  //turn MAGNETOPOT on:
// subtract the last reading:
  total = total - readings[readIndex];

// read from the sensor:
  readings[readIndex] = analogRead(inputPin);

// add the reading to the total:
  total = total + readings[readIndex];

// advance to the next position in the array:
  readIndex = readIndex + 1;

// if we're at the end of the array...
  if (readIndex >= numReadings) {

// ...wrap around to the beginning:
    readIndex = 0;
  }

// calculate the average:
  average = total / numReadings;

// send it to the computer as ASCII digits
//Serial.println(average);
  int distance = map (average, 20 , 990 , -290 , +210);

// float distance2 = distance / 10;
// Serial.println(distance);
  const float distance1 = -25;
  const float distance2 = 300;
  float distance3 = distance1 + ((distance2 - distance1)* average /1024);
//Serial.println (String(distance3) + "mm");
//Serial.println(readings[readIndex]);

  int distance4 = distance3;

  if (distance4 <= 0){
  distance4 = distance3 * 0;
  }

int thousands = (distance4 % 10000) / 1000;
int hundreds = (distance4 % 1000) / 100;
int tens = (distance4 % 100) / 10;
int ones = distance4 % 10;



  //turn DISPLAY on
// display MAGNETOPOT readings,

 // alpha4.writeDigitAscii(0, thousands + '0');
 // alpha4.writeDigitAscii(1, hundreds + '0');
 // alpha4.writeDigitAscii(2, tens + '0', true);
 // alpha4.writeDigitAscii(3, ones + '0');

    alpha4.writeDigitAscii(0, hundreds + '0');
    alpha4.writeDigitAscii(1, tens + '0', true);
    alpha4.writeDigitAscii(2, ones + '0');
    alpha4.writeDigitAscii(3, '+');
    alpha4.writeDisplay();

  delay(100);        // delay in between reads for stability
```

```
//turn LOAD SYSTEM on
    long currentReading = myScale.getReading();
  int tareReading = ((-132000)-(-123000))/435;
  int weightReading = (currentReading-(-122000))/tareReading;
  if (weightReading > 4000) {
    Serial.print("Weight Reading: ");
    Serial.println(weightReading);

}

    else{
    Serial.print("Weight Reading: ");
    Serial.println(weightReading);
    drv.selectLibrary(1);
    drv.setWaveform(0, 106);  // transition ramp up long smooth 1 - 0 to 50%
    drv.go();
}

  }
```

```
  else {
    // turn LED off:
     if (breathMode && ledState != LOW) {
    if (millis() - lastLedFadeTime > ledFadeInterval) {
      lastLedFadeTime = millis();
      analogWrite(ledPin, ledFadeValue);
      ledFadeValue += ledFadeStep;
      if (ledFadeValue > 255){
        ledFadeValue = 255 - ledFadeStep;
        ledFadeStep = -ledFadeStep;
      } else if (ledFadeValue < 0) {
        ledFadeValue = 0;
        ledFadeStep = -ledFadeStep;
      }
    }
  }
  alpha4.clear();
 alpha4.writeDisplay();

  }
}
```