Appendix

Plastic Identification Anywhere

Project by Jerry de Vos

Appendix

I

Project 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: de Vos 4407
initials: J. given name: Jerry
student number:
street & no.:
zipcode & city:
country:
phone:
email:

Your master programme (only select the options that apply to you):

IDE master(s): ★ IPD ☐ DfI ☐ SPD
2nd non-IDE master:
individual programme: - - (give date of approval)
honours programme: ☐ Honours Programme Master
specialisation / annotation: ☐ Medisign
☐ Tech. in Sustainable Design
☐ Entrepeneurship

SUPERVISORY TEAM **

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

** chair: JC Diehl dept. / section: SDE/DfS
** mentor: Jo van Engelen dept. / section: SDE/DfS
2nd mentor:
organisation:
city: country:

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): Although both JC and Jo are from the same department they both have their own unique focus area, in the case of JC Diehl this is the technical side of the project, for Jo van Engelen this is the business side of this project.

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

APPROVAL PROJECT BRIEF

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

chair _____ date 04 - 09 - 2020 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: 30 EC

Of which, taking the conditional requirements into account, can be part of the exam programme 30 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 J. J. de Bruin, SPA-IO date 08 - 09 - 2020 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 A. Huwae date 15 - 09 - 2020 signature _____

Initials & Name J. de Vos 4407 Student number _____

Title of Project Development of an open source plastic identification tool

Development of an open source plastic identification tool — 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 01 - 09 - 2020 — 01 - 02 - 2021 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, ...).

The amount of plastic products this is consumed around the world is still growing, most of this plastic is burned, piles up in a landfills or ends up in our oceans[1]. This is because there is not enough infrastructure for plastic recycling. Although recycling is becoming more important also new (bio)plastics are being developed making the recycling process even more complicated.

In order to make high quality products from recycled plastic it is mandatory to start with a raw material that is as pure a possible, so pure polypropylene, pure polyethylene. etc. etc. In order to retrieve a high purity raw material, plastic waste needs to be separated according to its primary chemical structure. To do so, plastic products often have markings that indicate what type of plastic it is. (figure 1) That said, not all plastics have it, and it is not always mandatory. This results is a long and slow separation process that takes up most of the time for recycling plastic, making it less profitable.

Many countries around the world (like India and China) do not have sophisticated recycling facilities as western countries have. They depend on independent recyclers in an informal sector that start recycling plastic. Reducing sorting time makes recycling for them much more viable, resulting in a big gain of plastic recycling around the world.

Innovation in the area of plastic recycling needs to happen fast, this because the problem is quickly growing. In order to facilitate fast innovation, development in this area should be shared open source. This drastically reduces the development time of new solutions and allows others to contribute and collectively solve global problems. In order to facilitate this open source way of working a viable business model needs to be developed to sustain the project (product service system for companies, development for other materials or paid extra's)

Partnerships in the field of plastic sorting can be wide based, each partner has key information about plastic, sorting or open source, this can help speed up the development process. to name a few potential partners:
NGO's:
- The Ocean Cleanup, sorting the plastic that comes from the sea
- Precious Plastic, over 300+ independent recycling workspace around the world

Academic:
- Delft Global Initiative, with the plastic free rivers project
- Open Science Community Delft (former DataChampions), With Delft Open Hardware

Professionals:
- Parley, environmental organization to reduce plastic pollution
- Polytential, YES Delft startup specialized in automatic plastic separation

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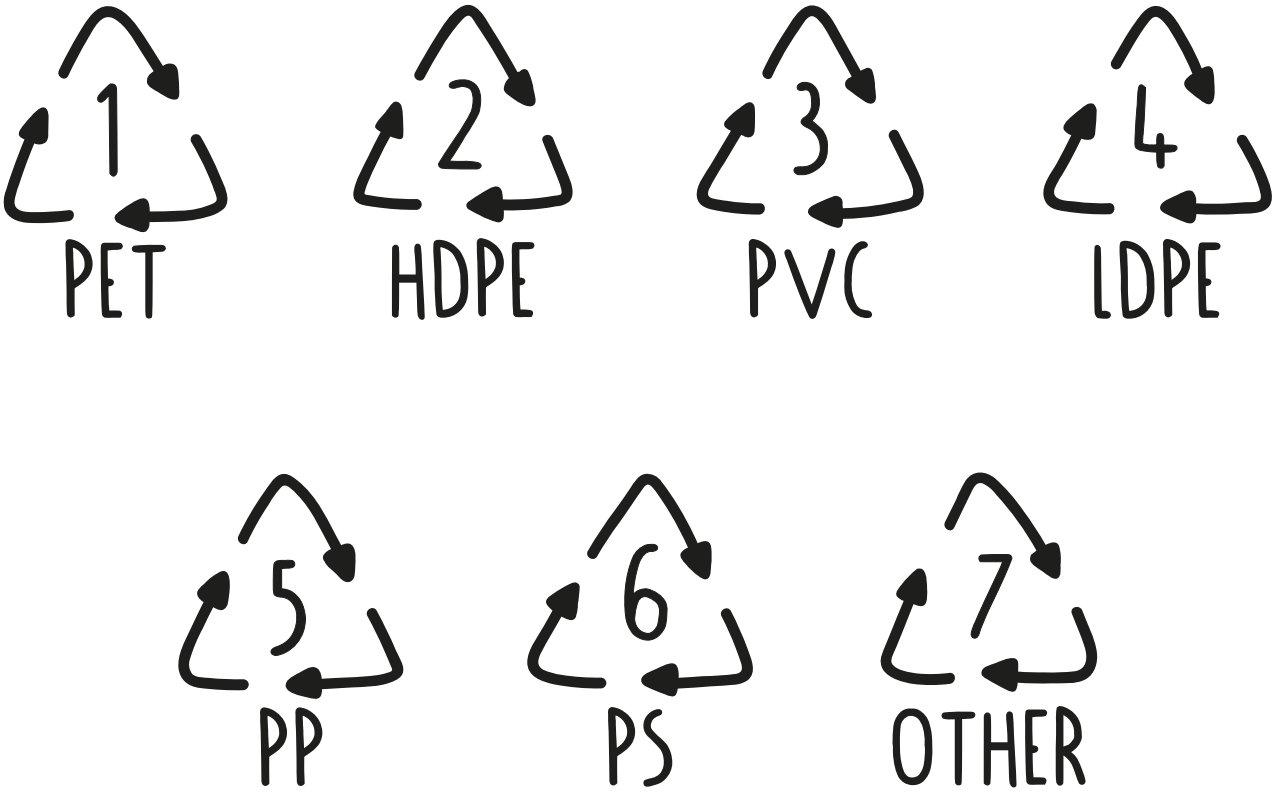
introduction (continued): space for images



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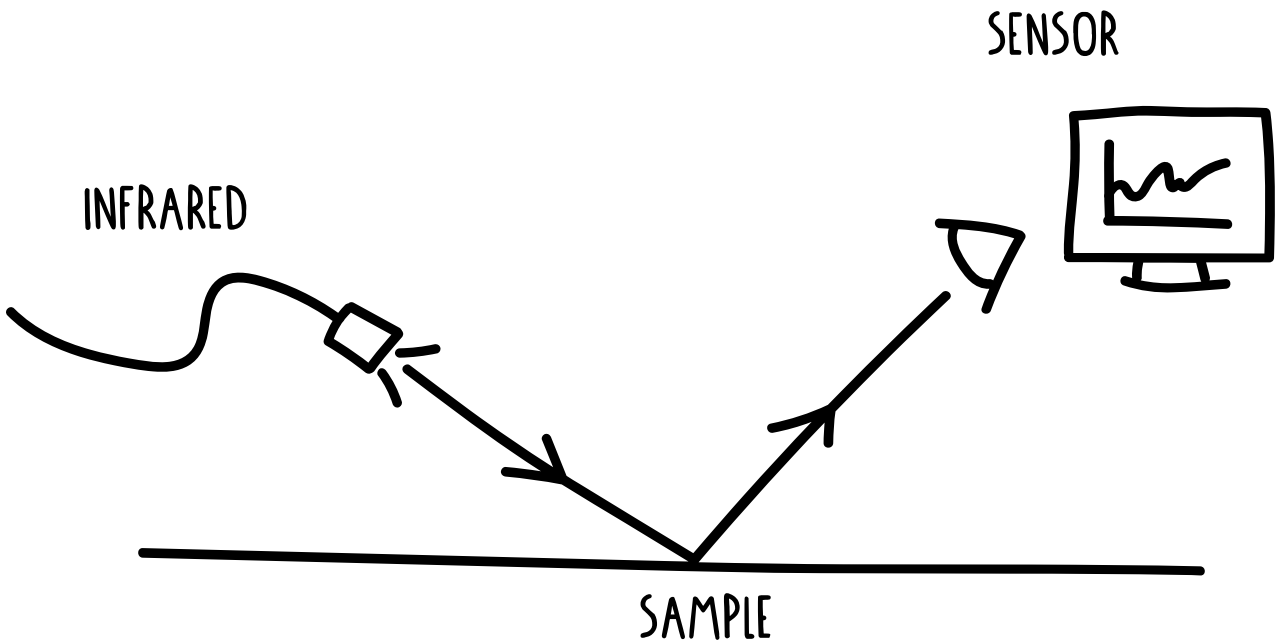


image / figure 2:

Initials & Name J. de Vos 4407 Student number

Title of Project Development of an open source plastic identification tool

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.

The goal of this project is to make the identification of plastics simpler. There are many ways to separate different types of plastics. Recycling industries often have many lines that each take out one specific plastic at a time. For smaller scale plastic recycling this is more difficult because the inflow stream is relatively random and the volume does not allow them do make dedicated lines. An identification method that can overcome this is NIR, Near infrared Spectrometry. This methods looks at a sample and is able to determine what type of plastic it is. (figure 2)

Working in an open source manner has been around since years, it has given light to the most amazing software packages and without it, the whole internet would come to a stop. Where open source started as a digital term in software, it has slowly gained momentum for hardware. Projects like Arduino, Prusa Printers and Precious Plastic. Open Source Hardware really gained momentum in the early days of the Covid pandemic at the start of 2020. Many projects were shared openly online, making it possible to innovate quick and being transparent and verifiable.
Having said that, only a fraction of the open source projects are seen as successful, often it is unclear why some of the project succeed and others don't, to gain a better understanding of this research and validation is required.

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.

Design a product that can identify polymers to help small to medium plastic recyclers to sort plastics. For the verification and continuation of project the contents are shared in an open source manner.

The problem definition consists of two parts, a technical part on NIR spectrometry and a strategic part on open source. Therefor the assignment will also be two sided.

The technical side aims to deliver a cost effective, handheld product that can identify plastic with the help of NIR spectrometry, focused on small to medium sized enterprises.

The strategic side aims to deliver concrete recommendations for good open source documentation by testing various levels of documentation and validating with end users the required level of documentation.

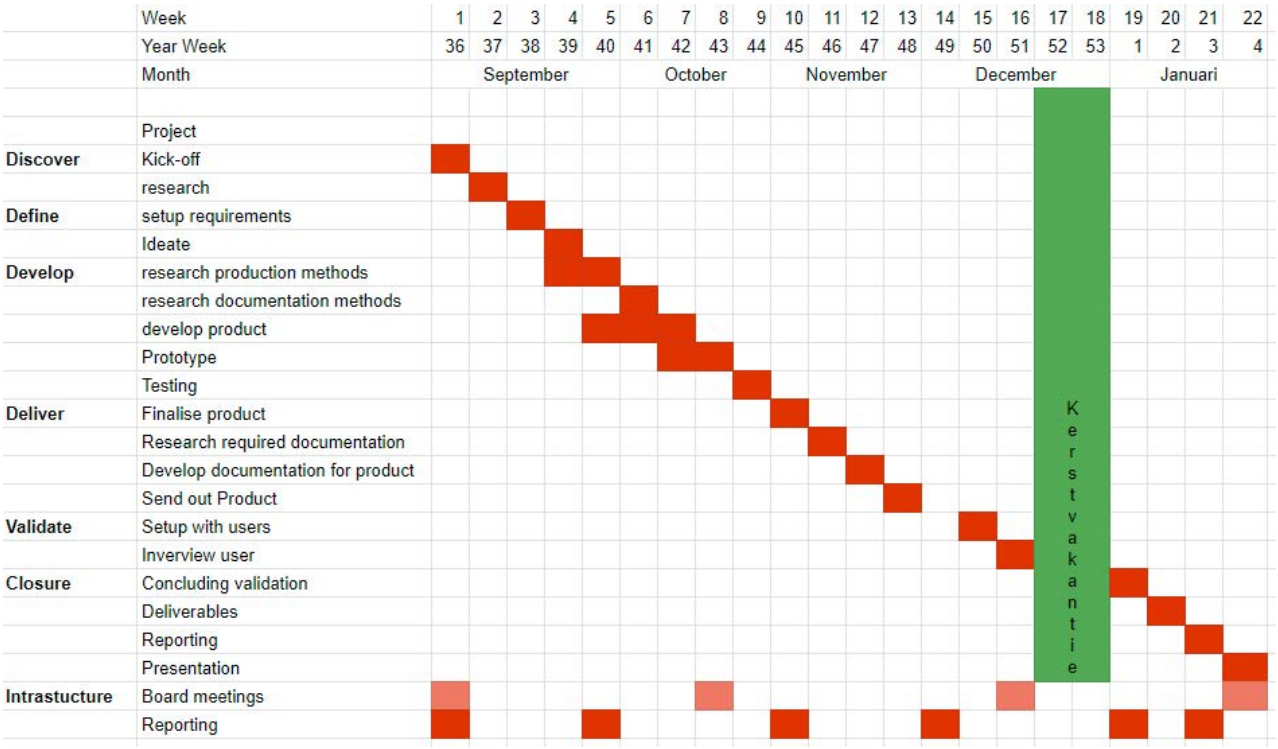
Initials & Name J. de Vos 4407 Student number

Title of Project Development of an open source plastic identification tool

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.

start date 1 - 9 - 2020 1 - 2 - 2021 end date



September - Research, Talking to experts, closing scope

October - Prioritizing requirements developing proof of principle

November - Build and test sensor

December - Validate prototype/level of OS

January - Make it perfect

Initials & Name J. de Vos 4407 Student number

Title of Project Development of an open source plastic identification tool

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.

My name is Jerry de Vos

As a designer I have four focus areas:
- I want to work on sustainable project, project that make the world a better place and not just make life easier.
- I use high tech electronics that bring a new solution space to existing problems.
- I build prototypes and products to validate my assumptions and turn them into facts
- I share knowledge in order for projects to grow and for others to learn from

Based on these focus areas I have developed myself as a professional designer.
- In 2017 I joined Precious Plastic where we make plastic recycling as simple as possible, with this I traveled the world and setup workspaces around the work in for example Maldives and Mauritius, places with huge ocean plastic problems.
- For my bachelor graduation (HBO) I joined the Technical Expert Group at Philips Drachten to research future tech and how Philips can use these technologies in new products
- Over the years I have spend many hours in the workspace, building, testing and developing new prototypes, these can be injection mould for iphone cases from recycled plastic, to microscopes that detect parasitic diseaces or reusing old electronics to fight ewaste
- Lastly I believe that it is time that we crowd solve global problems, sharing insight we find working on sustainable projects and setting aside personal gain for global win. Open source can help with this and resulted in writing a DIN standard on Open Source Hardware (DIN SPEC 3105) and setting up Delft Open Hardware to promote the development of open source projects. And I write a monthly blog where I share my learnings and showcase projects others can build

With my background and skills, I believe that I can take on this project, add value and conclude it in a successful matter.

Within this project I want to develop my knowledge and skills in embedded systems and machine learning together with improving my scientific writing skills.

"Be the solution, not the pollution"
Jerry de Vos

FINAL COMMENTS

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

[1]Production, use, and fate of all plastics ever made, BY ROLAND GEYER, JENNA R. JAMBECK, KARA LAVENDER LAW, SCIENCE ADVANCES19 JUL 2017 : E1700782

Initials & Name J. de Vos 4407 Student number

Title of Project Development of an open source plastic identification tool

Appendix

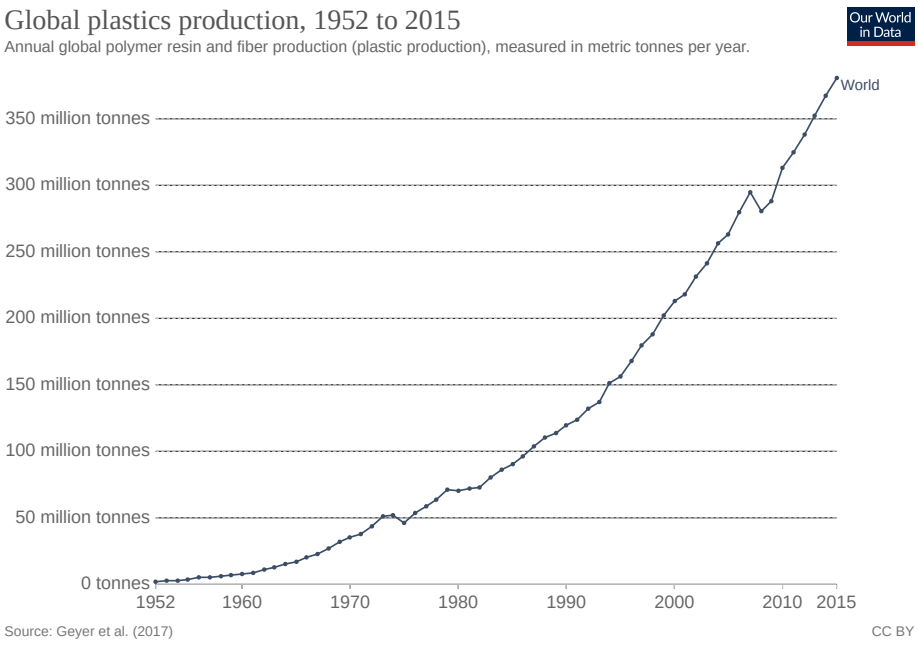
II

Plastic

Appendix II Plastic

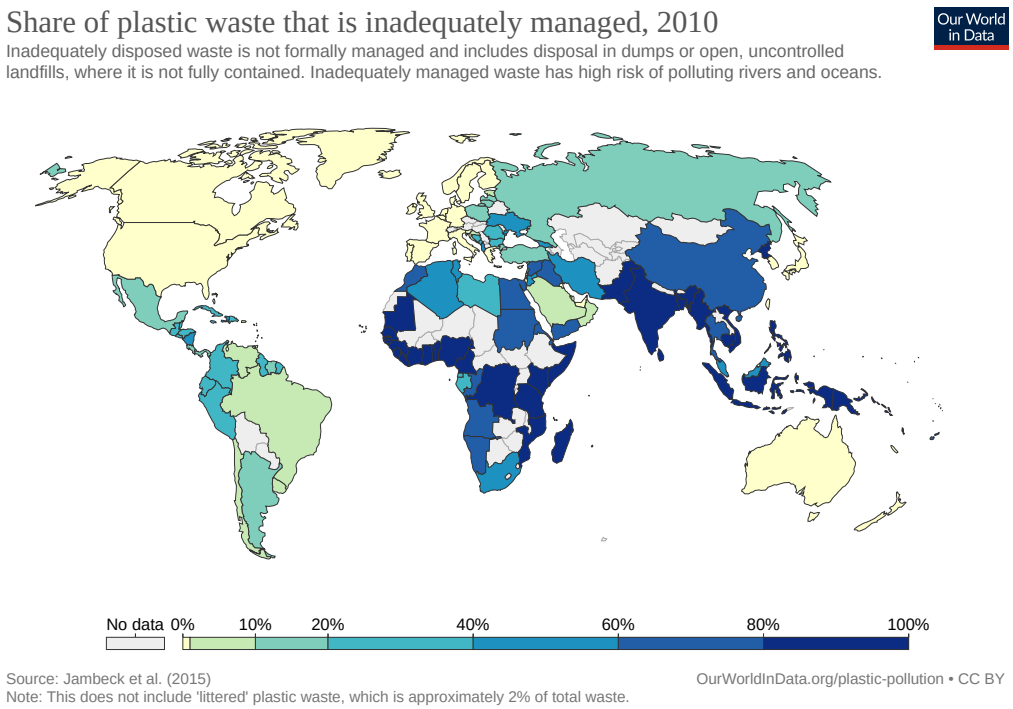
Plastic

One of the most impactful materials from the last century is plastic. Initially revolutionizing the world as a solution for just about anything, recently creating more harm than good. As of 2015, we have cumulatively created 7.8 billion tonnes of plastic, good of at least 1000kg of plastic, per person, alive today. The amount of plastic cumulated around the world is expected to still grow for the coming years, since global plastic production rates are still growing yearly.



After the production and "in-use" time of plastic products, plastic becomes waste. Currently around 55% of the plastic waste is discarded (landfill or lost in nature) , 25% is incinerated and 20% is recycled. (Geyer, Jambeck, & Law, 2017) with the exception of the part that is being recycled, this plastic waste is releasing emissions in our atmosphere, mostly co2 when it comes to incineration, microplastics and other toxins when it comes to landfilling and littering. All this plastic waste is having a negative impact on our oceans and wildlife health (Law, 2017) Most of the plastic that enters the ocean comes from mismanaged plastic waste, this can be through dumping in open landfills,

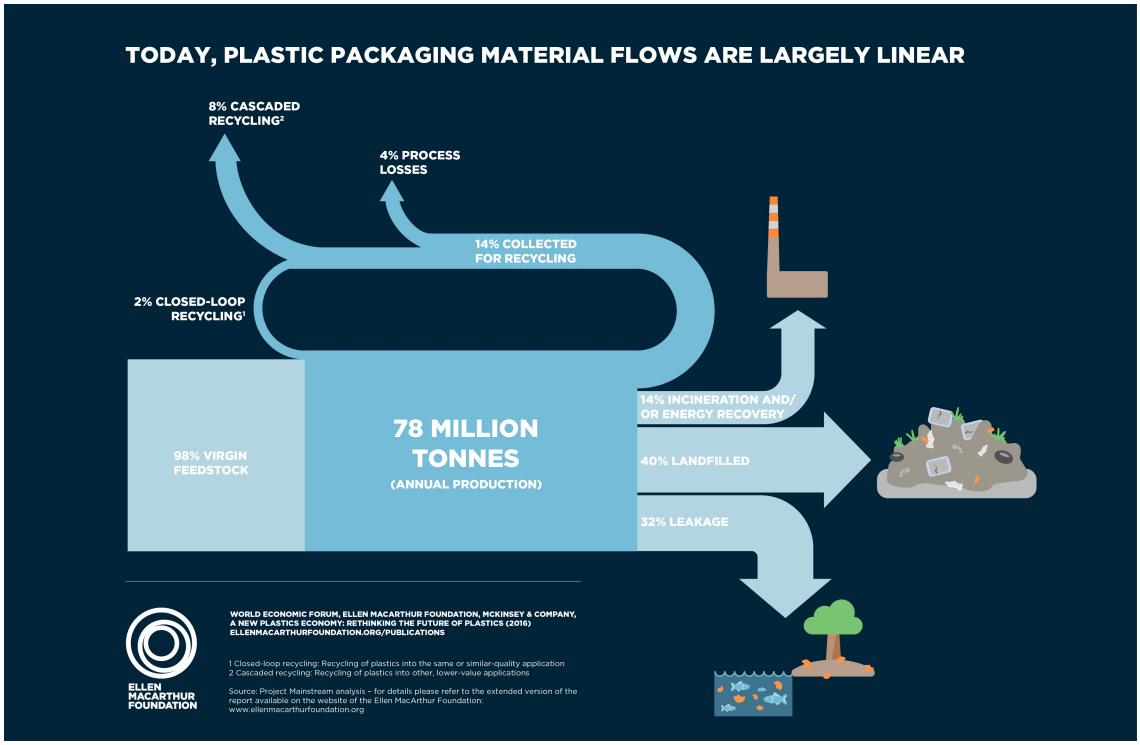
littering or by natural disasters. Mismanagement of plastic is more likely to happen in middle- and low-income countries (Jambeck et al., 2015).



Insight: Plastic pollution is harming our environment, most plastic pollution comes for poor waste management, which mostly happens in Asia and Africa.
Goal: Improve waste management in Asia and Africa
Next step: Research how to improve waste management

Plastic waste management process

Once plastic leaves its "in-use" time it moves to waste management process. The Ellen MacArthur foundation researched the material flows for plastic packaging (the biggest contributor in the plastic waste sector) This shows that just 14% of the plastic packaging is recycled and that 84% of the plastic packaging material is still in a linear process where most plastics are discarded after a single use.



(Ellen MacArthur Foundation and McKinsey & Company, 2016)

Insight: Essential for good waste management is increased recycling
Goal: Improve recycling process
Next step: Research plastic recycling process

Material flow in waste management

Materials and material processes can differ from country to country. Most mismanaged plastic waste comes from middle- to low-income countries. The Indian recycling industry belongs to the informal sector. most recycling units have low fixed capital and are generally run as small family businesses. estimated vary from a few thousand recycling units to tens of thousands micro enterprises engaged in the processing of plastic waste. On the consumption side of the plastic industry the composition of types of plastics looks as follows:

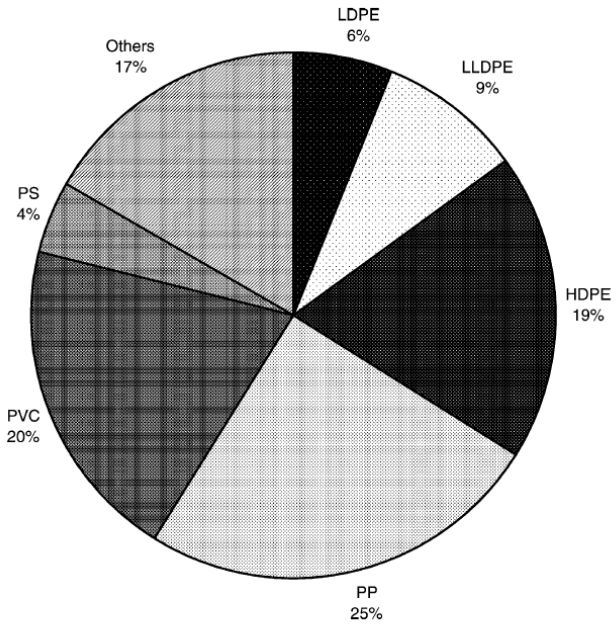


Fig. 2. Consumption pattern in India in 2000 (CPMA, 2000).

(Mutha, Patel, & Premnath, 2006)

> 💡 five different types of plastics make up 83% of the total plastic consumption in India.

Types of plastic recycling

Collection - Sorting - Cleaning - Shredding - Production

Within the context of plastic recycling, there are three main categories: mechanical recycling, biological recycling and thermal recycling. Thermal recycling is the incineration or pyrolysis of plastics to gain energy of fuel. Biological recycling is the composting of biodegradable plastic. Mechanical recycling is the reduction of the plastic particles in order to be used again as a raw material in new products. For the context of this study we are only going to look at mechanical recycling since this is the most common way of plastic recycling (Ellen MacArthur Foundation and McKinsey & Company, 2016)

The mechanical recycling process we generally see the following steps:

Collection → Sorting → Cleaning → Shredding → Production
(where sorting, cleaning and shredding can occur in different order)

Collection

Collection is often done in one of the following ways:

1. Plastic is collected as waste facility, the inflow of types of plastic is unknown, desired plastic needs to be identified and sorted out of the complete mix, plastics are often mixed with other contaminants, people are willing to pay to dispose their waste.
2. Plastic is collected as material facility, the inflow of plastic is specific, often only allow the disposal of one type of plastic or product. Collector knows the value of the plastic, requires relative clean products and is willing to give (small) rewards. Inflow might be contaminated with other materials but is limited or known contamination (e.g. HDPE bottle cap on PET bottle)

> 💡 **Insight:** Selection of the desired material can be before or after collection

Sorting

Sorting plastic is the separation of different plastics based on their physical properties. Main techniques in plastic recycling fit in the following main categories: Optical, magnetism, weight or size

Within the recycling process Sorting is the most predominant factor for the quality of the output product. Contamination in the recycling process can cause serious processing problems later in the production chain (Carvalho, Ferreira, Portela, & Santos, 2009)

Cleaning

Cleaning plastic is relatively straight forward, mostly done with fluid (often water) and a detergent (soap or soda(?))

In small scale plastic recycling, cleaning is often done in a pre shred state. the plastic is de-labeled, washed and dried before being shred into small flakes.

In Industrial scale plastic recycling often an automated process is implemented where plastic is first shred, then cleaned and lastly sorted.

The difference in order is mainly due to the fact that small scale recyclers often rely on hand-sorting where the person sorting the plastic needs to still recognize the type of plastic.

Shredding

contamination of other materials (e.g. metals or stones) can have a big impact on the shredding process. Recyclers that start their process with shredding often do have an inspection phase to ensure stability of the batch/process.

Production

Most places that recycle plastic deliver a semi finished product, this can either be in the form of shredded flakes of one type of plastic with a guaranteed purity level or regranulated pellets ready for production

only a few places have a complete recycling process in house where they also use plastic processing machines to develop an new plastic product

Insight: Quality of plastic recycling depends strongly on the quality of sorting
Goal: Focus on plastic sorting
Next step: research on different types of plastic sorting

Types of sorting methods

Optical - Electro magnetism - Weight - Size

Sorting methods follow up on each other until the desired purity is achieved. depending on the collection system first the plastics from the non plastics are sorted. In the case that the inflow is known, often contaminants are simple to filter out, in the case that the inflow is unknown each piece needs to be examined. sorting can be on type, shape, color or other physical property.

A few of the following sorting methods are also highlighted in a video I made for Precious Plastic last year.

https://youtu.be/T5lAKQij1F4?t=932

Optical

Near Infrared Spectrometry

Reflectance of infrared light determines the type of plastic, it is non invasive but requires a database of known samples

Manual sorting

Person sorting plastic based on marking, shape or size. Requires prior knowledge to identify product based on visual properties. Products often have Resin code on them. Very labor intensive.

Burn testing

Properties of flame and smoke indicate the type of plastic that is burned. although simple it is a destructive test and harmful for operator.

Electro-magnetism

Static

Difference in static behavior of plastics helps to sort different plastics. Separates only two types of plastics at a time and requires high voltage setup.

Magnetic density separation

Plastics are moved through a liquid, this liquid has a increasing density from top to bottom, separating plastics with different densities in heigth

Weight

Air classification

Lighter particles are separated with the help of continuous air flows. An example of this can be a Dyson vacuum. This does not separate on the type of plastic but is able to take out foils.

Sink Float

Similar to magnetic density separation, but with an homogenous fluid of one density. Also separates just two types of plastics at a time

Size

Ballistic separation

Oscillating paddles sort plastic based on their harmonic behavior. separates rigid plastics from flexible or foam products. Does not separate on type of plastic.

Drum Screening

Plastics are moved through a rotating drum with different size mesh, allowing for separation of big and small products. This sorts on size, not on type.

Additives are added to plastics to get their desired properties, this also interferes with the sorting process.

💡 Optical sorting is easily scaled to the desired remand, other sorting methods need bigger up front facilities to sort the plastic

💡 NIR Spectrometry is the most technical, but also the most developing sorting method

Interesting video of most recycling processes combined to sort Dutch household waste

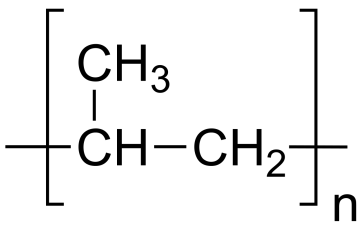
https://youtu.be/WB0nMz8pgdY

💡 **Insight:** NIR Spectrometry seems most interesting for innovation
Goal: Improve NIR Spectrometry sorting methods
Next step: Research the working of NIR Spectrometry

Plastic types

PP

Polypropylene



PS

Polystyrene

PE

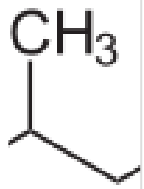
Polyethylene

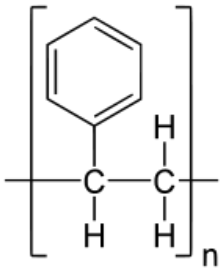
(C3H6)n

Polypropylene

Polypropylene (PP), also known as polypropene,

𝕎 https://en.wikipedia.org/wiki/Polypropylene



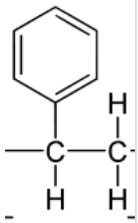


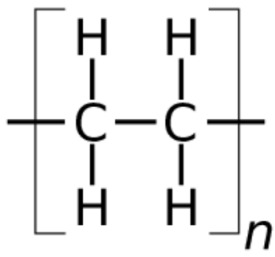
(C8H8)n

Polystyrene

Polystyrene (PS) is a synthetic

𝕎 https://en.wikipedia.org/wiki/Polystyrene



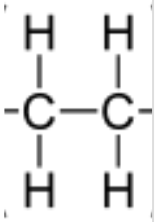


(C2H4)n

Polyethylene

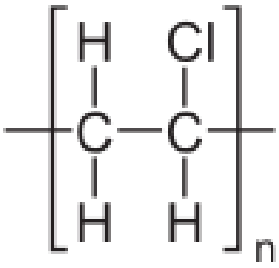
Polyethylene or polythene (abbreviated

𝕎 https://en.wikipedia.org/wiki/Polyethylene



PVC

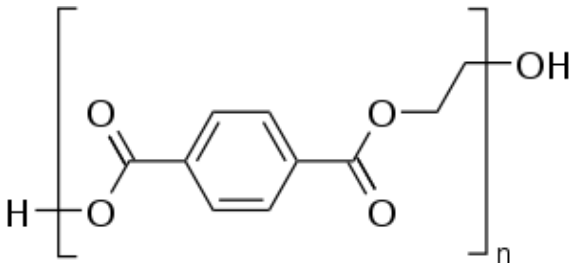
Polyvinyl chloride



(C2H3Cl)n

PET

Polyethylene terephthalate

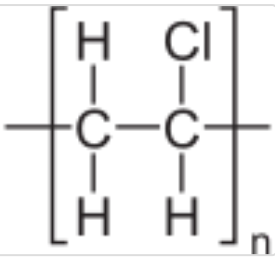


(C10H8O4)n

Polyvinyl chloride

Polyvinyl chloride colloquial: polyvinyl, vinyl ; abbreviated:

𝕎 https://en.wikipedia.org/wiki/Polyvinyl_chloride



Polyethylene terephthalate

Polyethylene terephthalate (sometimes written poly(ethylene terephthalate)),

𝕎 https://en.wikipedia.org/wiki/Polyethylene_terephthalate

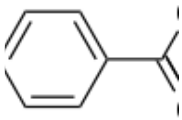


FIGURE 2: MAIN PLASTIC RESIN TYPES AND THEIR APPLICATIONS IN PACKAGING

Source: Project MainStream analysis.

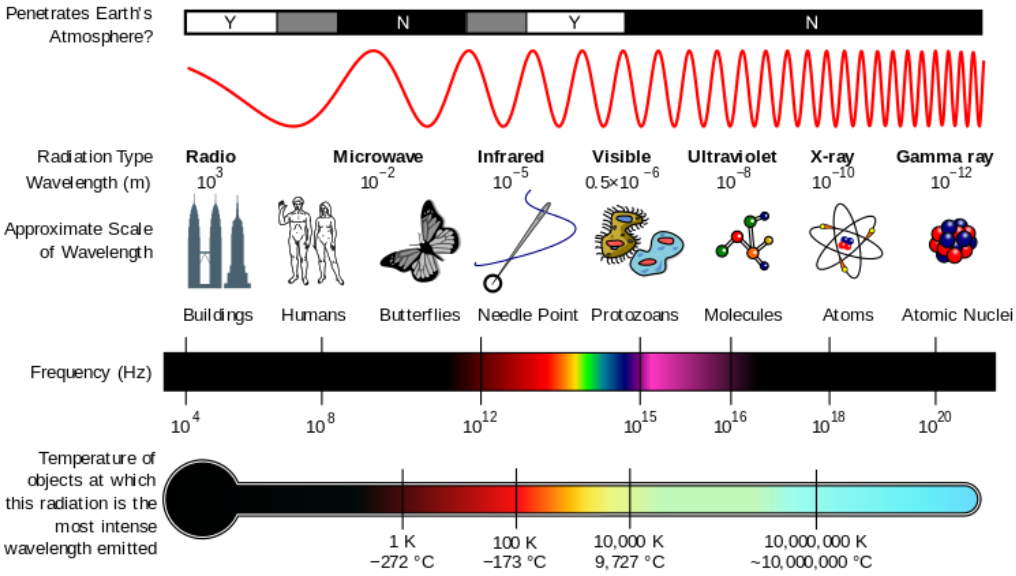
Appendix

III

Identification

Appendix III Identification

Spectrometry is the study of the interaction between matter and electromagnetic radiation. It shoots electromagnetic radiation on an object, the reflection (or transmission) is interpreted and gives information of the object. The electro magnetic spectrum ranges from radio waves to gamma radiation, whereas the near infrared spectrum covers a range of 700 to 2500nm



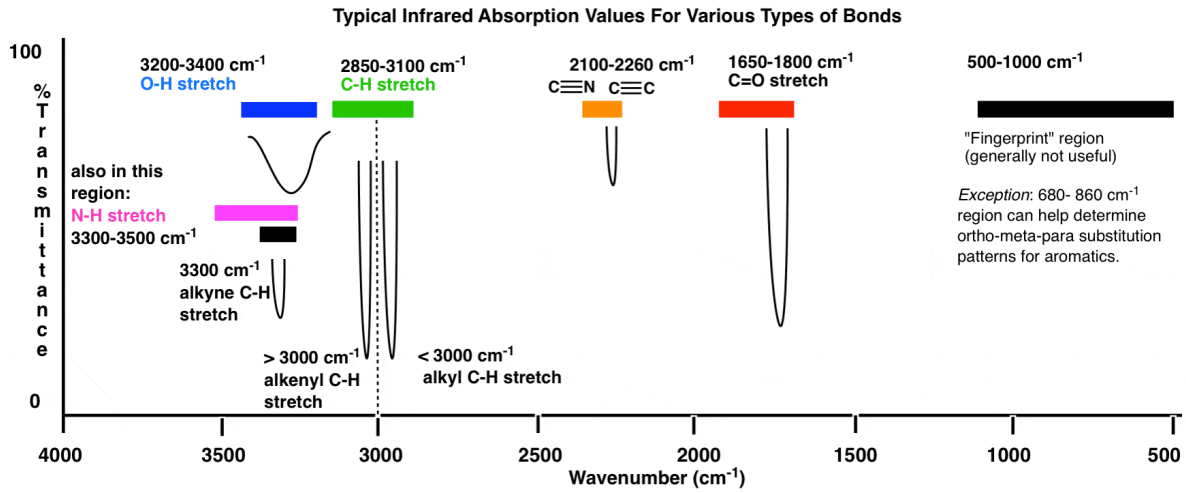
Example: If you look at an object and it appears to be blue, this is because white light shining on the object is absorbed and only blue light is reflected and caught on the retina on the observer. this gives the observer information about the physical properties of the object. the object is blue. The same can be done with infrared light, only in this case the reflection can tell something about the chemical structure of the object.

`wavelenth to wavenumber conversion:`

$$x\ nm = 10,000,000\ /\ x\ cm–1$$

Introduction into NIR

where absorption within the visible spectrum gives information about the color of a product, absorption in the infrared spectrum gives information about the chemical bonds associated with the atoms of a group. Different chemical bonds (like O–H, C–H and N–H) vary in strength and hence the amount of energy required for the bond vibration to move from one level to the next. This variation in energy will be seen in a spectrum as a series of absorptions at different wavelengths. (Davies, 2005)



Plastic identification with NIR

Near infrared spectrometry can be used to identify different types of plastics since different types of plastics have different absorbance peaks, for example: PVC has an absorbance peak at 1660nm and PET has an absorbance peak 1716nm. Bases on this principle D.M. Scott was able to successfully separate PET from PVC in 1995. (Scott, 1995)

Limitations of Plastic identification of NIR

Black samples (carbon black additive)

Carbon black tends to absorb all of the infrared light, making it difficult to interpret the reflectance.

Thickness of sample

Solved by looking at the absorption rate in stead of value (Lambert- Beer Law)

Influence of external light

Various ways to fix, like IR remote or black box

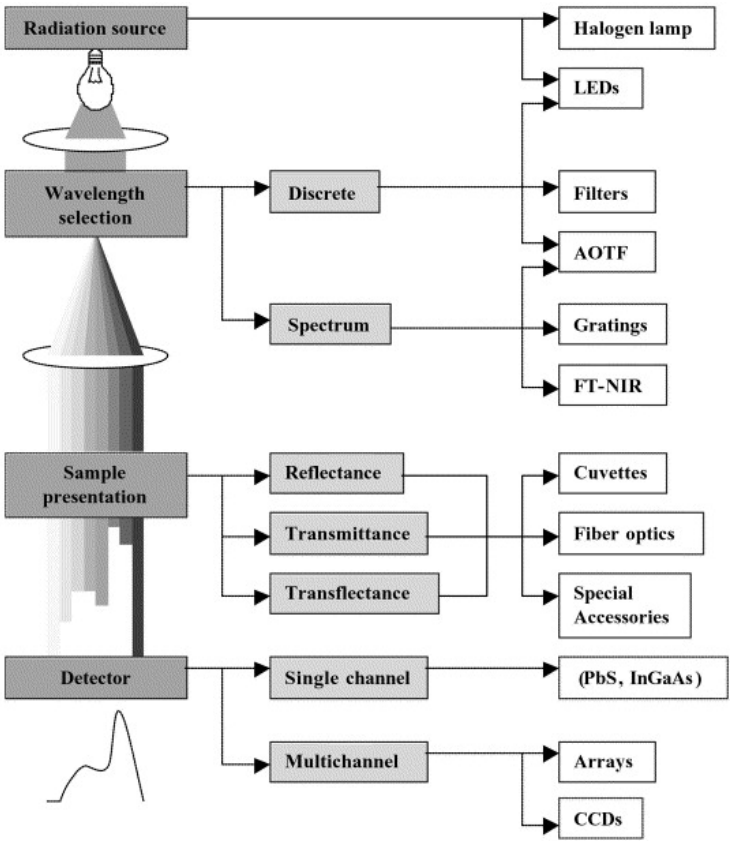
Requirements of reference samples

Identification is based on known samples, the quality of these samples have influence on the prediction of the samples plastic.

Anatomy of NIR spectrometers

In the last 25 year many Near infrared spectrometers are developed for a wide variaty of applications, from pharmasutical, to aggroculture to polymer identification.

the principle of nir spectormetry stays the same; shine light at a sample and sense which wavelengths are absorbed in the reflection. In practice this can be done in various ways:



Descrete vs spectrum anaysis

Discrete analysis looks at just enough specific wavelengths to discriminate different plastics

Spectrum analysis collects the full range of wavelengths and plots a graph of absorbance

light filtering vs sensor filtering

to distinguish different wavelengths either the radiant source (light) needs to be filtered, or the sensor needs to be filtered.

light filtering can be done by using (multiple) lights that shine at a specific wavelength one after each other.

sensor filtering can be done with the help of filters or prisms, filters filter out specific wavelengths. these filters can be multiple fixed filters, linear variable filters or Acousto-optic tunable filter. Prisms can be grating prisms or optical prisms(?)

Conclusion

Within the scope to trying to tackle plastic pollution a further focus area has been applied. The biggest impact can be obtained by providing better waste management in middle- to low-income countries. Plastic recycling seems the area that can benefit the most from innovation. Within plastic recycling, mechanical recycling is the most widely used and can easily be integrated by others. Five different types of plastics make up 83% of the total plastic consumption in India. Near infrared spectrometry can make a distinguishment between these 5 plastics.

Plastic pollution

Improved waste management in middle- to low-income countries

Plastic recycling

Mechanical recyling

NIR infrared

Identification of 5 most common types

💡 Design goal: to identify opportunities within the context of plastic recyclers in the global south that apply mechanical recycling of the five most used plastics (PP,PE,PS,PET,PVC)

https://plotly.com/~jerzeek/1/?share_key=xnn5xoNI9B57UnK12VUqdk

Spectral reflection analysis - Graph 1

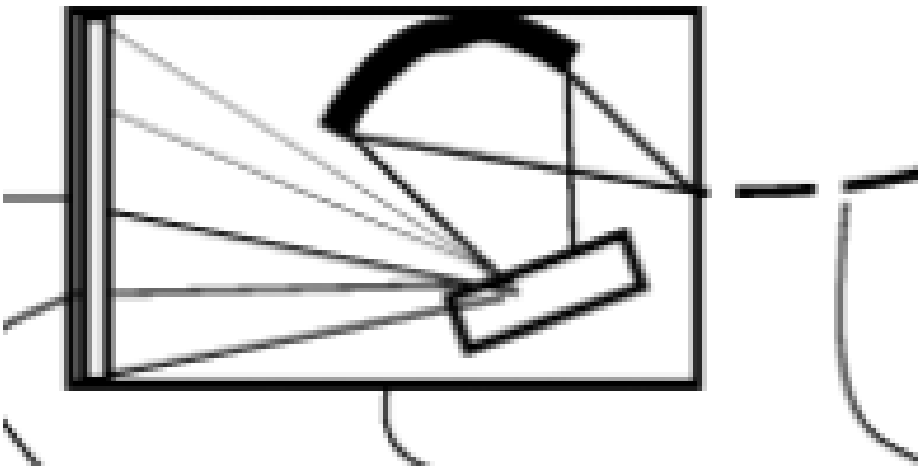
ReReMeter

The market analysis shows that the ReReMeter is currently the most low cost and most open to development product in the field of NIR Spectrometry

How is it low cost?

What sets the ReReMeter apart is the fact that it does not collect full spectrum information.

Traditional IR spectrometry is done by shining a mixture of IR light at a sample and sensing the defracted reflection. This allows to collect full spectrum information but also requires sensor arrays and grating optics. `add picture to explain`



In 2012 Masoumi et al. showed that it is possible to separate 5 types of plastic by observing the relative reflection ratio between just two wavelengths, 1656 & 1724nm (Green lines in graph).

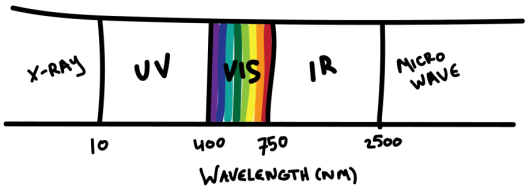
Based on this concept Straller and Gessler developed a discrete NIR spectroscope, The ReReMeter (2019). The working principle is flipped where not a spectrum of light but only a specific wavelength is shined on a sample. The refection is captured with a single pixel sensor. This reduces the cost for optical components and sensor arrays in the product, only specific wavelength infrared LEDs need to illuminate the sample one by one. `add picture to explain`

Their current prototype is able to distinguish samples of PET, HDPE, PP and PS. with IR LEDs at 850,960,1200,1300,1450,1550 and 1650 nm (Pink lines in graph). The recommendations of the paper are to reduce the influence of external light and addition of extra wavelength LEDs

Explaination

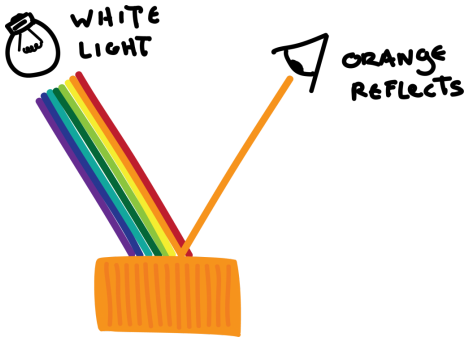
The technology to identify plastic is near-infrared spectroscopy. Spectroscopy is the study of the interaction between matter and electromagnetic radiation, near-infrared indicates the wavelength range, so between 750nm to 2500nm.

electromagnetic specturm



To help you understand near-infrared spectroscopy, I will give examples where I replace IR light with visible light, this is just a shift in the electromagnetic spectrum. The visible spectrum ranges from 400nm to 750nm.

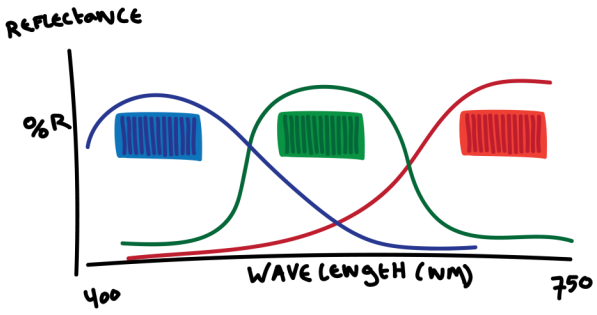
Observing an orange bottlecap



If you see an object, you see it because light is reflected off it into your eye. If you shine white light on an object, all the different wavelengths get absorbed and only the wavelengths of the color of the object are reflected back in your eye. Thus, you can see that an object is orange.

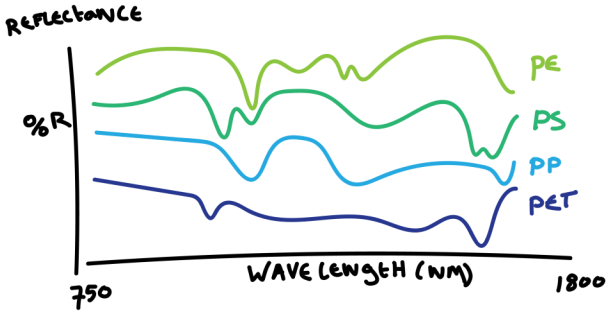
If you replace your eye with a spectroscope in the image above you get different graphs for different colors of bottle caps.

Different color bottle caps give different reflection curves on a spectroscope



The same can be done with infrared light and plastic objects. If infrared light is shined on a plastic object, some of the wavelengths are absorbed and some are reflected. Different chemical bonds absorbe energy differently, resulting in dips in reflection. Based on this you can start to see the differences between different types of plastic!

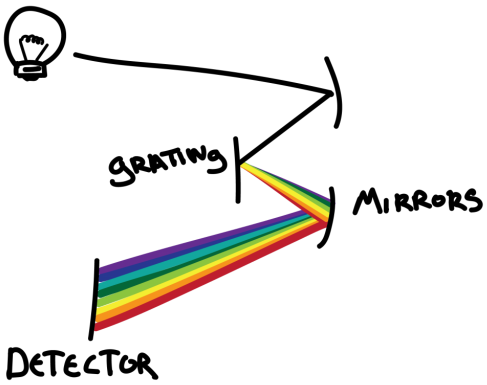
Different reflection curves based on chemical structure.



At the end of the blog there is a link to more detailed information

Big recycling infrastructure has been using this technology for a while. the spectrum of the plastic waste is collected and based on that sorted, often with compressed air.

Splitting light and detecting the different wavelengths.



Even handheld scanners are available that can identify 30 different types of plastic, like for example

this one

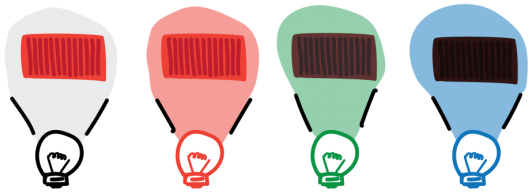
. A slight downside, these start at 50.000 euro. A 50.000 euro scanner is not viable for plastic recyclers all over the world. for this, the price should go down by around 100 times at least. The most expensive components in these scanners are the optics and the sensors. The mixed infrared light needs to be split into different wavelengths (as a prism does with visible light). The intensity of these different wavelengths is measured individually and gives the reflection chart you can see above. The splitting of the light can be done with traditional optics but also with MEMS sensors. A simplified view of how this is split can be seen in the image below.

If you look at the reflection curves of the different plastics there are a few distinct dips. Based on that knowledge, Masoumi and Safavi researched to see if they could separate common plastics with just two wavelengths, they made two filters that blocked all wavelengths except 1656nm and 1724nm. based on the ratios between these values they were successful in sorting plastic, hurray!

(link to the paper at the end)

The downside was that they needed very complex and precise filters, still very expensive.... To significantly reduce the price, Straller and Gessler set out to develop a low-cost solution. They basically turned the mechanism upside down, instead of filtering out specific wavelengths, why not send out specific wavelengths. They gathered common IR LEDs with specific wavelengths and used these for reflection measurement.

A red object reflects strong with red and white light, but weak with green and blue filtered light.



To give an example with visible light, you can think of it this way: If you shine all wavelengths on an object (white light) it reflects the wavelength of its color(red). If you shine a red light on a red object, the reflection will be very strong, this will be less with green and blue filtered lights.

In order to make the product work, different wavelength LEDs are shine on an object one by one, and each time the intensity of the reflection is measured. NIR LEDs that are easily available are 1650, 1550, 1450, 1300, 1200, 1050, 950, and 850nm.

This results in 8 measurement points on the reflection curve, enough to identify the five most common plastics!Until next time, Jerry

Market analysis

Name	Contact person	Data sheet	Price	Type	wavelength
MicroNIR	Taylor Hogarth - CAE	micronir-onsite-w-data-sheets-en.pdf	€15,000.00	128ppixel spectrum, with linear variable filter	950-1650
ReReMeter			€500.00		
Thermo Fisher	Ronald van de Laak - Beun de Ronde	microPHAZIRPC-handheld-plastics-analyzer.pdf	€30,000.00	diffuse reflectance	1600-2400
trinamiX Near-Infrared Spectroscopy			€2,500.00		
Polytential		Virtual-Chemist-1.3-Datasheet.pdf			
Matoha		90e52b_3566f994b6be4a77a4af3a1461876406.pdf			
Stellarcase	Stephanie Boxel - Stellarcase	StellarNet-StellarCASE-NIR-SPEC.pdf	€20,000.00	512pixel ingaas detector optical	900-1700
NIRvaScan		QuickGuide-NIR-M-T1_QSG_20180515-ASP.pdf	€2,000.00	TI - mems ingaas 128 pixel	900-1700
SCiO			€2,000.00		

Name	Contact person	Data sheet	Price	Type	wavelength
Recycling Identifying Device			€0.00		
Hamamatsu	Arie van Gool - Hamamatsu Photonics Deutschland GmbH				
AgroCares			€3,000.00	MEMS,Spectrum	
NeoSpectra	Ruud van de Noord - Te Lintelo Systems	NeoSpectra-SWS62231-Datasheet.v2-2.5-22-19.pdf	€2,950.00	MEMS,Spectrum	1350-2500
Untitled					

Appendix

IV

Anywhere

Appendix IV Anywhere

Literature - Personal - Interviews - Media - Conclusion - Sources

Literature on waste management in low- to middle-income countries

Products will always see an end-of-life phase, whether it is in a linear or a circular economy. what happens in this phase is critical for the affects is has on mankind and the environment. Proper waste management and especially solid waste management has the biggest impact on reducing pollution in nature.

Over the years there has been a lot of research in effective solid waste management and research in material flows and waste management in low- to middle-income countries the following paragraph shows examples of literature research in Asia with a specific paper on India, Africa with a specific paper on Kenya and a paper on solid waste management in Trinidad and Tobago.

Asia

Plastic solid waste has grown to 15% of the total solid waste in 2012. The main role in solid waste recycling in low income countries is done by the informal sector, these involve scavengers and waste pickers. A simplified overview can be found here:

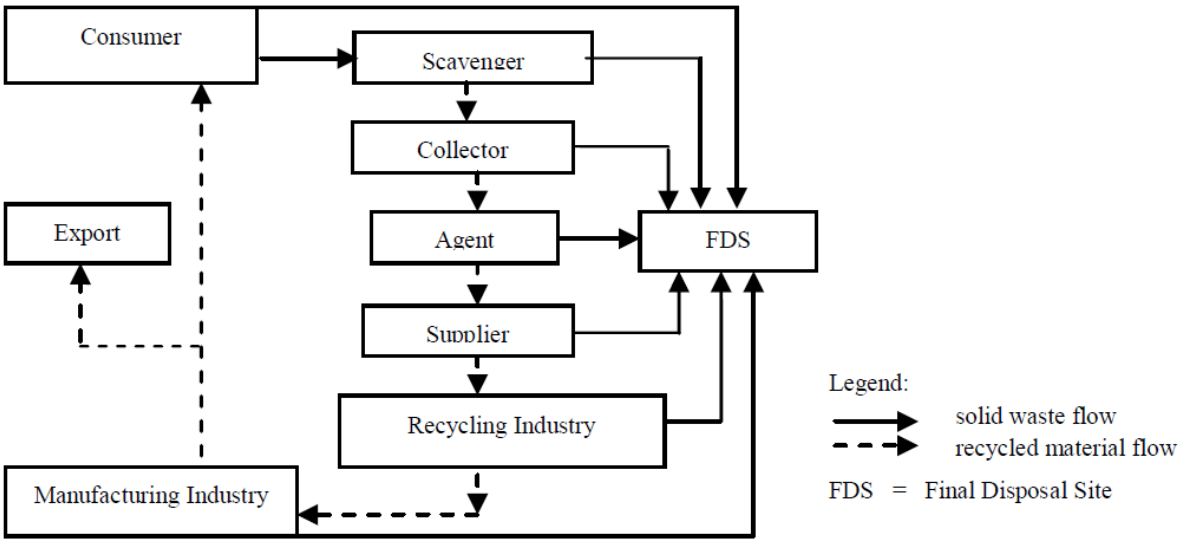


Figure 1. Informal sector role in municipal SW reduction [19]

(Dhokhikah, Yeny & Trihadiningrum,2012)

Plastic waste from consumers go through many actors before ending at the recycling industry, each with their own specialization.

India

Plastic consumption in India is expected to grow by a factor of 6 between 2000 and 2030, Most of these plastics are PE, PP and PVC. It is expected that the market share of PVC will decrease slowly and will be replaced by PP and HDPE

75% of the plastic processed is extrusion based, think of wires, pipes, films, sheets or profiles.

The recycling sector in India has developed autonomously, mainly due to the low cost of labour and the fairly large market for second-grade products.

In India, households segregate most of the plastic products, e.g. bottles, footwear, etc.,
after use and sell them to intermediate dealers. although lightweight and dirty plastics are still disposed together with the household waste.

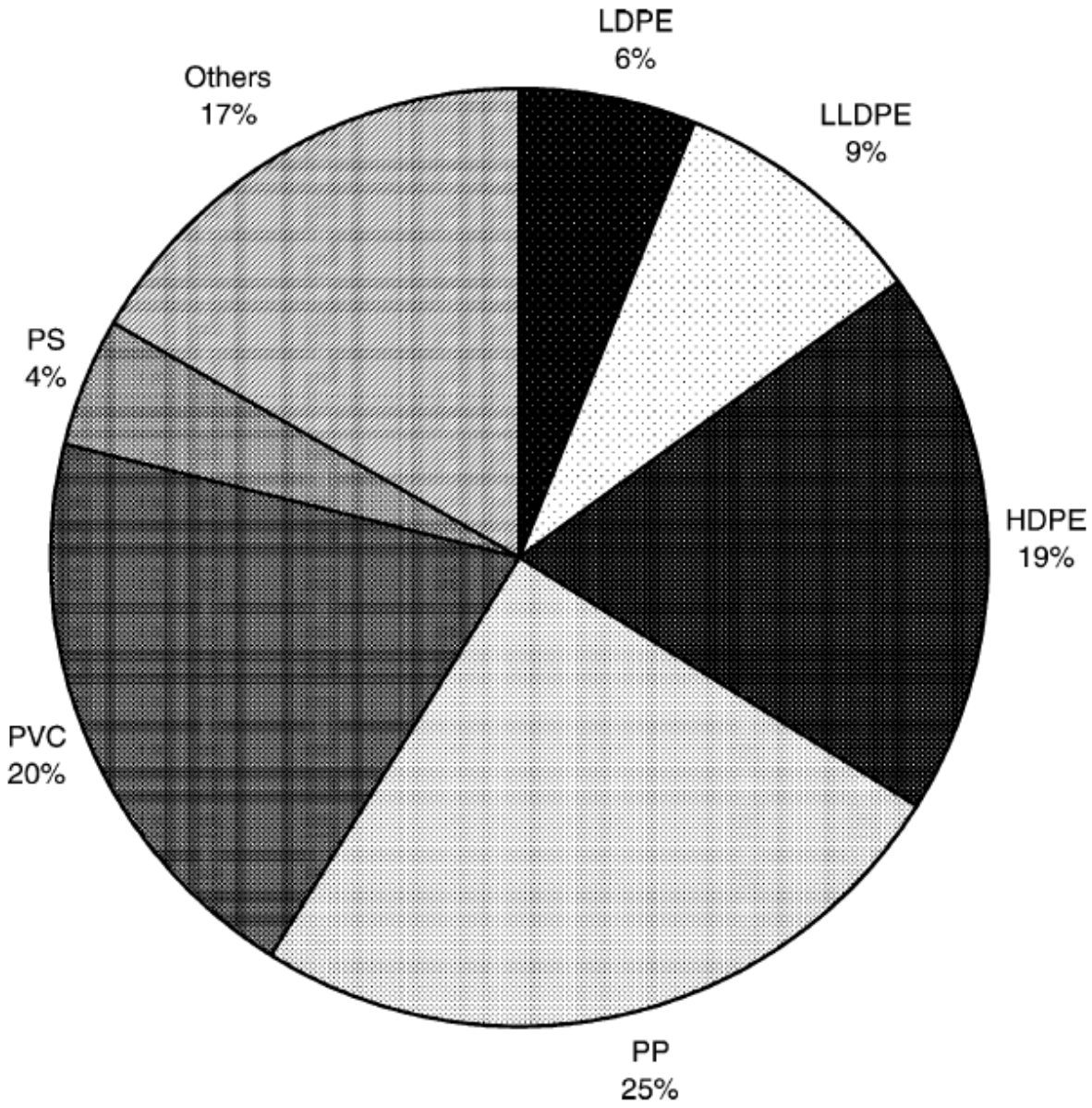


Fig. 2. Consumption pattern in India in 2000 (CPMA, 2000).

In general the flow of plastic looks like this:

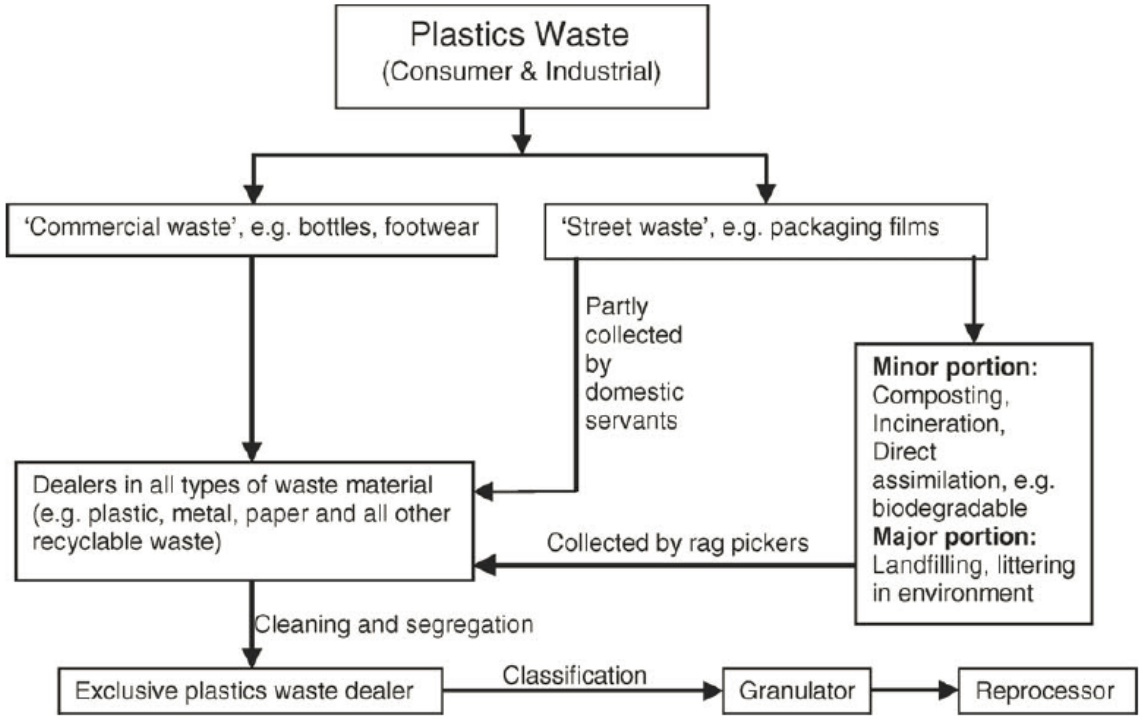


Fig. 7. Flowchart for the plastics waste.

Most of the recycling units have very low fixed capital, are often run as a family business and are not registered as enterprises. Thus the actual size of the Indian recycling sector is hard to estimate. If compared to the plastic production industry around five times more people work in the plastic industry in India compared to the Netherlands. This factor can also be used as an indication of the size of the Indian recycling industry. (Mutha, Patel, & Premnath, 2006)

Most recycling units in India have low capital, the units cannot afford expensive equipment

Both the informal sectors (garbage collectors, waste pickers, waste dealers, small stores and itinerant merchants) and the households in India, play a vital role in recovering consumer waste. An overview of main actor(groups) is shown in the figure below

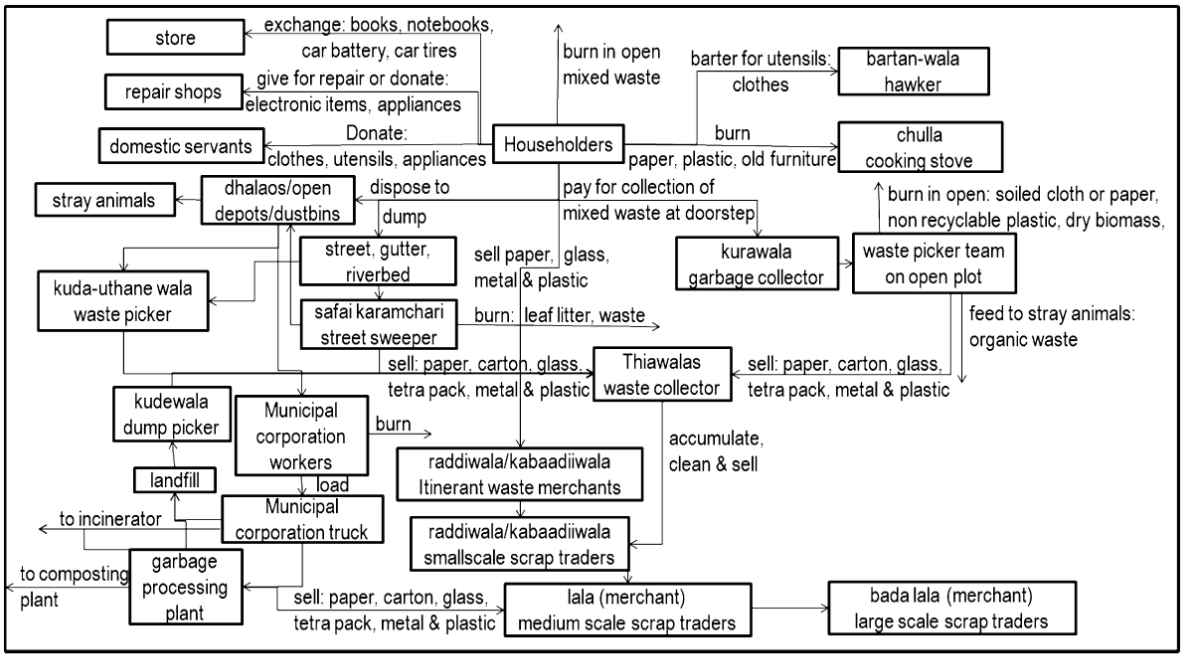


Fig. 1. Real-world waste disposal scenario in India.

The raddiwala

Is the itinerant waste merchant, usually owns a bicycle, purchases recyclable materials from households and stores, and sells large quantities of well sorted clean material at a higher price to a specialized waste trader (kabaadiwala)

The kude-uthane walas

Mostly work on bus terminals and in train stations, on streets, on markets, on illicit dumping grounds, around municipal waste collection points and on municipal landfill sites. Take out materials that are clean or easy to sort and recycle, like cardboard, metal, glass or plastic.

The kurawala

collects mixed soiled waste ate the houses, they have their own tricycle, their own territory and are paid a small monthly fee by the households.

The thiawala

accumulate, sorts and cleans wet or soiled waste stream items and sells to kabaadiwala

The kabaadiwala (overarching name for recycler according to Prad)

scrap dealer

The kabadiwalas

Accumulates further and sells to recycling plants.

> 💡 Recycling industry in India is quite mature, all actors have their own defined role together with their own specific waste stream.

The households that do recycle part of their plastic waste, segregation at source is usually restricted to a minor fraction of the overall plastic waste generated (e.g. old buckets, canisters and boxes and occasionally bottles) but not polyethylene bags and packaging material. Garbage collectors collect more than 70% of the plastic that is thrown in the mixed household waste, Packaging is the most important application area for plastic in India, accounting for over 40%.

Despite being illiterate, they are well informed about the economic value of the material they recover. The expectations of most garbage collectors and their teams are moderate. The garbage collectors covered in our study, daily sort through approximately 100–200 kg of mixed waste to ultimately recover 50–80 kg of soiled recyclables which they sell at a rate of ~4 INR/kg to earn ~200–300 INR/day (~3–5 USD/day at a conversion rate of 60 INR/USD). (Nandy et al., 2015)

Africa

In densely populated residential areas there are significant challenges in solid waste management. Companies like Wecyclers and Recycle Points(Nigeria) TakaTaka(Kenya) PolyCo(South Africa) have started to collect recyclable materials like plastic bottles glass and cardboard. This is done directly from households and are incentivized with awarded points. Proplast was one of the first who started plastic recycling in 1997 in Senegal. Other projects are SoleRebels, EcoPost, Ocean Sole, Repurpose Schoolbags, All Woman Recycling.(Jambeck et al., 2018)

Kenya

For two decades solid waste management systems of east African major urban centers have been below par. This is due to a lack of human,financial and technological resources. Since 1980 individual waste pickers, yard shops and small-scale traders have been selling unprocessed plastic waste to plastic producers in Kenya.

There are three main actor groups within plastic recycling in Kenya

community based organizations

Collect plastic, sort by colour and type, bulk and sell

collect from household

less than 250 kg per week

funded by NGO's

motivated by social and environmental issues

community based organizations & Savings and Credit Cooperative Societies

Collect plastic, sort by colour and type, wash dry and semi-process and pack.

collect from households or community based organizations

around 1000 kg per month

mostly funded by NGO's

motivated by economic empowerment

Yard shops

Sort plastic by colour and type, wash, dry and bulk.

Get plastic from wastepickers, supermarkts or manufacturing industries

collect over 1000kg per week

funded by family business

motivated by employment of family

💡 Economic standpoint drives local people to get started, mainly in the informal sector. Most NGO's start from social or environmental standpoint.

Informal actors are often faced with deplorable working conditions, lack of clear guidelines and lack of governmental recognition. Formal industrial actors face governmental policies that have not been sensitive to recycling trajectories. And all actors lack incentives and converging expectations of preventive solutions. (Oyake-Ombis, Vliet, & Mol, 2015)

Trinidad and Tobago

The management of plastic is a practical issue for Trinidad and Tobago, it accounts for 19% of the municipal solid waste. there is a lack of environmental protection. Most common plastic waste in Trinidad and Tobago is PET, HDPE, PP, LDPE, PS. (Millette, Williams, & Hull, 2019)

💡 Plastics used in literature about waste management in low- to middle-income countries are: PP,(HD&LD)PE, PET,PS,PVC

💡 Each country has its own context and details that make the waste management unique, but overall waste management in low- to middle-income countries is based on an informal sector with many small players that each sort and segregate their own material.

Personal experience on recycling in low- to middle-income countries

In the past years I have helped setup different recycling workspaces around the world each workspace in a totally unique environment and with it's own context. This has given a better understanding on waste management in low- to middle-income countries

Kenya - 2018

In cooperation with UN-Habitat created a plastic recycling workspace in Kisii, Kenya. Trying to tackle plastic pollution as well as youth unemployment. Points worth mentioning: Bureaucracy slows down many things, tribes play a huge role for the social dynamics, create incentives for the people, main types of plastic were HDPE and PET, collection of plastic can be hard, people easily see dollar signs.

https://www.youtube.com/watch?v=4aPR45Dju-w

Littering in Kenya

Plastic Sorting

Landfill Dandora

Maldives - 2019

In cooperation with Parley build a Plastic recycling workspace in a shipping container. Although small, the capital of the Maldives (Male) is overflown with plastic, either from personal consumption or because of imported goods for tourists. Points worth mentioning: Transforming and shipping a container is simpler than you think, designating one island for trash sort of helps, PET is the most common used plastic, quite structured waste management.

https://www.youtube.com/watch?v=Pf-foTVBmMQ

Plastic entering the ocean

Landfill Thilafushi

Plastic sorting

Mauritius - 2020

As a sponsorship from the International Olympic Committee a team of volunteers setup a workspace in Blue Bay, I joined for a month to help. Points worth mentioning: People realize the problem and are willing to volunteer, politics do not always realize the problem and take a long time to cooperate, PET and HDPE are the most common types of plastic, plastic recycling is not always priority.

https://www.youtube.com/watch?v=wYrl07crlHg

Washed up plastic.

Collection system

Sorting system plastic

💡 The demand on new recycling initiatives is ever growing. More and more people and governments want to start recycling and improve the recycling infrastructure. Precious plastics workspaces are a great mix between education, local manufacturing, social empowerment and recycling infrastructure.

Interviews with recyclers in low- to middle-income countries

Apart from the written literature and personal experiences in low- to middle-income countries a better understanding of the situation is gained through interviews. Although interviews are very explicit and only show a glimpse of the whole situation does add to a more complete picture of the waste management in low- and middle-income countries. Four vastly different recycling workspaces at different locations in the global south were interviewed on their background and process.

The interviews show what motivated them to get started recycling plastic, what difficulties they faced and how they fit in the local waste management system. This also provides a starting ground for later collaboration and user testing.

Robries Gallery - Indonesia

Background - Resulting from a graduation project Tita started her own plastic recycling business in Surabaya named Robries Gallery. In the beginning it was difficult to get project and it needed a lot of convincing people, mainly because it was more expensive than wood, recently it is becoming easier to find and maintain projects.

Team and workspace - The team consists out of 4 people, it is based on a university campus area within the city. 400kg of plastic recycled each month, they work 6 days a week. Inventory consists of a shredder, extruder and sheetpress. Typical product like their chairs go for around 40 dollar a piece.


Tita robries

Material supply - Raw material for production is bought from local collection point. PP and HDPE are the most common plastics and are readily available as recycled material, recycled PET is processed by big companies or exported to China. Material comes in shredded flakes and is not guaranteed good quality or purity. It is also possible to ask scavenger to a specific color or type, and they will collect it for you, but more expensive. Plastic is bought for around 1 dollar per kg.

Waste management - In Indonesia there are many scavengers that pick the waste and sort it, they bring it to a collection point. They feel type of plastic by hand, or sometimes to burn testing. They pick it up from households, streets or landfills. Tita is happy to connect me with scavenger if I have specific questions.

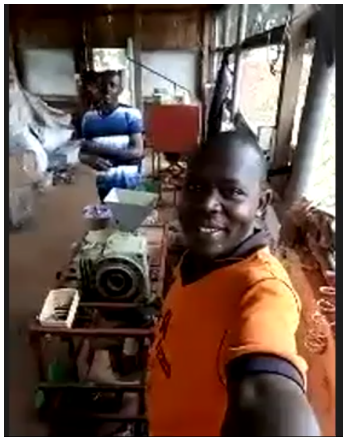
Precious plastic Kisii - Kenya

Background - Precious plastic Kisii got started as a pilot project, a team from the Netherlands helped to set it up and educate the local population on how to recycle plastic. As part of a UN habitat

Team and workspace - Manduku together with two others maintain the project. even though resources are low they manage to keep the machines running and have a video call with me. their inventory consists of a shredder, compression machine, injection machine and extrusion machine. HDPE and PET is mostly used for making bowls, wire is extruded and braided into bowls. het sells the bowls for around 30 dollar(?) Usually works around 2 or 3 days a week.

Material supply - The team collect their own plastic from the dumpsite. At the dumpsite all useful plastic is collected and cleaned. Once brought back to the workspace it is sorted according to type of plastic (PP,PE,PS,PET and MIX) Plastic is sorted based on resin codes on the product, if not present they use a sink-float method. They shred the plastic at the workspace.

Waste management -



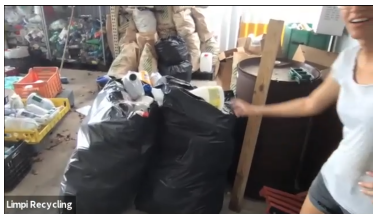
Limpi - Curacao

Background - Limpi is an initiative from by Debrah (Curacao) and Mitchell (Netherlands) who started three years ago. They found there is an absolute lack of plastic recycling on Curacao.

Team and workspace - Recently corona has hit their business hard, many of the project were cancelled and no new projects are incoming. Inventory consists of a pneumatic injection machine, sheet press, shredder and plastic drying machine. Most common plastics Limpi uses is HDPE, secondly PP.

Material supply - Individuals bring cleaned plastic at irregular intervals, mostly this is not a problem since the products they make are relatively small. This plastic still needs to be sorted but is relatively easy since most products have a resin code. There is one other place where it is possible to get recycled plastic, though this is mostly post industrial grade.

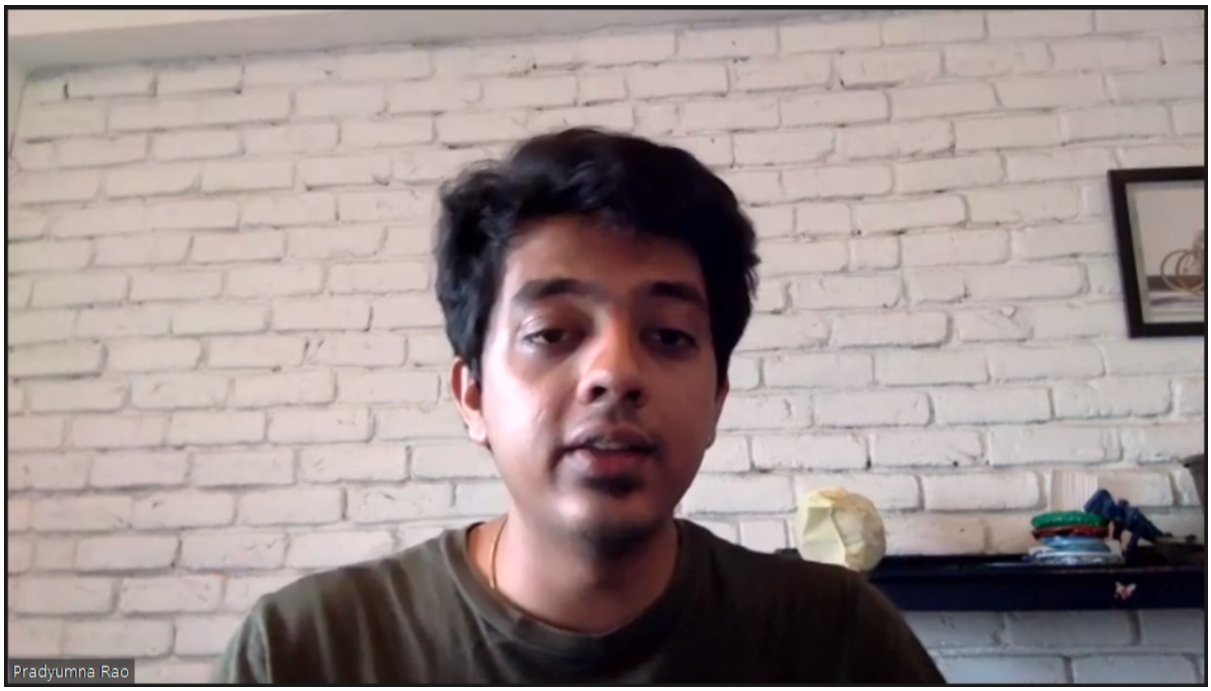
Waste management - Limpi, together with two other places in Curacao that recycle plastic. Waste management is existing but only transfers everything to the landfill.



Samsara - India

Background - Prad started mid 2018 with his recycling business in Madras, India. Build the machines himself and started collecting, sorting and making plastic.

Team and workspace - Currently Prad is running the workspace together with his partner, they have purely focused on the making part of recycled plastic and source their recycled plastic from other places. inventory consists of a shredder (currently not in use), extrusion machine and sheet press oven. Mostly use HDPE


Pradyumna Rao

Material supply - In India it is very easy to buy recycled plastic material, there are many local small shops that buy and sell used material. each shop has its own focus and can deliver on demand. It is possible to buy different grade plastics (A, B or C) although the exact quality is unclear. Plastic waste from his business can be sold back to the plastic recycler.

Waste management - The waste management in India is very informal, exactly as described as in literature. Plastic is collected by kabaadiwalas and brought to local shops. Most common plastics PP PE PVC and some PS & PET. Prad is more than happy to connect me to his contacts in the recycling industry for more in depth questions about the plastic collection and sorting methods.

💡 Plastic used in interviewees country are the most common 5 types of plastics. film material is often discarded.

💡 Most developed plastic waste stream is PET, big quantities are collected and processed or shipped to China. Recycled on big industrial scale.

💡 3 out of the 4 interviewees have outsourced plastic collection, sorting and shredding process. At these places the market is big enough for others to be specialize on that part of the recycling process.

💡 Exact content or quality of bought shredded flakes is often unknown

💡 Findings from interviewees overlap with known literature

Media on plastic waste management

Observations on the context of waste management and plastic recycling are currently extremely difficult. Luckily there are videos and documentaries on daily life in waste management and recycling in low- to middle-income countries. A short collection to give an overview is presented here:

https://www.youtube.com/watch?v=tWGvYIIV7Ns

https://www.youtube.com/watch?v=-wmb-4GQf1M

https://www.youtube.com/watch?v=bAh7nVq0mvg

https://www.youtube.com/watch?v=ijqb4yJbWWU&ab_channel=youthbusiness

https://www.youtube.com/watch?v=GvZbc9INFFk

https://www.youtube.com/watch?v=PBMDGcYWPvU

https://www.youtube.com/watch?v=3eJHLxD3rhw

https://www.youtube.com/watch?v=0E4SkTcCB8c

https://www.youtube.com/watch?v=YMAhhmgxN-E

Conclusion

Plastic recycling in low- to middle-income countries is heavily based on an informal sector, this is supported by literature, interviews and observations. Since this sector is heavily based on individuals no specific goal is pursued. This results in individuals choosing a waste stream that is most viable and not

always the one that is most needed. Currently most scavengers pick out one specific type of plastic, this makes their process simple and easy to maintain. Most waste is sorted manually since labor cost is very low.

Working conditions described in literature (harsh and very low income) were not confirmed by the interviewees, this can be explained by the fact that these interviewees were contacted through the internet and belong to a higher class plastic recyclers. They tend to recycle plastic for a cause, not for a living.

An open call to eight active plastic recycling workspaces resulted in very positive an interested reactions. 6 out of 8 workspaces were very interested in an improved sorting and identification process. They acknowledge the difficulty in sorting and identification of plastics.

Appendix

V

Partners

Appendix V Partners

Precious Plastic

Background

Precious Plastic is an open source project that aims to make plastic recycling simpler. Since 2014 they have been sharing plans on how to build your own recycling machines. It is now grown to a community of 80.000 people and more than 300 workspaces around the world. It has become the go to place for anything related to plastic recycling.

How Precious Plastic can benefit from my project

By adding a NIR sensor to the product family it is possible to provide solutions to a larger target group.

How I can benefit from Precious Plastic

Connection to a global community of recycling experts, maintainer of the project in the future.

Contact

Contact with the founder, Dave Hakkens, interview included in the link below.

Copy of Interview Dave Hakkens

Outcome interview

> 💡 Precious Plastic is willing to be the maintainer of the project, they can include it in their download pack and set up a webspace where people can interact with this project.

Reflow

Background

Reflow is a company that makes 3D printer filament from recycled PET. Founded by Jasper Middendorp, in 2017 it is on a mission to make recycling viable and prove the raw material for a new industrial revolution.

How Reflow can benefit from my project

The materials used to make the 3D filament are recycled PET bottles, they need to be collected and sorted before they can be used as raw material for filament.

How I can benefit from Reflow

Reflow can provide a specific use case in which a NIR sensor can be of use.

Contact

In Contact with Jasper van Middendorp, founder of Reflow. Summery of the phonecall below

Copy of Phonecall Jasper

Outcome interview

💡 Collaboration with Reflow is difficult. Currently Reflow is not in charge or the collection, sorting and shredding process of PET, they by granulated recycled PET from medical waste in the EU. No connection to the Global South. They do have small consultancy projects where they need to sort a few 1000kg of plastics, but this is not on a regular interval.

Ocean Cleanup

Background

Started as a project by Boyan Slat in 2013 with the aim to remove 90% of the ocean plastic pollution. With the help of a floating barrier plastic accumulates and can be extracted with ships

THE OCEAN CLEANUP

How the Ocean Cleanup can benefit from my project

Many of the plastic products collected from the ocean to not have resin identification codes on them or have broken down beyond recognition. Having a sensor that can detect what plastic a product is made from can be useful

How I can benefit from the Ocean Cleanup

The Ocean Cleanup can provide a specific use case where plastic needs to be identified with the help of NIR spectrometry.

Contact

In contact with Eva Snijder, head of material development, summery of the phonecall below

interview Eva Snijder

Outcome interview

> 💡 There is a good match between my project and the Ocean Cleanup, they have difficulties with sorting fishingnets, often from HDPE of PP, currently use sensors that are 30.000 euro, would like to do offshore sorting but now not possible.

Open Science TU Delft

Background

The Open Science Community Delft is aiming to be the frontrunner in the area of Open Science. The programme is led by Rob Mudde (vice-rector of the TU Delft) together with Wilma van Wezenbeek (library director)

Open Science Community Delft

Open Science at TU Delft

Various products and services will be developed in these projects, which will not only benefit TU Delft researchers, teachers and students, but also alumni and the general

https://www.tudelft.nl/library/actuele-themas/tu-delft-open-science/os/open-science-at-tu-delft/

How Open Science Community Delft can benefit from my project

The Open Science Community Delft is looking for bottom up examples of students and phd'ers that want to work in an open manner. This project could be a great showcase

How I can benefit from the Open Science Community Delft

The Open Science Community has the possibility to fund projects that they deem important. They can also help with the communication externally of the project.

Contact

In contact with Santosh Ilamparuthi and Marta Teperek, data steward and head of research data services.

Copy of Interview Santosh

Outcome contact

Open Science Community Delft is happy to support me, they would like to make me the first Open Hardware graduate student, can also help with funding for research and development of the project.

Appendix

VI

Build Log

Appendix VI Build Log

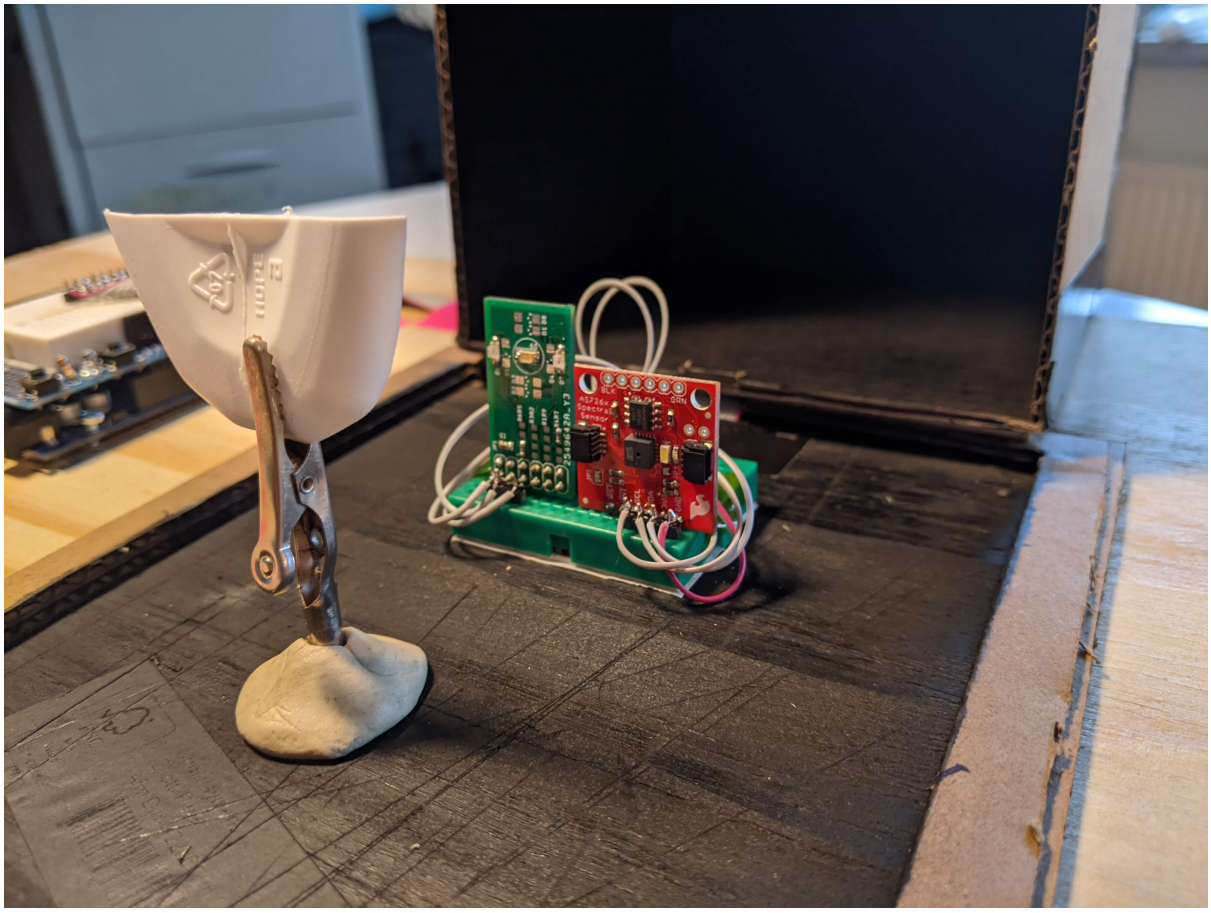
Part one - start to MVP

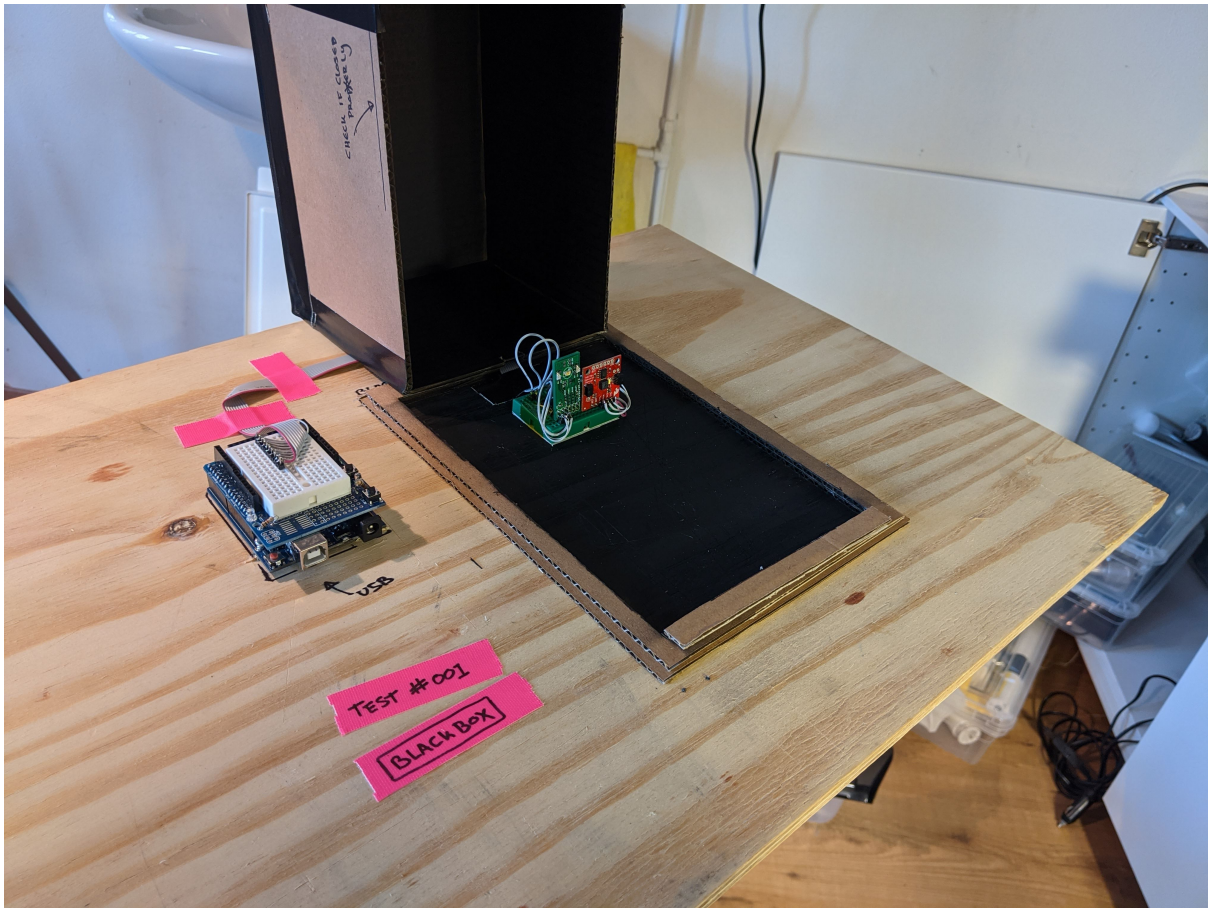
Test #001 - separate IR leds

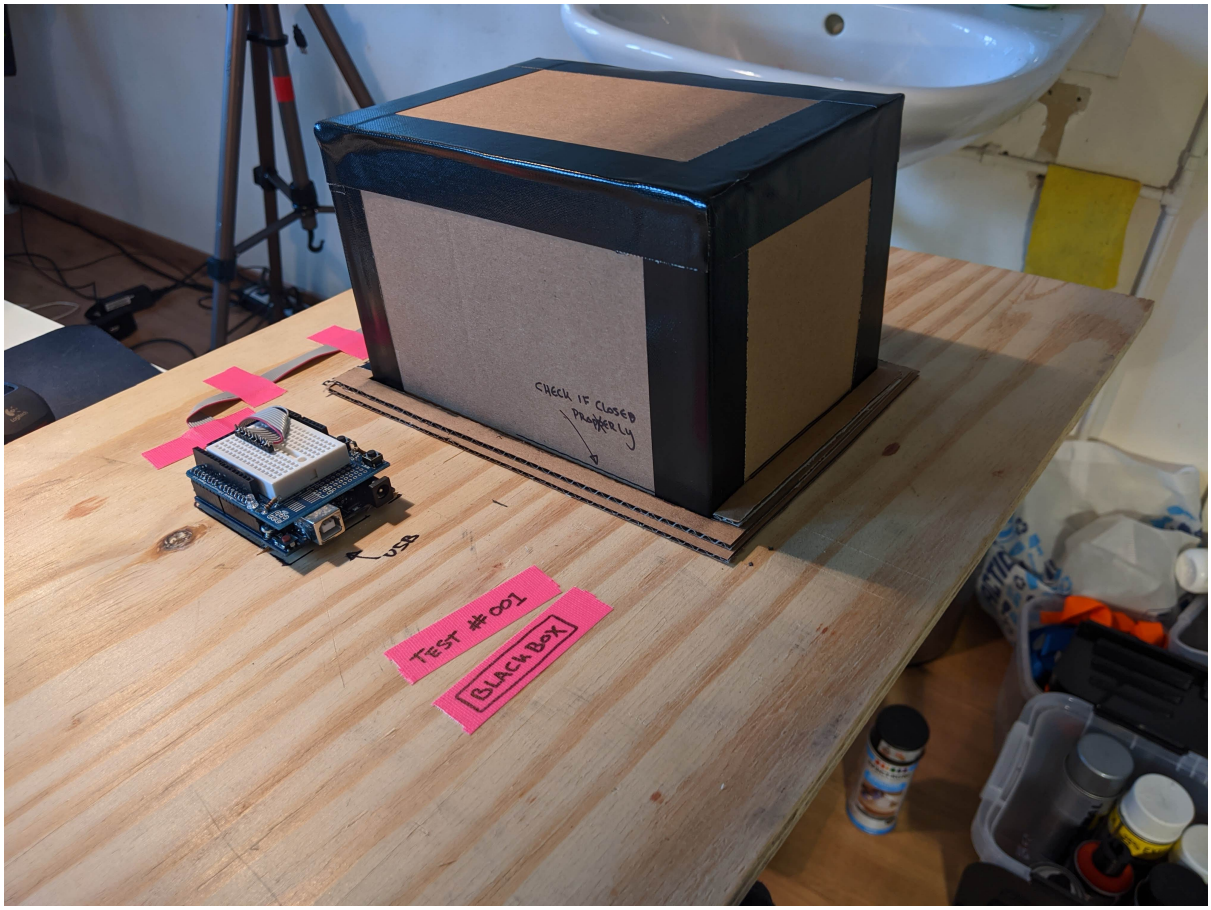
Goal: Test the difference in reflectance of different types of plastic in a lab setting. The plastics should have different reflections and if two wavelengths are used also different ratio's

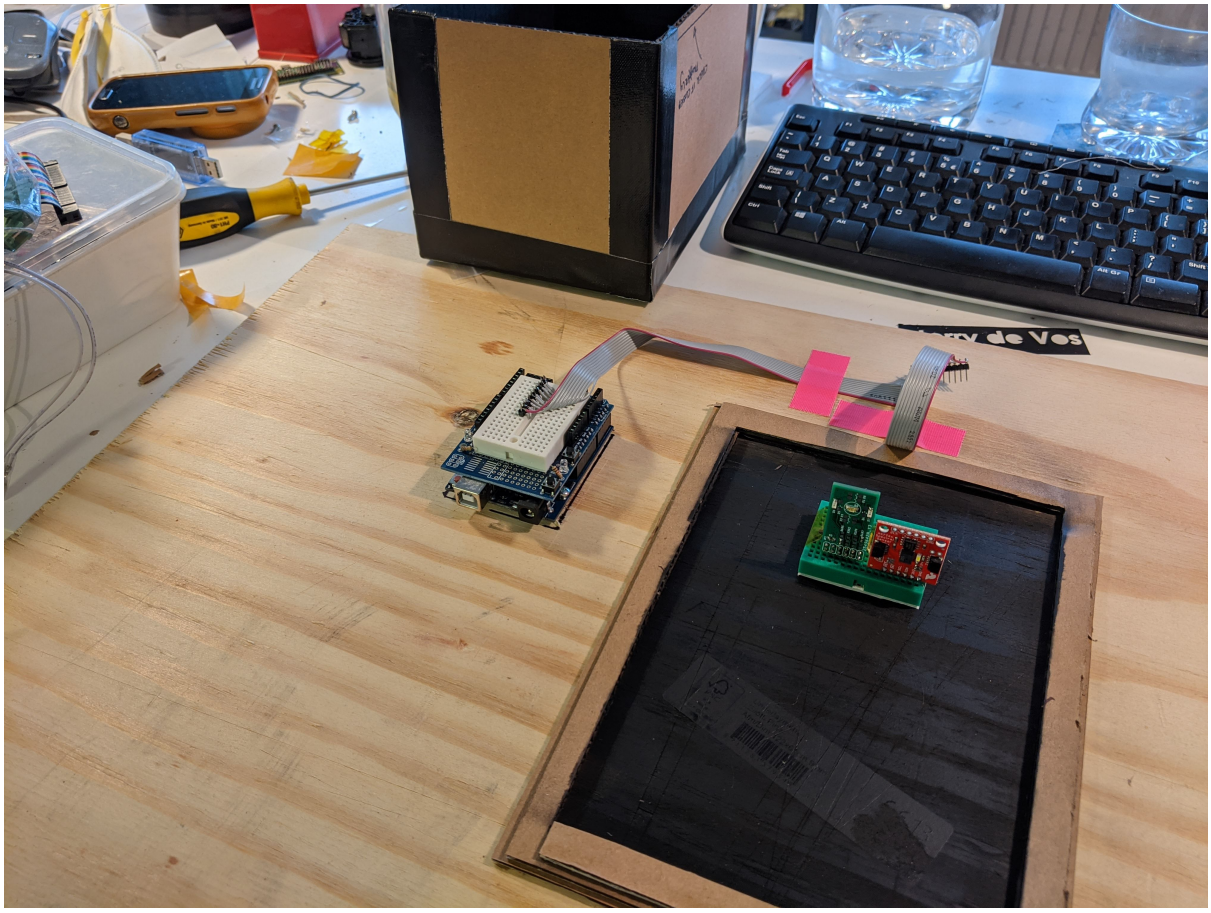
Materials required:

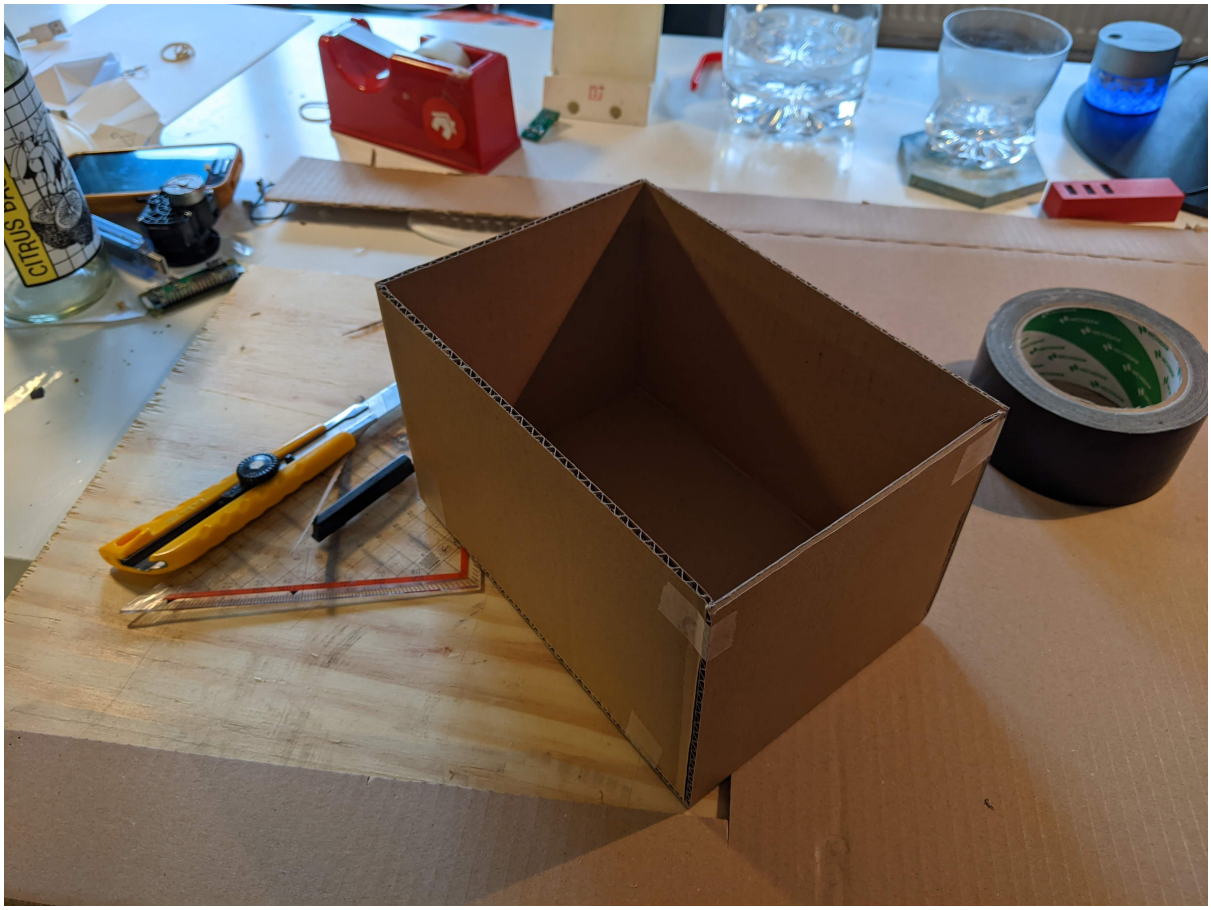
- [x] ~~two IR leds 850 and 950nm~~
- [x] ~~InGaAs sensor~~
- [x] ~~multimeter~~
- [x] ~~microcontroller~~
- [x] ~~Blackbox~~
- [x] ~~plastic samples~~
- [ ]

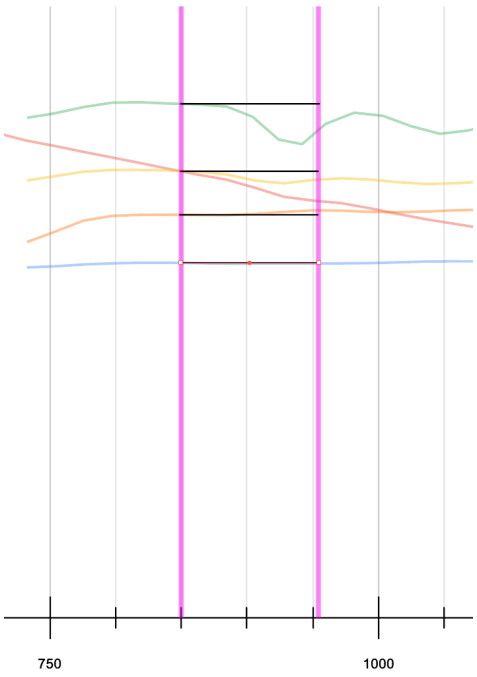



CHECK IF CLOSED
PROPERLY
USB
TEST #001
BLACK BOX


CHECK IF CLOSED
PROPERLY
USB
TEST #001
BLACK BOX







Datasheet Compontents

850nm IR ledPatrizio Manganiello

1.45V - 80mA (`current setup for 3.3v!`)

960nm IR led

1.30V - 80mA (`current setup for 3.3v!`)

InGaAs sensor

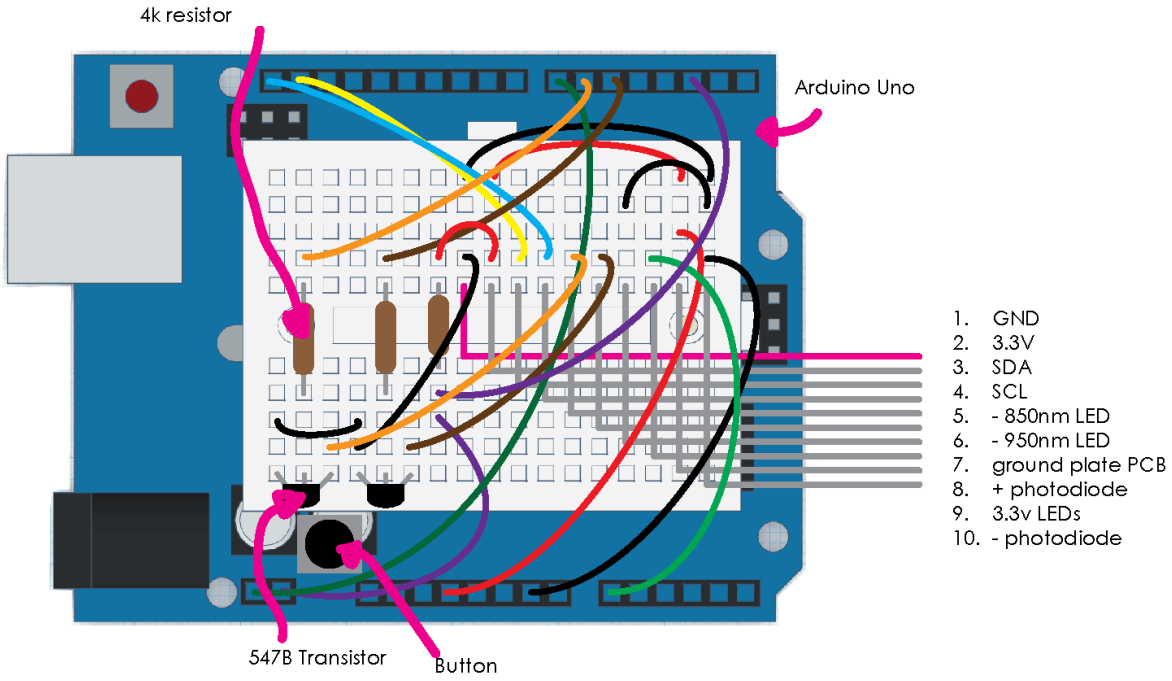
How do I connect a photodiode?

Thanks for contributing an answer to Electrical Engineering Stack Exchange! Please be sure to answer the question. Provide details and share your research! Asking for help,

https://electronics.stackexchange.com/questions/33659/how-do-i-connect-a-photodiode

Arduino Uno

Connection diagram



Procedure:

1. Connect arduino to computer
2. Open serial monitor
3. Turn on system
4. Output on serial that everything booted successfully
5. Load sample
6. Close box
7. Press button to run program
8. Pre light measurement of photodiode
9. IR 850nm led turns on for 0.5sec
10. Measure photodiode value with IR 850nm led on
11. IR 850nm led turns off
12. IR 950nm led turns on for 0.5sec
13. Measure photodiode value with IR 950nm led on
14. IR 950nm led turns off
15. Post light measurement of photodiode

16. Write down values
17. redo step 5 to 16 with other samples.

Code:

```
int sensorPin = A0;    // select the input pin for the potentiometer
const int buttonPin = 2;
int ir850LedPin = 5;      // select the pin for the LED
int ir950LedPin = 6;      // select the pin for the LED
int LedPin = 7;      // select the pin for the LED
int sensorValue850 = 0;  // variable to store the value coming from the sensor
int sensorValue950 = 0;  // variable to store the value coming from the sensor
int preSensorValue = 0; // variable to store the value coming from the sensor
int postSensorValue = 0; // variable to store the value coming from the sensor
int buttonState = 0;

void setup() {
  // declare the ledPin as an OUTPUT:
  pinMode(ir850LedPin, OUTPUT);
  pinMode(ir950LedPin, OUTPUT);
  pinMode(LedPin, OUTPUT);
  pinMode(buttonPin, INPUT);
  Serial.begin(9600);
  Serial.println("all good and ready to go!");

}

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) {
    delay(500);
    // read the value from the sensor:
    preSensorValue = analogRead(sensorPin);
    // turn the ledPin on
    digitalWrite(ir850LedPin, HIGH);
    digitalWrite(ir950LedPin, LOW);
    digitalWrite(LedPin, HIGH);
    // stop the program for <sensorValue> milliseconds:
    delay(500);
    sensorValue850 = analogRead(sensorPin);
    // turn the ledPin off:
    digitalWrite(ir850LedPin, LOW);
    digitalWrite(ir950LedPin, HIGH);
    delay(500);
    sensorValue950 = analogRead(sensorPin);
    digitalWrite(ir950LedPin, LOW);
    digitalWrite(ir850LedPin, LOW);
    digitalWrite(LedPin, LOW);
    delay(500);
    postSensorValue = analogRead(sensorPin);
    String p1 = ", ";
```

```
    //Serial.println("pre-sensorValue,850, 950,post-sensorValue");
    Serial.println(preSensorValue + p1 + sensorValue850 + p1 + sensorValue950 + p1 + post
SensorValue );
    //Serial.println("ready for new measurement");
  }
  else {}

}
```

Data

https://s3-us-west-2.amazonaws.com/secure.notion-static.com/dd886a46-baf4-4001-8371-19a4df291394/nse-8594812268165778995-Test_001.m4a.m4a

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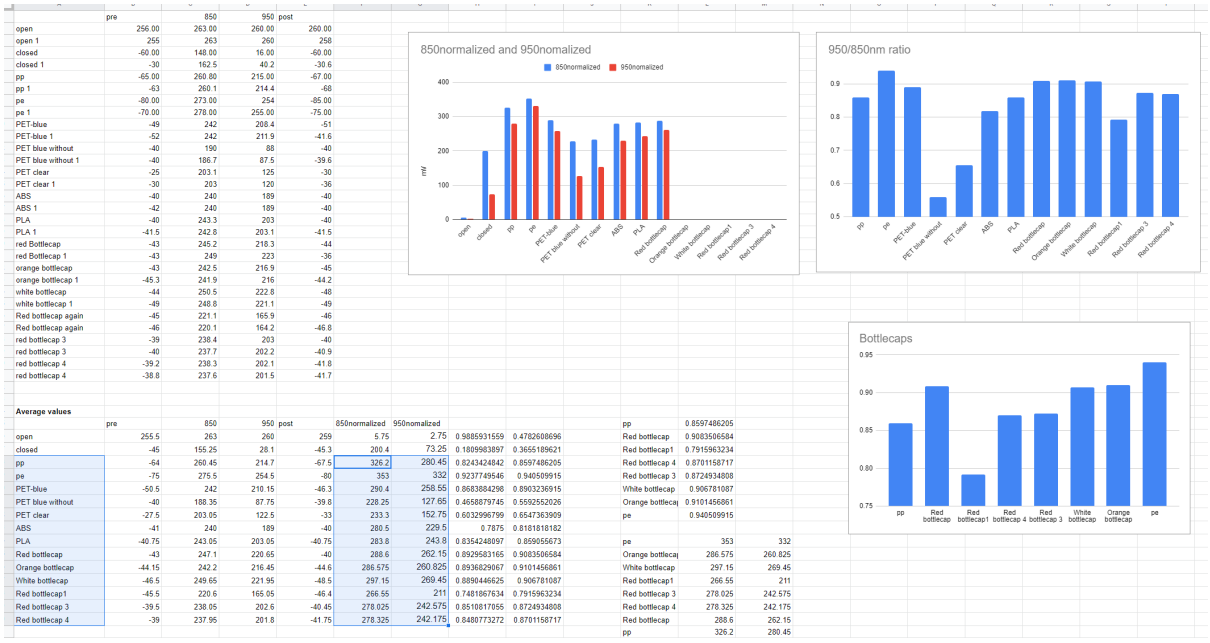

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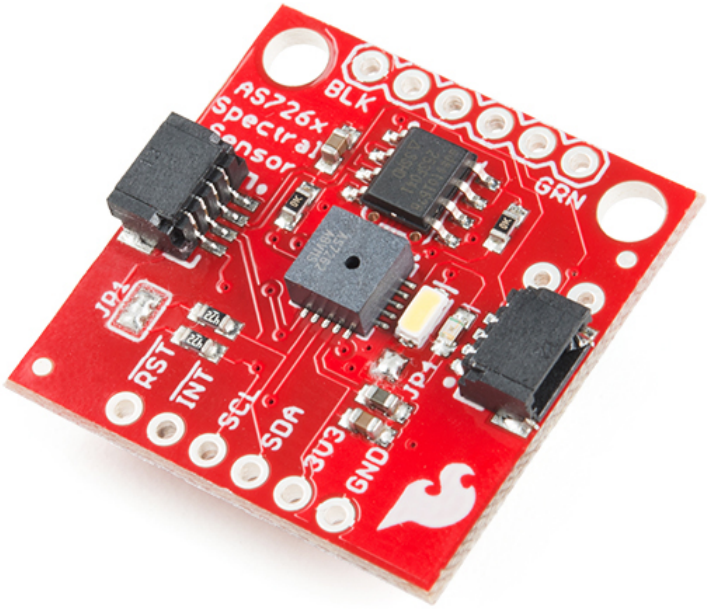
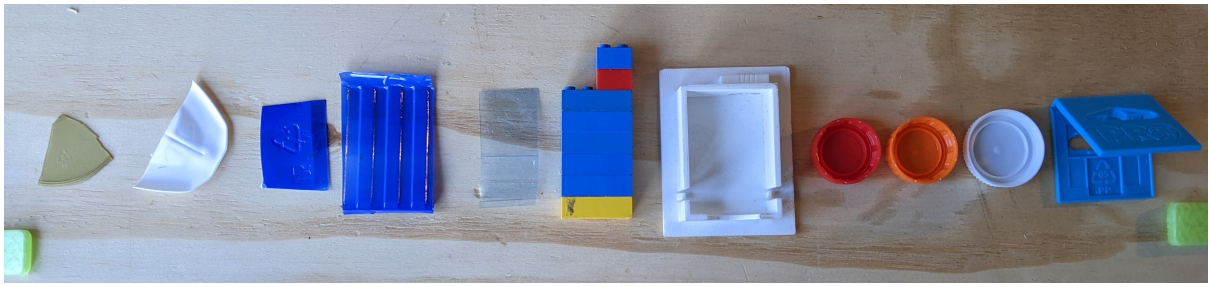
https://docs.google.com/spreadsheets/d/1Y6ClbqgBltEQMfYAZsKhDQXxaw_ChxwskxfhrUXOdRQ/edit#gid=1643584099

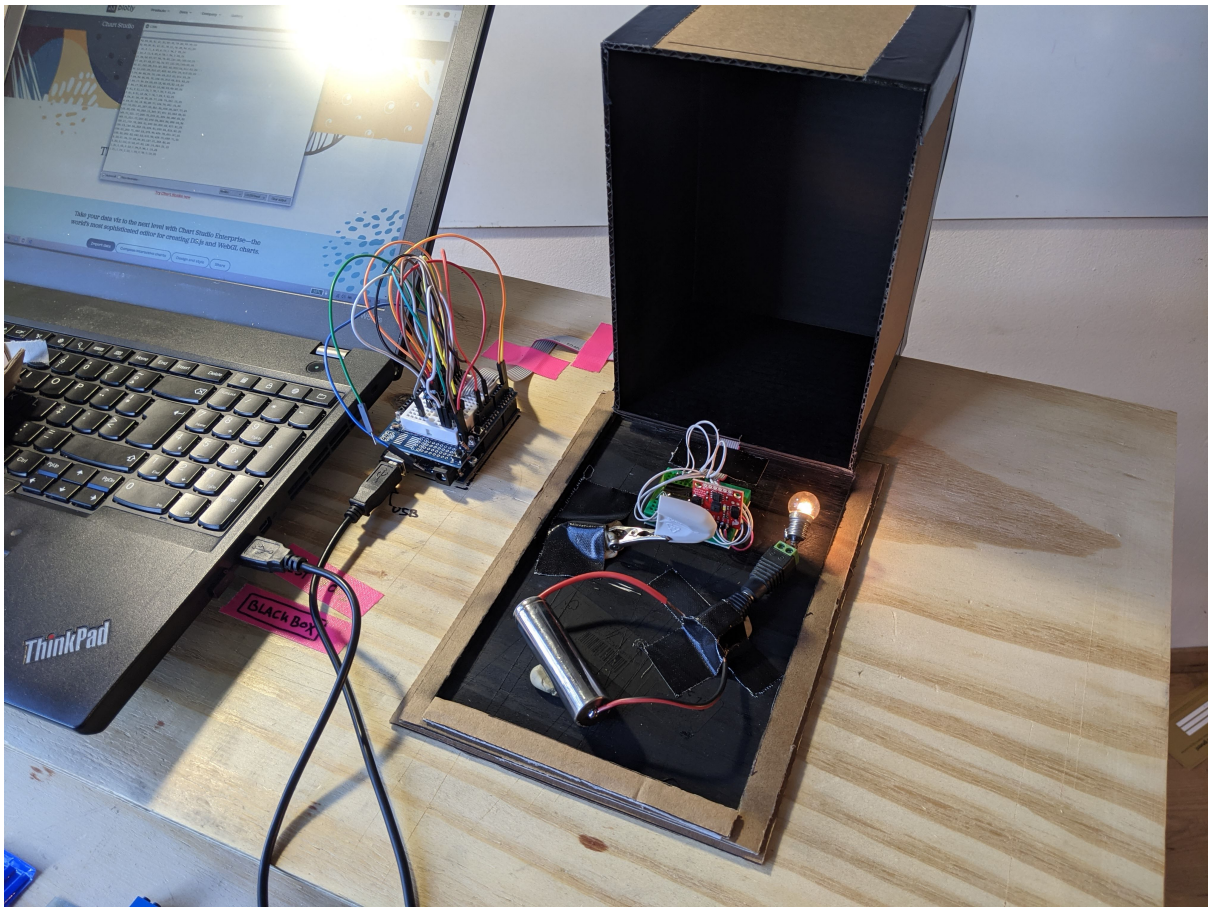
Test #002 - NIR

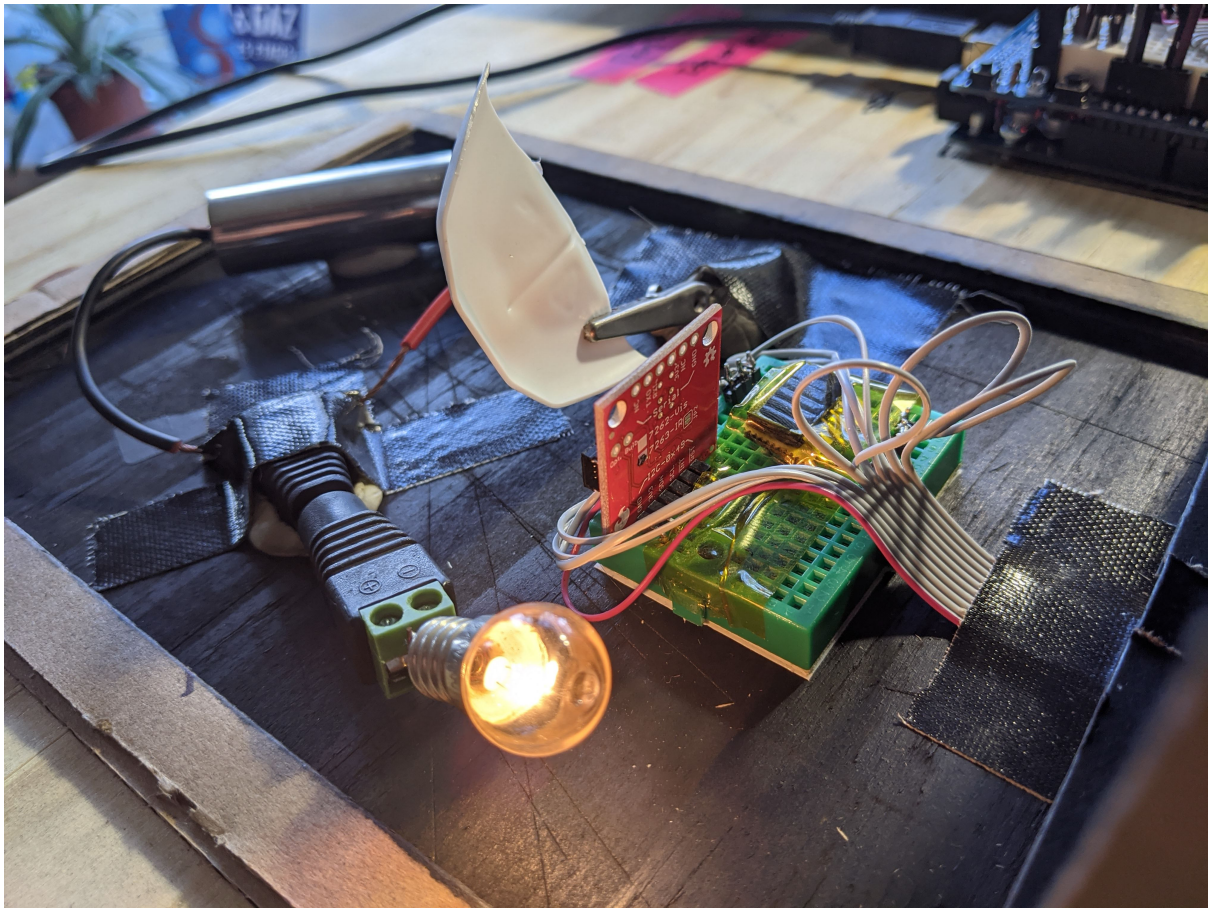
Goal: Test quality of Sparkfun Spectrical sensor for NIR

based on the AMS7263 sensor, it measures at 610,680,730,760,810,860nm, note that this is very minimal infrared and mostly normal red (wikipedia suggest that visible range is till 700nm, ir range starts at 780nm)






ThinkPad
BLACK BOX



Materials

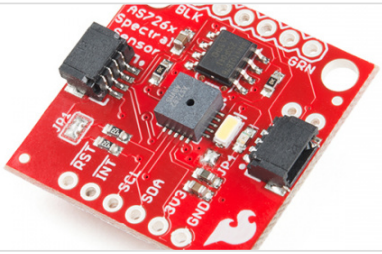
- [x] ~~Arduino uno~~
- [x] ~~prototype shield~~
- [x] ~~Sparkfun AS7263 breakout board~~
- [x] ~~Incandescent light (ir source)~~
- [x] ~~battery to drive light~~

Datasheets

AS726X NIR/VIS Spectral Sensor Hookup Guide

The AS726X Spectral Sensors from AMS brings a field of study to consumers that was previously unavailable, spectroscopy! It's now easier than ever to measure and characterize how

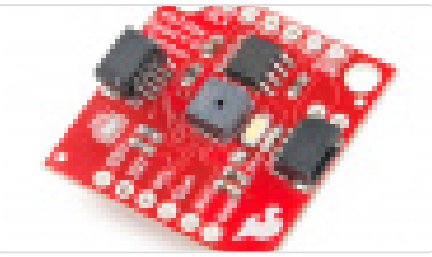
https://learn.sparkfun.com/tutorials/as726x-nirvi



SparkFun Spectral Sensor Breakout - AS7263 NIR (Qwiic)

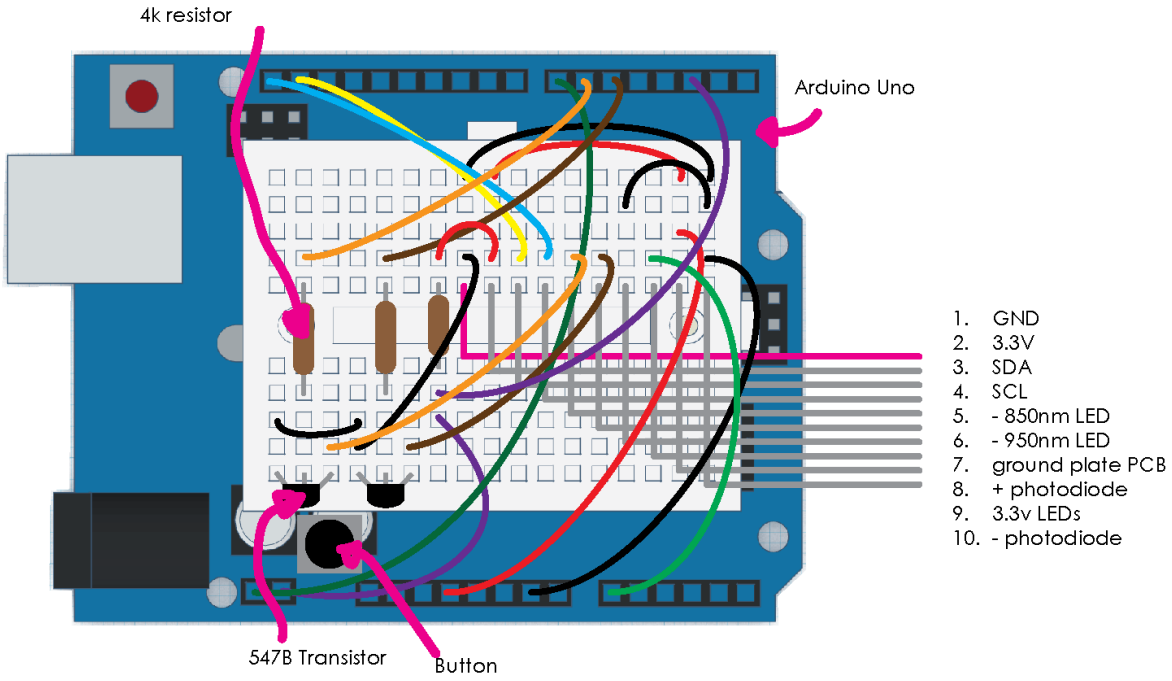
The board is basically the AS7263 reference circuit with the Qwiic connectors. It's part of a Qwiic family that makes it easy to integrate these, though I am using them one at a time. The

https://www.sparkfun.com/products/14351



https://s3-us-west-2.amazonaws.com/secure.notion-static.com/3a4e8532-5326-4fee-86ec-7634cc7cd814/AS7263.pdf

Connection diagram



Procedure:

1. Connect arduino to computer
2. Open serial monitor
3. Turn on system
4. Output on serial that everything booted successfully
5. Turn on incandescent light source
6. Load sample

7. Close box
8. Press button to run program
9. Measure data over i2c
10. Write down values
11. redo step 6 to 10 with other samples.

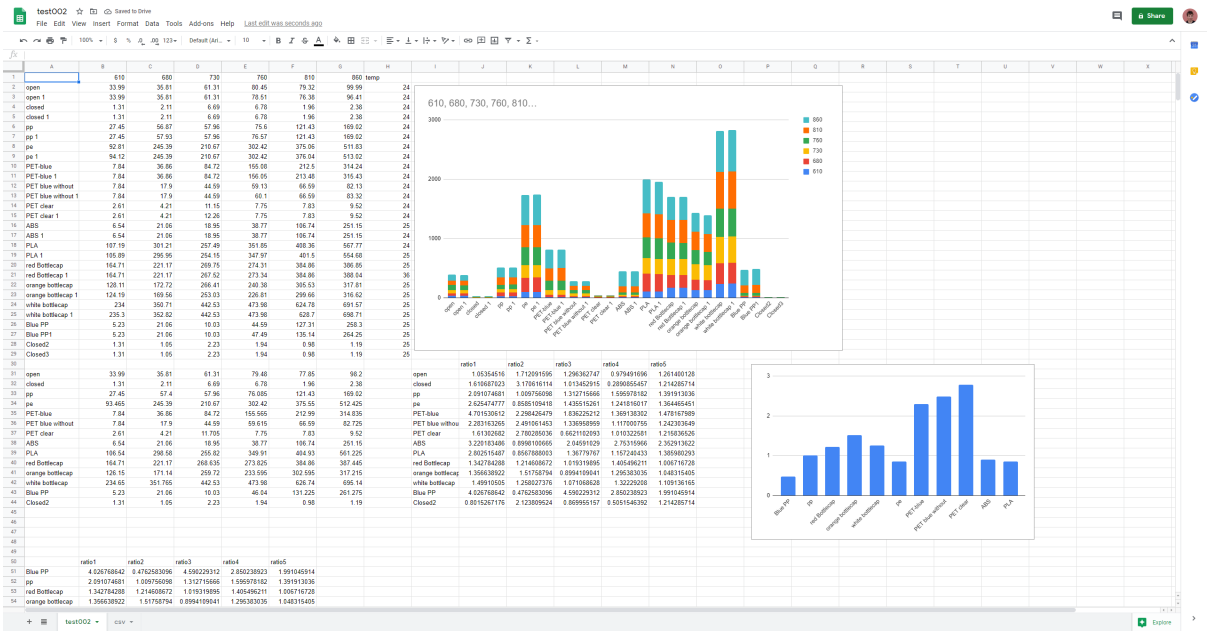
Code

```
#include "AS726X.h"
AS726X sensor;
byte GAIN = 2;
byte MEASUREMENT_MODE = 0;
const int buttonPin = 2;
int buttonState = 0;
int ir950LedPin = 5;      // select the pin for the LED


void setup() {
  Wire.begin();
  pinMode(buttonPin, INPUT);
  pinMode(ir950LedPin, OUTPUT);

  Serial.begin(115200);
  Serial.print("All good and ready to go!");
  //sensor.begin(Wire, GAIN, MEASUREMENT_MODE);
  sensor.begin();
}

void loop() {
  buttonState = digitalRead(buttonPin);
  if (buttonState == LOW) {
    digitalWrite(ir950LedPin, HIGH);
    delay(1000);
    sensor.takeMeasurements();
    Serial.print(sensor.getCalibratedR(), 2);
    Serial.print(",");
    Serial.print(sensor.getCalibratedS(), 2);
    Serial.print(",");
    Serial.print(sensor.getCalibratedT(), 2);
    Serial.print(",");
    Serial.print(sensor.getCalibratedU(), 2);
    Serial.print(",");
    Serial.print(sensor.getCalibratedV(), 2);
    Serial.print(",");
    Serial.print(sensor.getCalibratedW(), 2);
    Serial.print(",");
    Serial.println(sensor.getTemperature(), 1);
    digitalWrite(ir950LedPin, LOW);

  }
}
```

Data

https://s3-us-west-2.amazonaws.com/secure.notion-static.com/41530b6c-bdc3-46bb-b01c-ac11c71c138d/nse-9169831003110951454-Test_002.m4a.m4a

https://s3-us-west-2.amazonaws.com/secure.notion-static.com/37c883cb-0752-4006-99bf-d67dd269b4d1/nse-6474556936723787782-Test_002.txt.txt



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https://docs.google.com/spreadsheets/d/1v_DW7bnc7OH6w_c7wx28bsmIL6QLgBrp_2-I_UhsbB8/edit?usp=sharing

Test #003 - Data interpretation

The vast amount of sensor data collected can make interpretation difficult. By outsourcing this interpretation of data to a machine learning algorithm it is possible to cope with these amounts of data. given the responses at different wavelengths it is possible to cluster this in groups of plastic

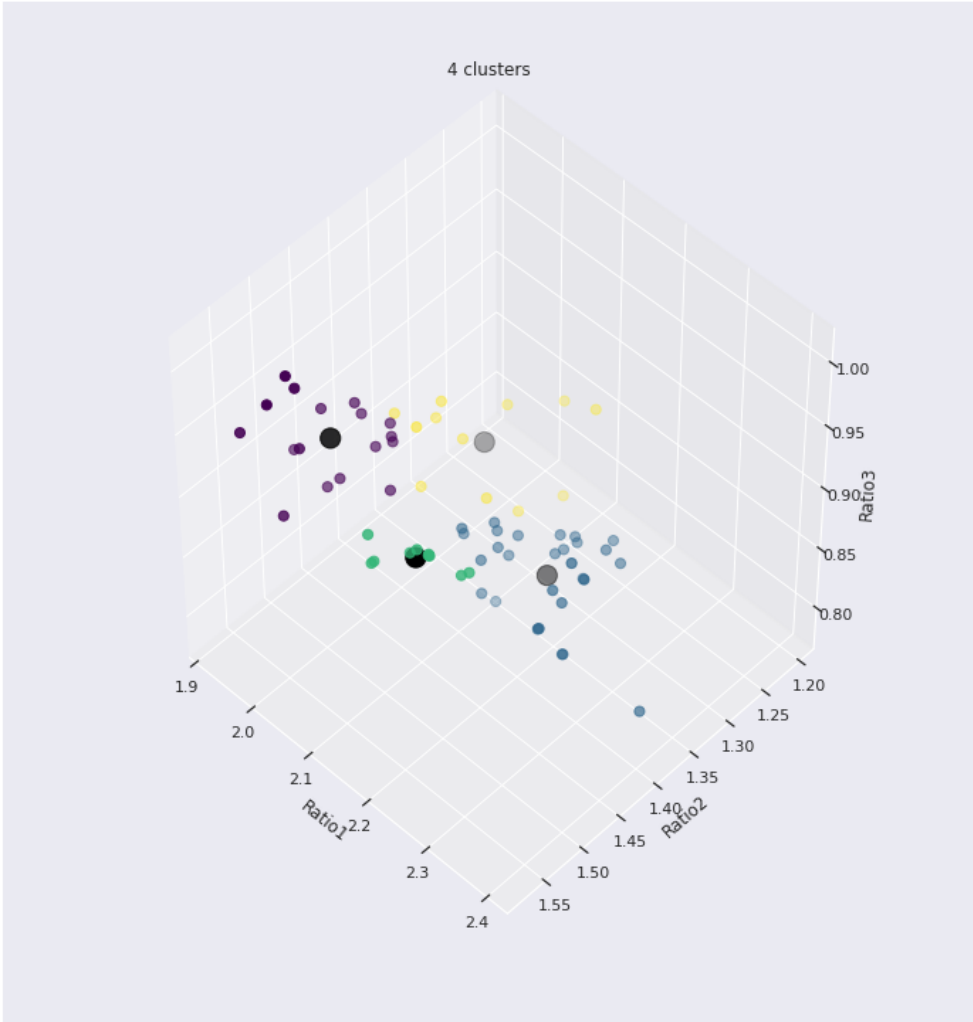
Data analysis of sample data shows that unsupervised k-means clustering of 3 variable data is almost as good as supervised clustering

More data and more dimensional data should be able to make a more accurate prediction

Supervised vs Unsupervised

To analyze this data in a orderly fashion Google Colab is used, a web-based interactive computational environment that runs in the cloud and stores its notebooks on Google Drive. These electronic lab notebooks allow to write code and comment for scientific computing. Similar to MatLab

```
1
2  fig = plt.figure(figsize=(10, 10))
3  ax = Axes3D(fig, rect=[0, 0, .95, 1], elev=48, azim=134)
4  estimators = KMeans(n_clusters=4)
5  estimators.fit(data)
6  labels = estimators.predict(data)
7  centers = estimators.cluster_centers_
8
9  ax.scatter(data.ratio1, data.ratio2, data.ratio3, c=labels, s=50,cmap='viridis')
10 ax.scatter(centers[:, 0], centers[:, 1], centers[:, 2], c="black", s=200)
11 ax.set_xlabel('Ratio1')
12 ax.set_ylabel('Ratio2')
13 ax.set_zlabel('Ratio3')
14 ax.set_title('4 clusters')
15
16 ax.invert_xaxis()
17
18 #ax.invert_zaxis()
19 ax.invert_yaxis()
20 ax.dist = 12
21 plt.show()
```



first notebook to start exploring data processing

Google Colaboratory

https://colab.research.google.com/drive/1VhE44qtx_0IxjiJurAEw5YMU-tC46ycm

Part two - MVP to MK1

The different use cases each have different requirements, the goal of the Minimal Viable Product(MVP) is to create a configuration matrix that helps users chose which configuration is desired. It can be a simple sensor that can only separate two types or plastic, or a more sophisticated sensor that is capable of separating 5 types of plastic.

For now three configurations are taken into account, simple, medium and expert. these different types tailor to the different use cases. the more complex the product, the more components are required and the longer the processing time. All these variables should be answered in the configuration matrix.

The design of the MVP is based on the ReReMeter

Light source

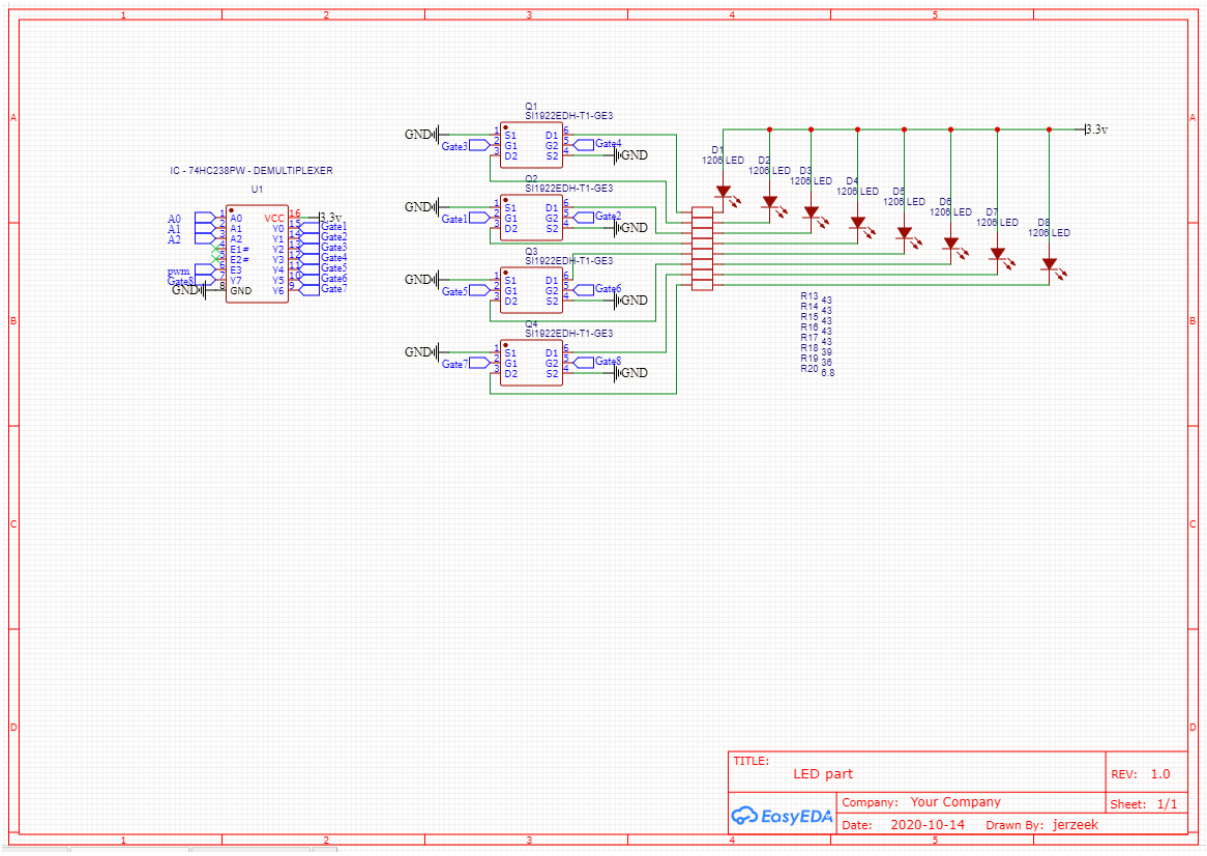
Improved in contrast to the ReReMeter, no more dedicated i2c led driver, currently it is a demultiplexer with dedicated mosfets. this allows for modulation which can help with noise reduction.

~~Similar to the ReReMeter, I2C led driver, constant current indicidual current control. individual channel mosfets, waveform creation~~

- 8x 850nm to 1650nm Descrete NIR LEDs
- ~~TLC59208F, i2c led driver~~

https://s3-us-west-2.amazonaws.com/secure.notion-static.com/493f9aa3-c861-4825-94db-a1b2d7966c0c/tlc59208f.pdf

- IC - 74HC238
- SI1922
- SN74HCS238 demultiplexer
-



Sensor part

Similar to the ReReMeter, SPI analog to digital converter

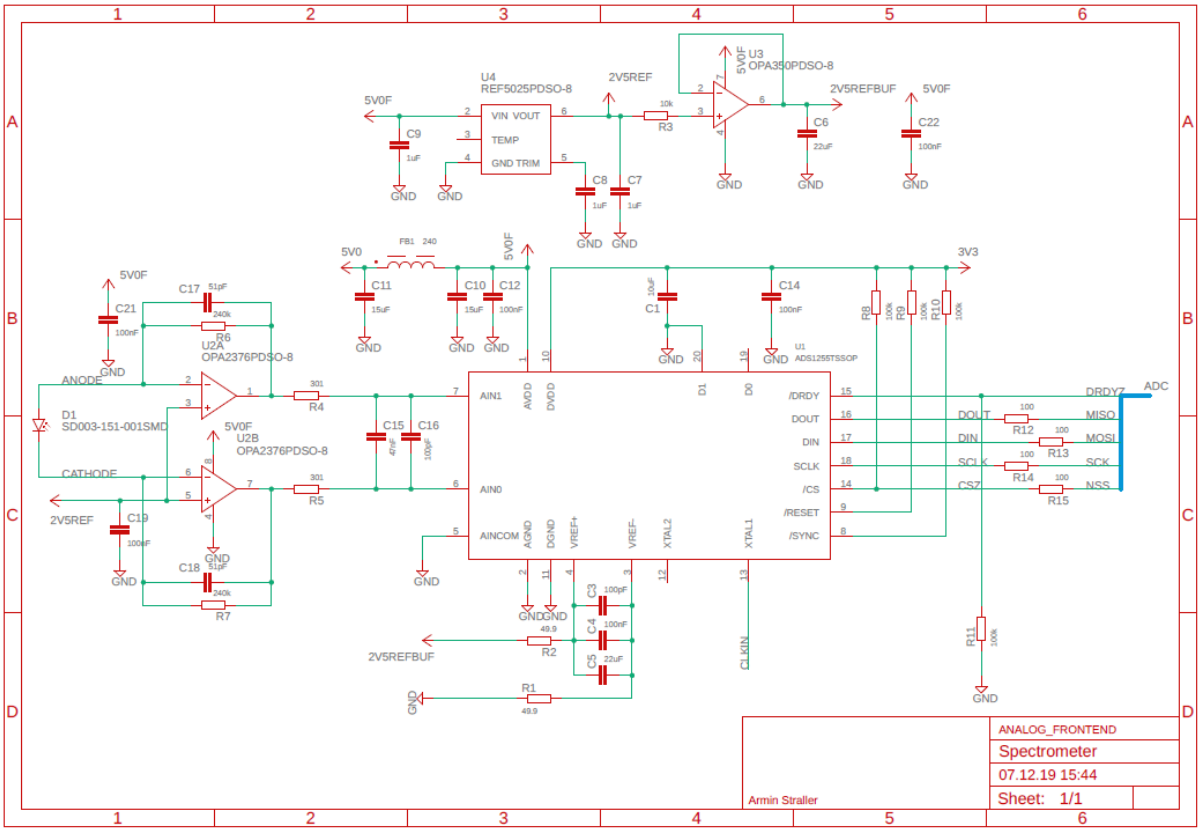
Components:

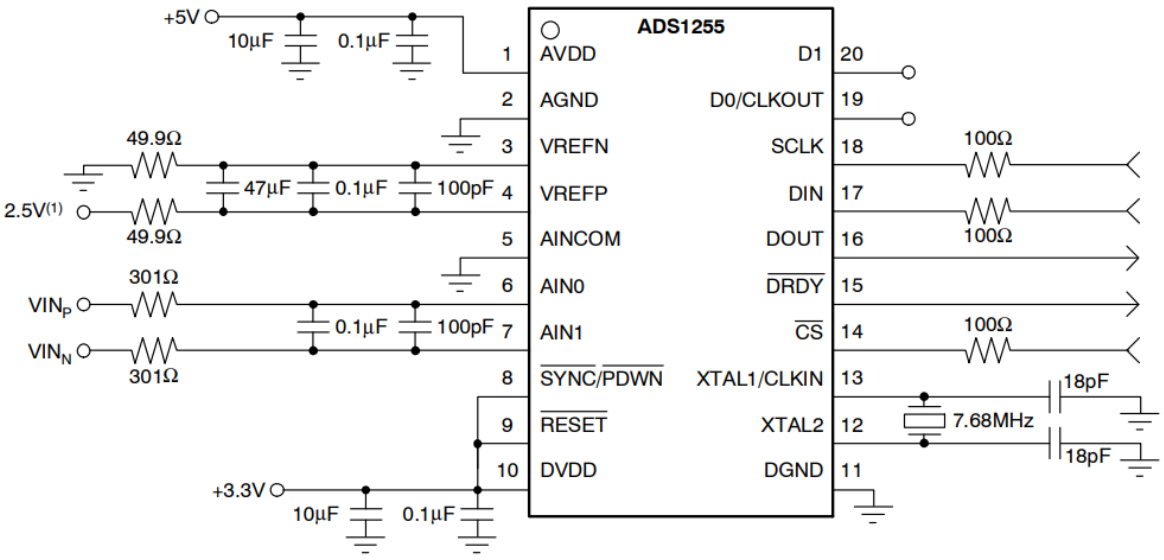
- InGaAs

- ADS1255

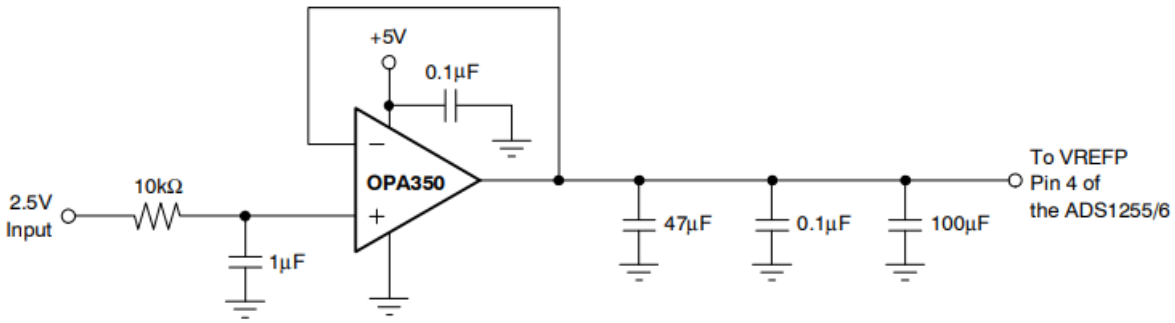
  https://s3-us-west-2.amazonaws.com/secure.notion-static.com/5a72d8f6-caea-49aa-8649-eef4454f5f9d/Texas-Instruments-TI-ADS1255IDB_C29001.pdf

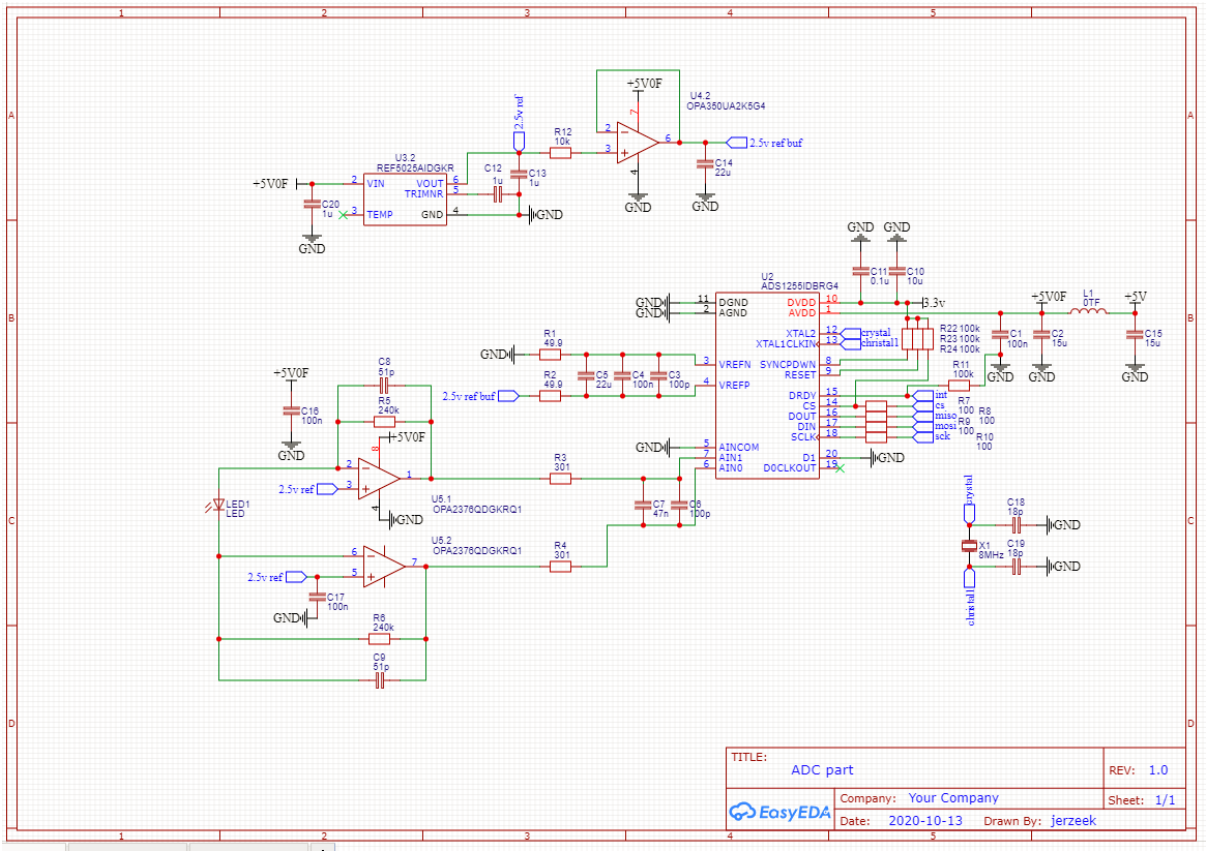
- 2,5v reference voltage
- opamps





NOTE: (1) See Figure 26 for the recommended voltage reference buffer.





Processing part

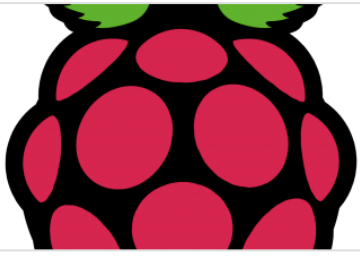
use external processor, Raspberry Pi, ESP32, Connector

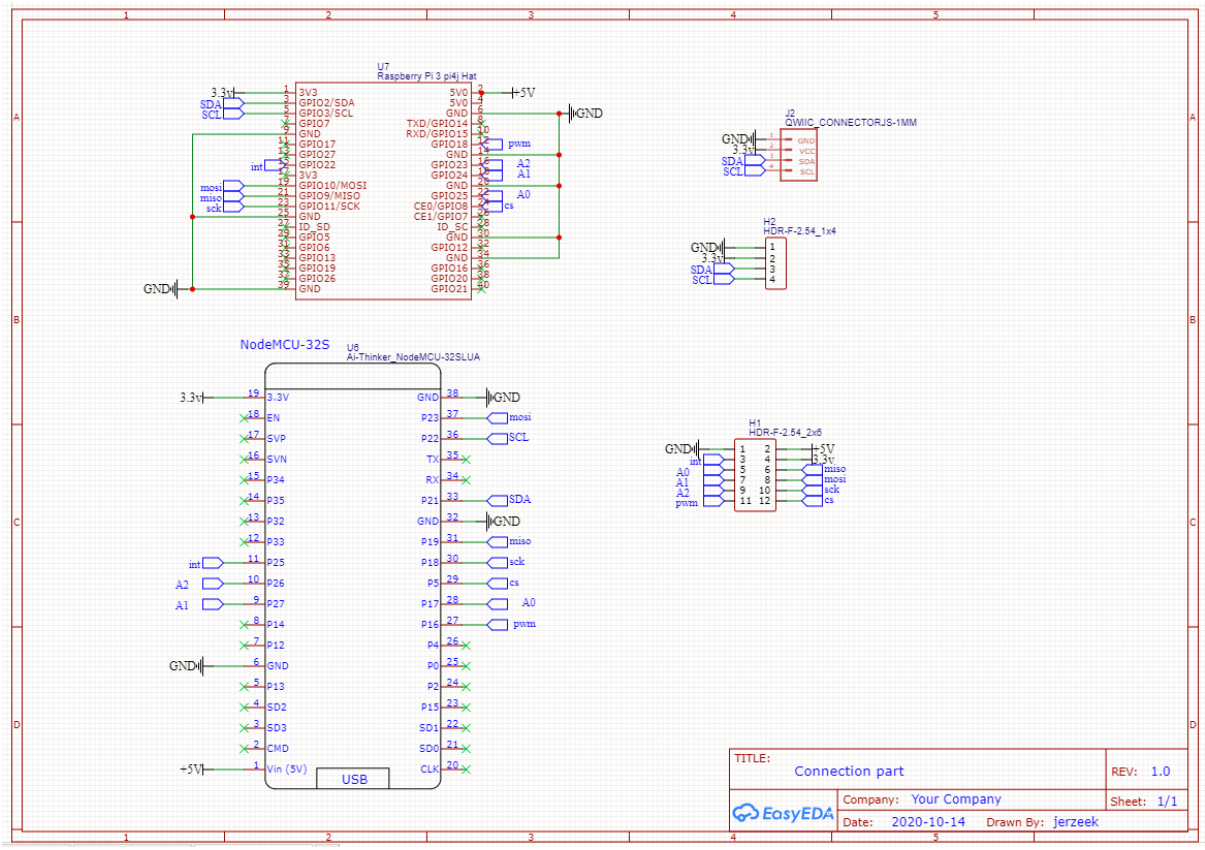
- Pi header
- esp32 header
- 10 pin header

raspberrypi/hats

NOTE All references to GPIO numbers within this document are referring to the BCM283x GPIOs (NOT pin numbers on the Pi GPIO header). The Raspberry Pi boards with 40W GPIO

https://github.com/raspberrypi/hats





Final pcb

NIR Spectroscope

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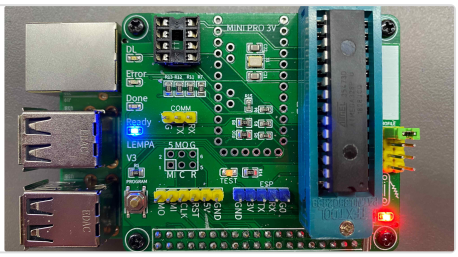
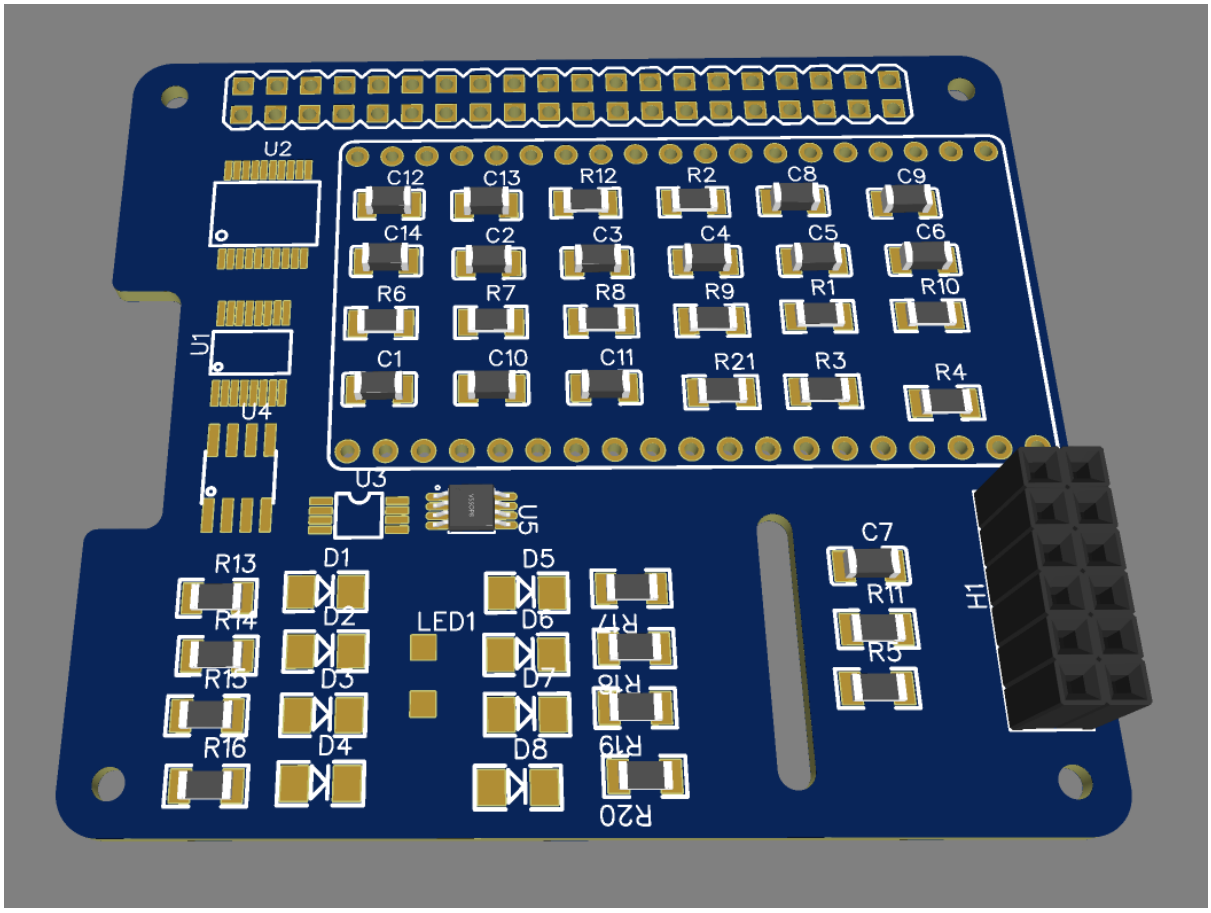
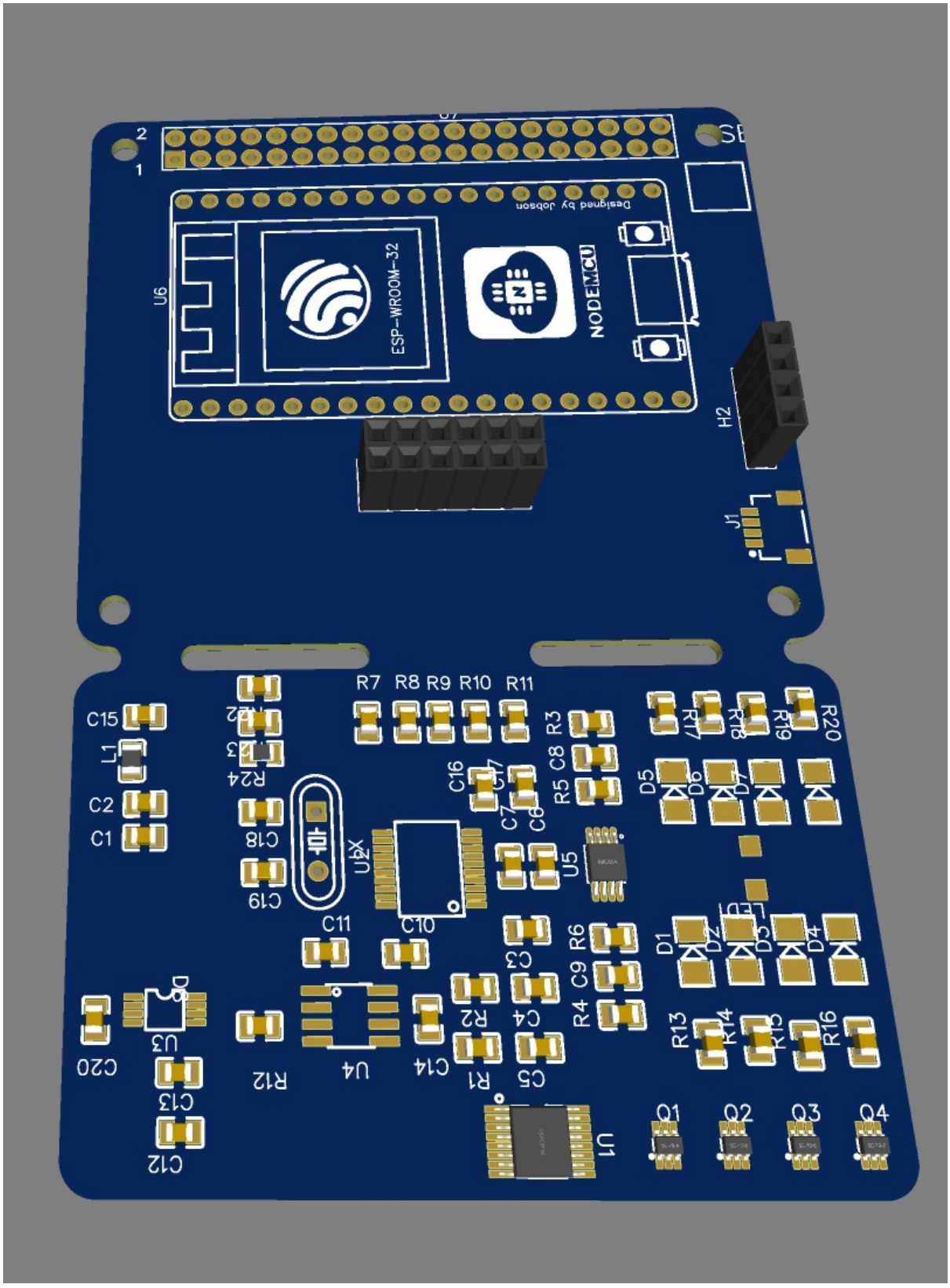
https://easyeda.com/jerzeek/nir-spectroscope



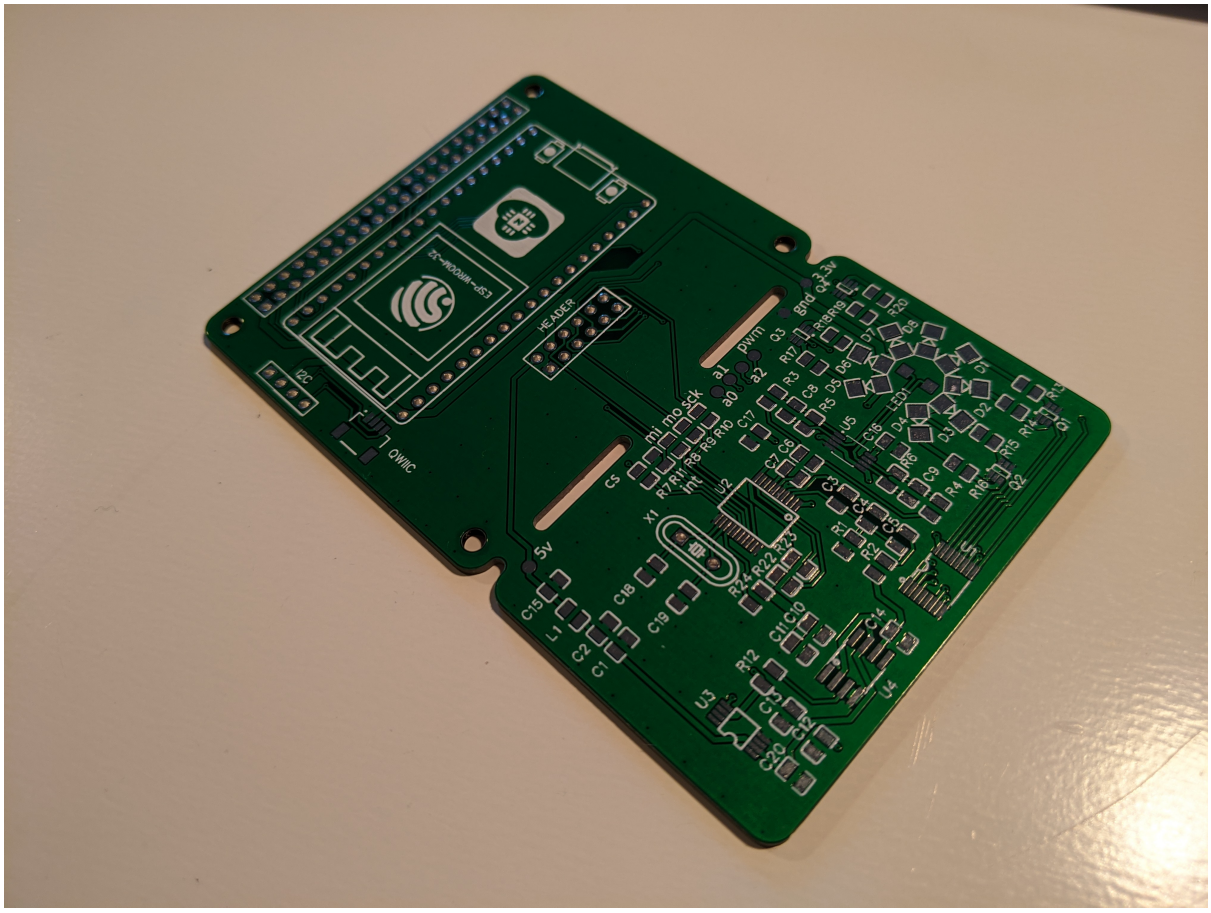

U2
C12
C13
R12
R2
C8
C9
C14
C2
C3
C4
C5
C6
R6
R7
R8
R9
R1
R10
U1
C1
C10
C11
R21
R3
R4
U4
U3
U5
C7
R13
D1
D5
R17
R11
H1
R14
D2
LED1
D6
R18
R5
R15
D3
D7
R16
D4
D8
R19
R20



Copy of Bill of materials

Component	Quantity	Price	Comment

Component	Quantity	Price	Comment
PCB	1	€2.00	from JLCpcb
NIR leds	8	€62.88	850 to 1650 nm
ADS1255	1	€12.00	analog to digital converter
Opa350	1	€4.00	Op amp
Opa273	2	€10.00	Op amp
SN74HCS138	1	€0.48	Demultiplexer
SSM6N7002	4	€3.45	N channel mosfet
Resistor	23	€5.00	Values between 6.8 ohm to 240k
Capacitor	20	€6.00	Values between 18p to 20u
REF5025AIDGKR	1	€5.00	Reference voltage
JST connector	1	€0.47	1mm spacing
Pi header	1	€2.00	2×20 2.54mm header
ESP	2	€1.00	1×19 pin 2.54 header
shipping	1	€20.00	



Configuration matrix

Sensor configuration tool

Configurator Input,Output processor,raspberry pi,Prediction quality for 2 type sorting,95,% interface,display,Prediction quality for 5 type sorting,90,% amounth of leds,8,processing

https://docs.google.com/spreadsheets/d/1zwLT93bZkt-QvbFK8N9ittTk-3s7endn7cZ-4BHJRHg/edit?usp=sharing

Input		Output		
Processor	ESP32	Prediction quality for 2 type sorting	80	%
Interface	LEDs	Prediction quality for 5 type sorting	50	%
Amounth of leds	3	Processing time	6	sec
Color sensor	Yes			
Housing	Handheld			
Processing	Online			
		Total price	165.55	euro

Input		Output		
processor	sensor only	Prediction quality for 2 type sorting	80	%
interface	online	Prediction quality for 5 type sorting	50	%
amounth of leds	3	processing time	1	sec
Color sensor	No			
Housing	Bare PCB			
		price	120	euro

Testing

Test general spi on raspberry pi

test OK ✅

used an 1.8inch tft screen and adafruit tutorial

1.8" TFT Display Breakout and Shield

This tutorial is for our 1.8" diagonal TFT display & microSD in both the shield and breakout board configurations. These displays are a great way to add a small, colorful and bright

https://learn.adafruit.com/1-8-tft-display/python-wiring-and-setup

Testing general spi on raspberry pi with pcb header

Connecting to header and changing reset and a0(DC) pin worked sucessfully

test OK ✅

Testing signal demultiplexer

test OK ✅ (12-11-2020)

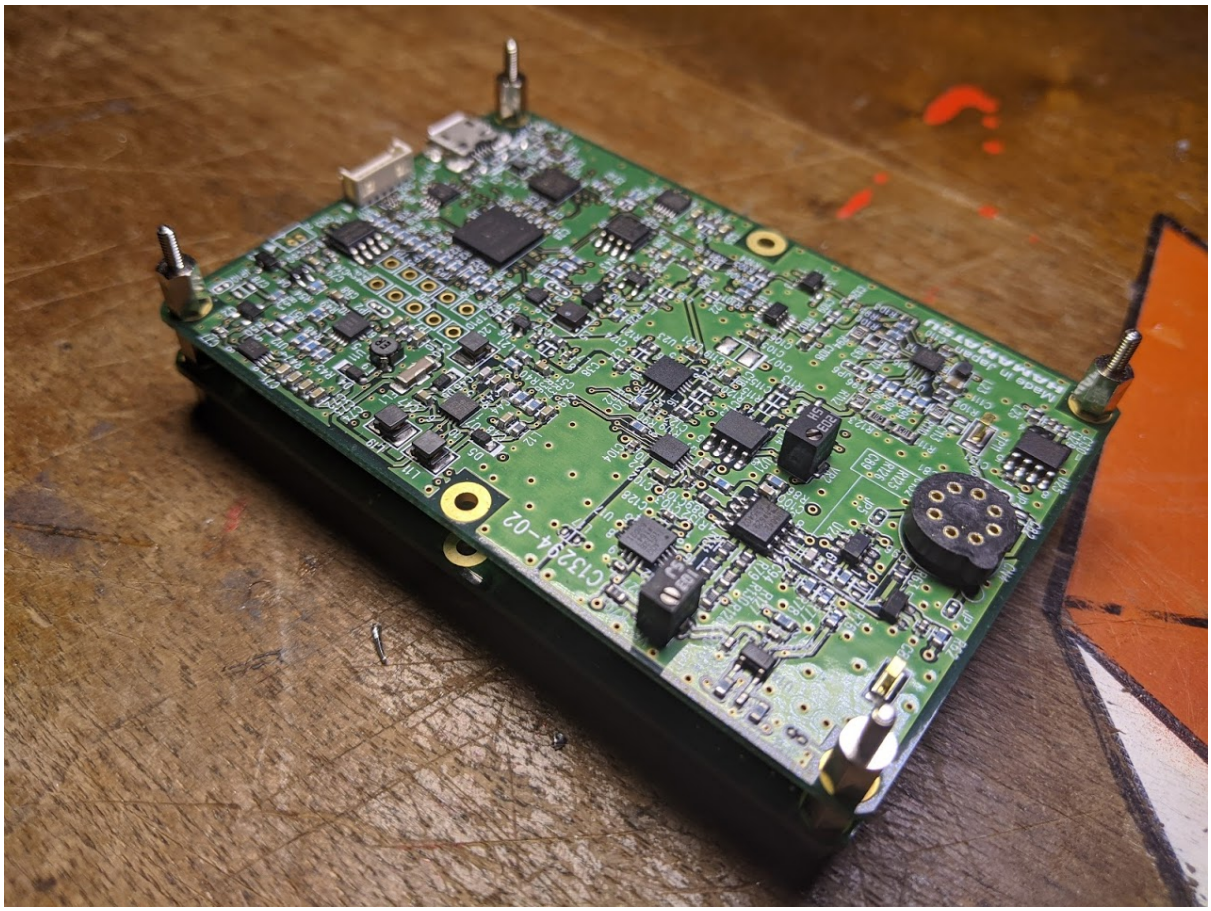
Testing function demultiplexer

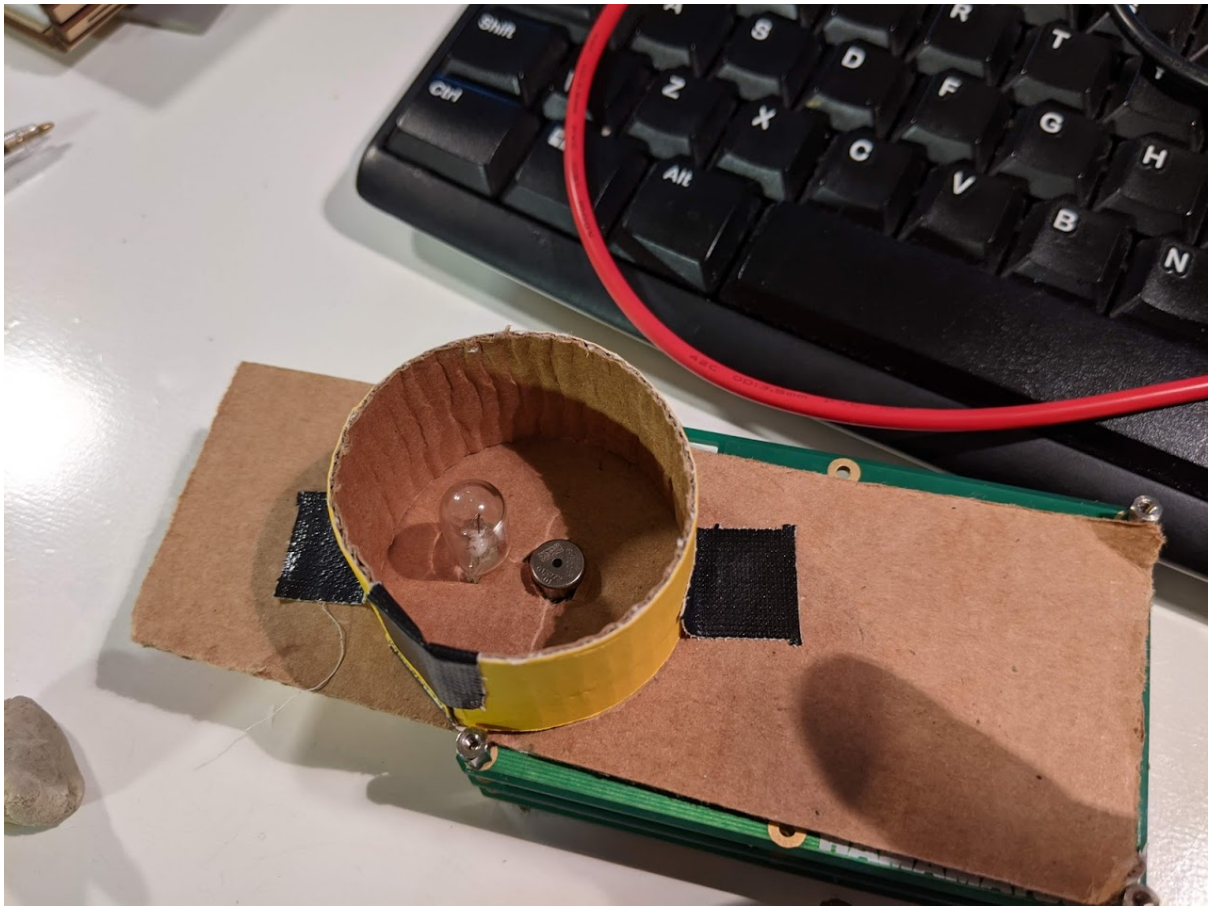
test OK ✅ (12-11-2020)

Test oled screen

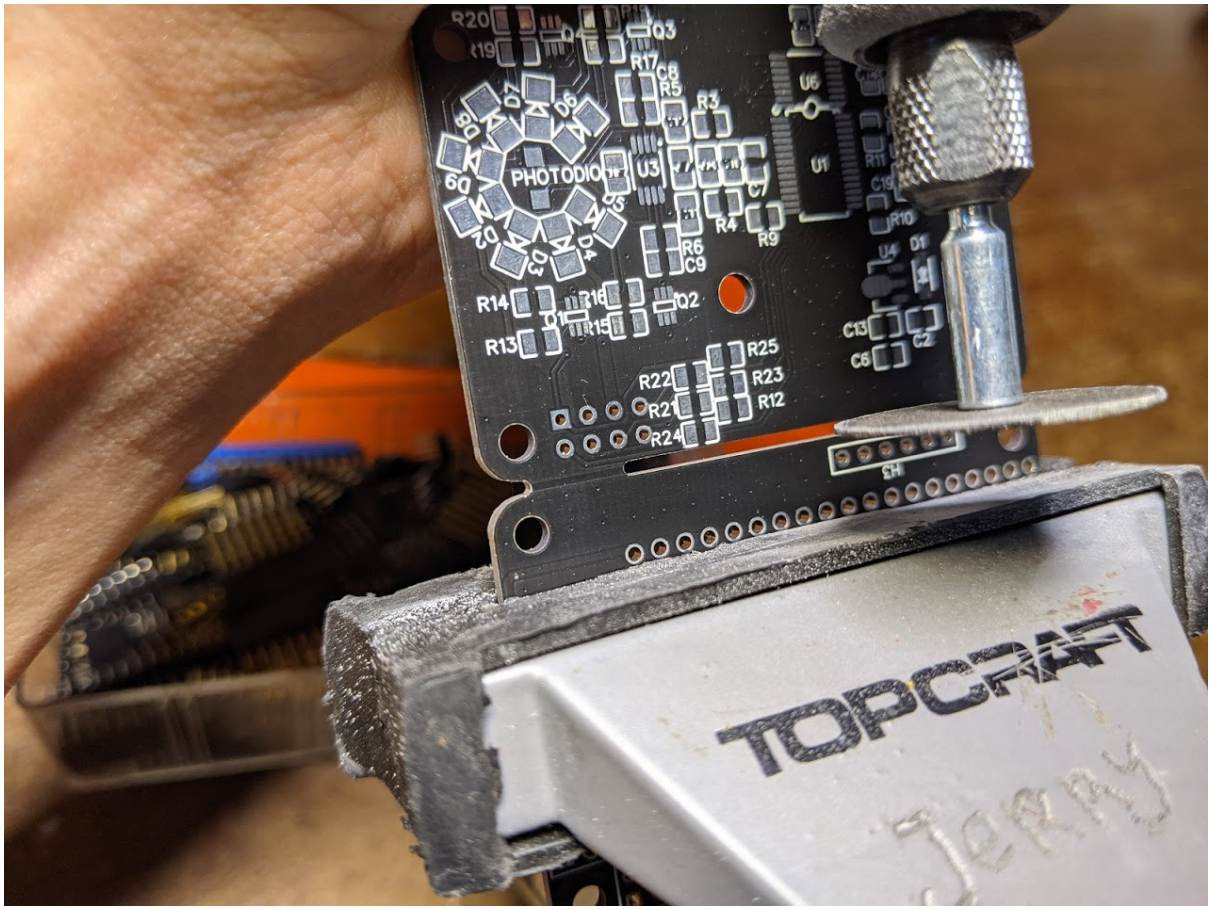
Added button

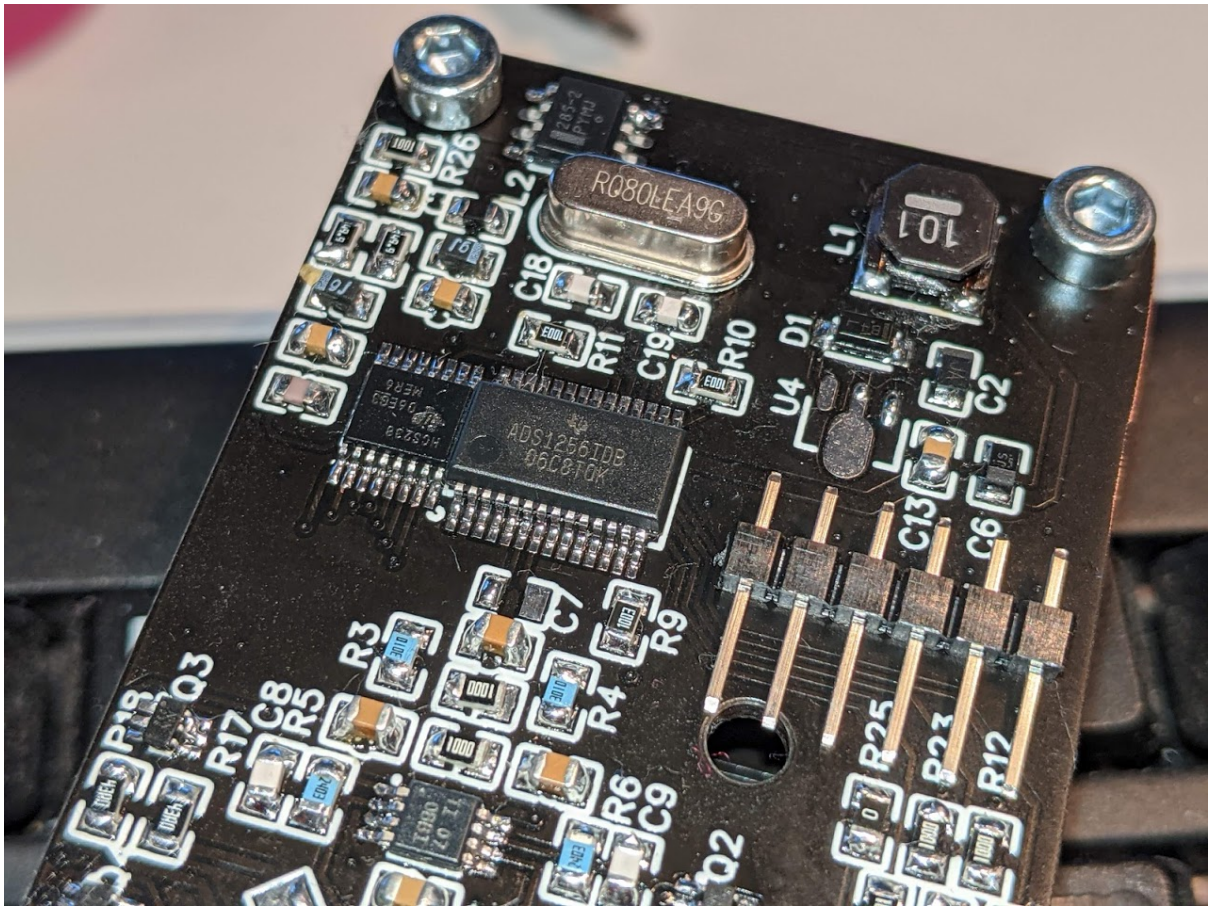
Added .csv support





Part three - MK1 plastic scanner


PHOTODIO
TOPCRAFT



based on the minimal viable product a new design is proposed

main features:

- sensor pcb and daugther pcb
- ads1256 adc
- demultiplexer
- boost converter
- compatible with reremeter
-

exchangeability vs buildability

compatibility reremeter v2 (for expert)

design choices

Test voltage boost

prototype was not working

checked pcb, initially found a problem with a bridged connector on one of the mosfets.

found a problem with resistor R26(1k) this resistor is connected inline after the voltage regulator this should be before the 5v enters the voltage regulator. this is fixed by cutting the line a place [X] and placing a 1k resistor over top. at the place of the R26 a 0 ohm resistor is placed.

Test reference voltage

after the fix of it is now giving a clean 2.505v reference voltage.

Test ADS + spi

Test Demultiplexer

Ressiliance for

esp32 update

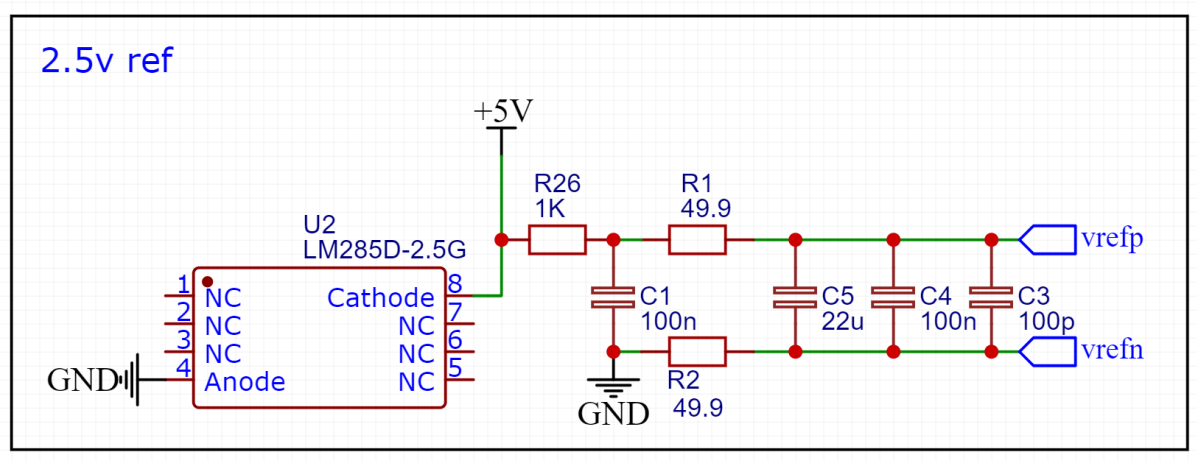
pi 4 usage

battery powered

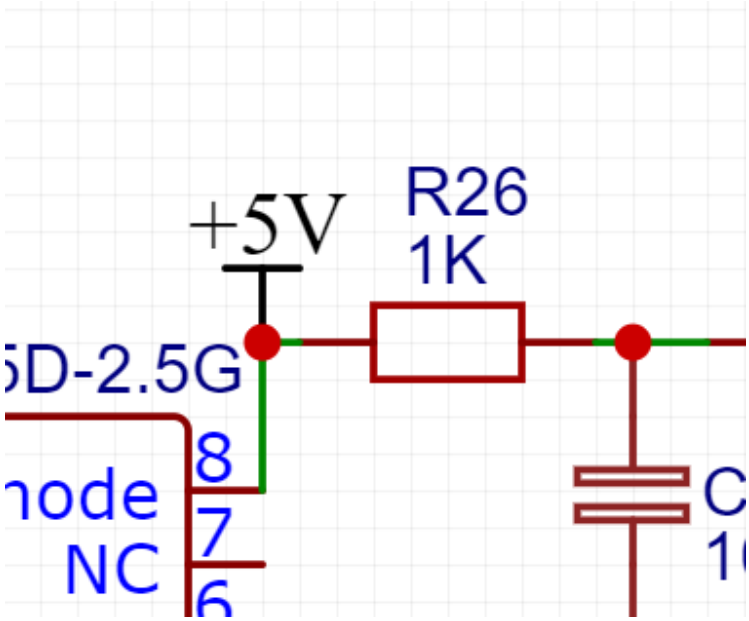
Problem 1

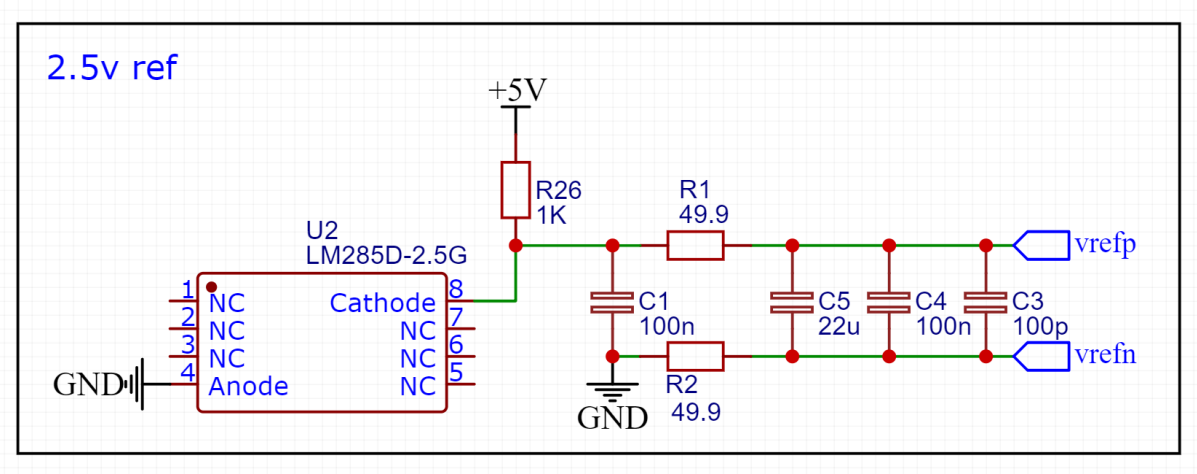
incorrect placement of resistor R26 (1000OHM)

this resistor should be placed inline with the 5 volt line, this to limit the current to the the reference voltage IC in the current pcb it is placed between the IC and the 2,5v reference.



old situation



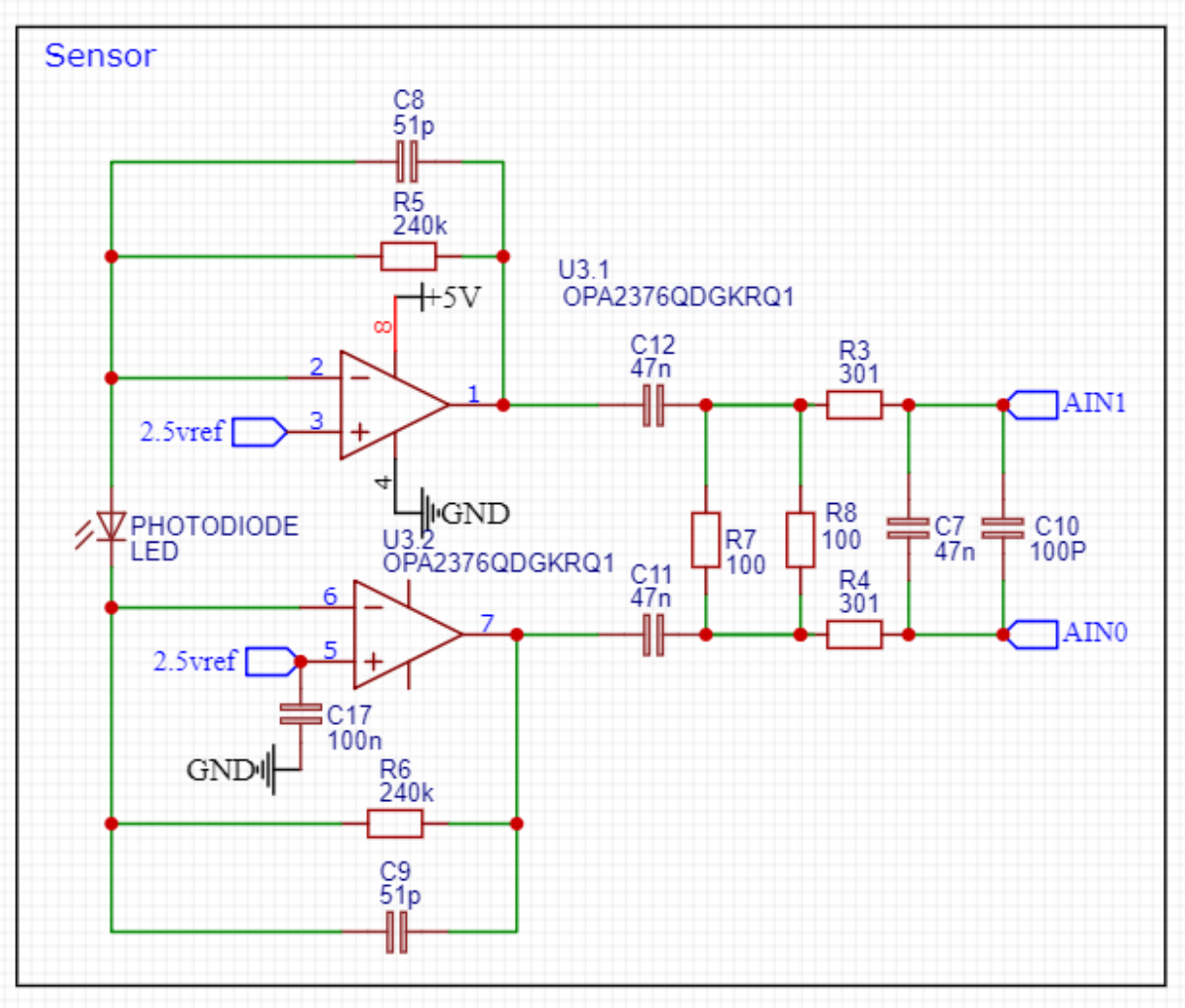


new situation

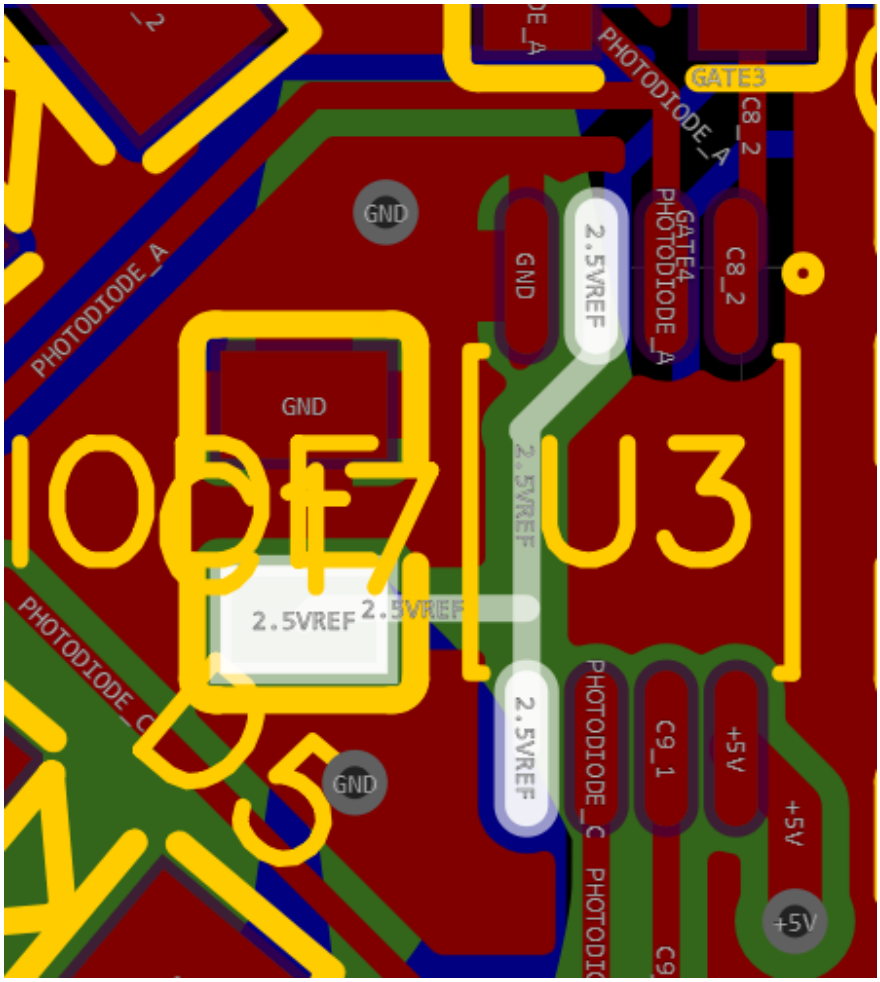
Picture of fix

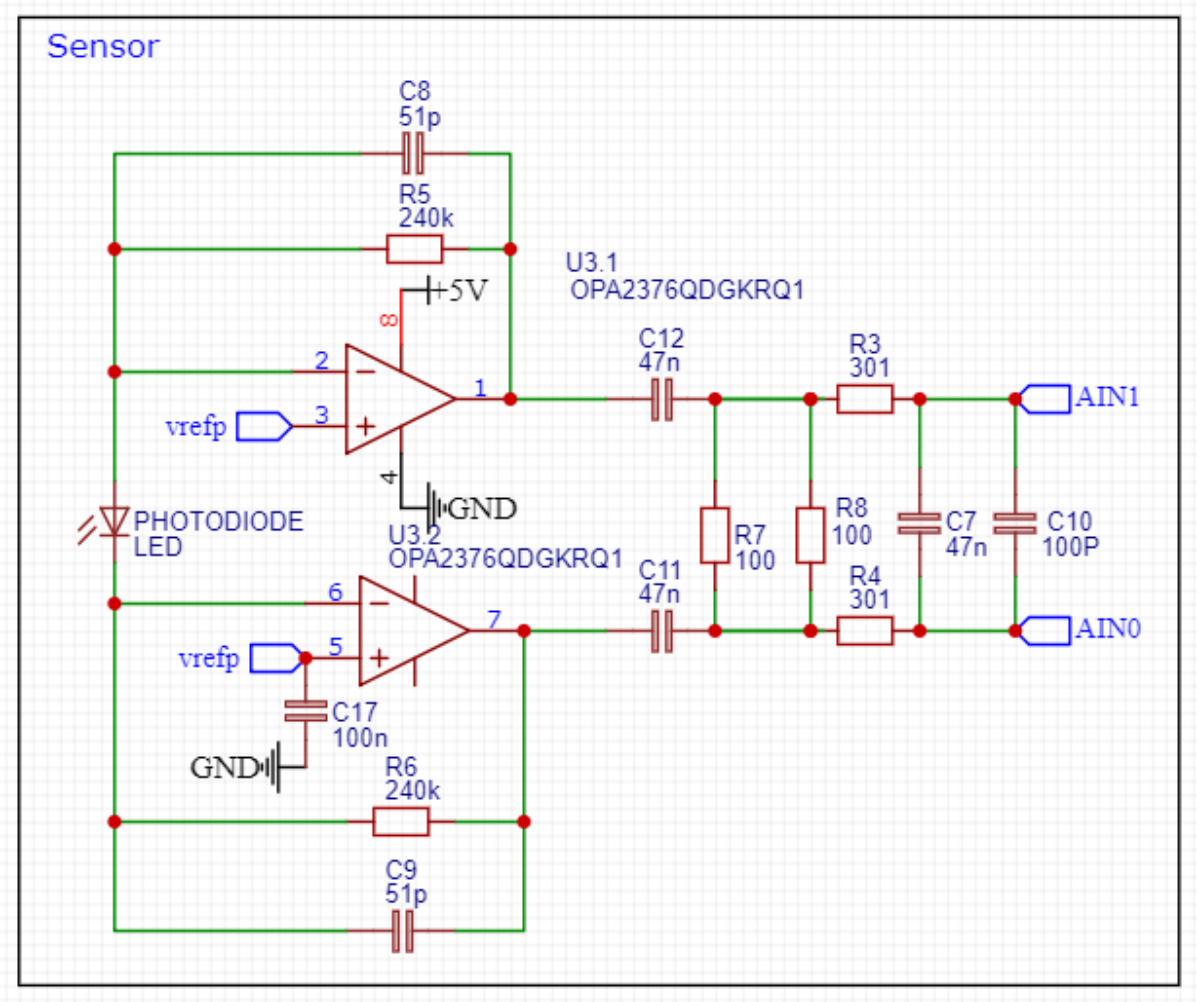
Problem 2

lose pads of 2,5v reference voltage



Old situation


GATE3
PHOTODIODE_A
C8_2
GND
2.5VREF
GATE4
PHOTODIODE_A
C8_2
GND
PHOTODIODE_A
U3
2.5VREF
2.5VREF
2.5VREF
PHOTODIODE_C
C9_1
+5V
+5V
GND
+5V

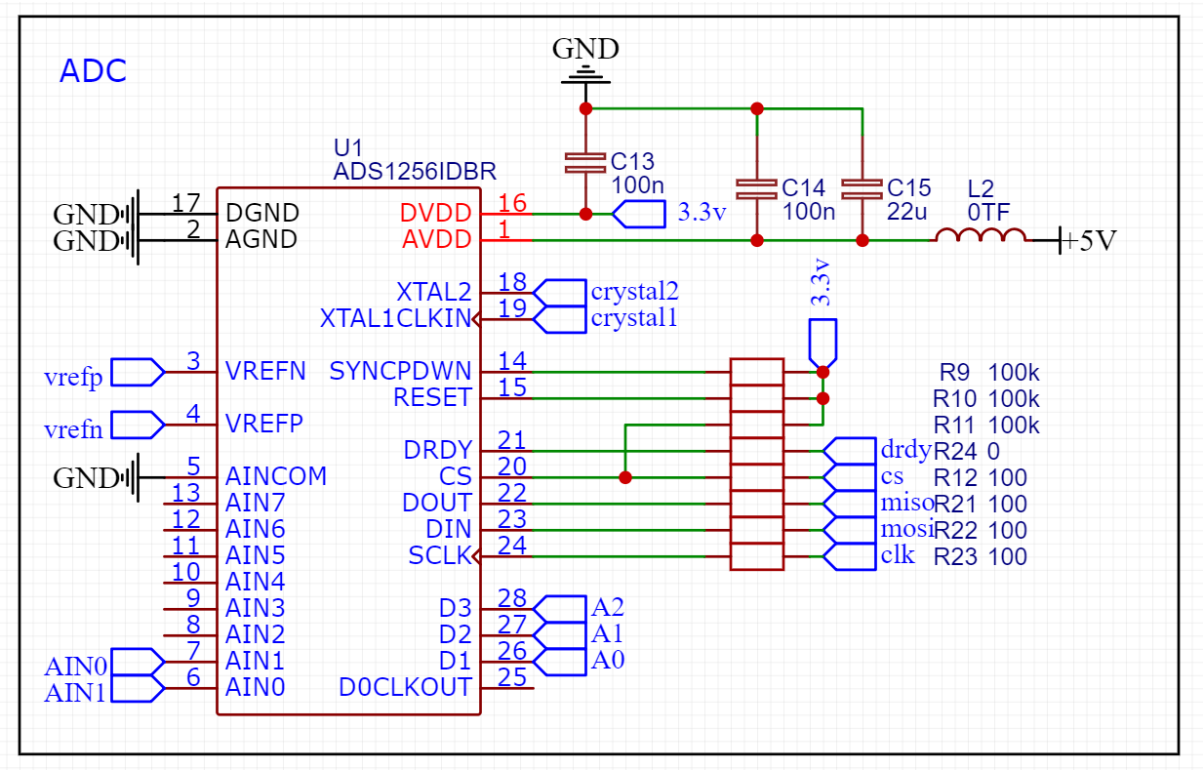


New Situation

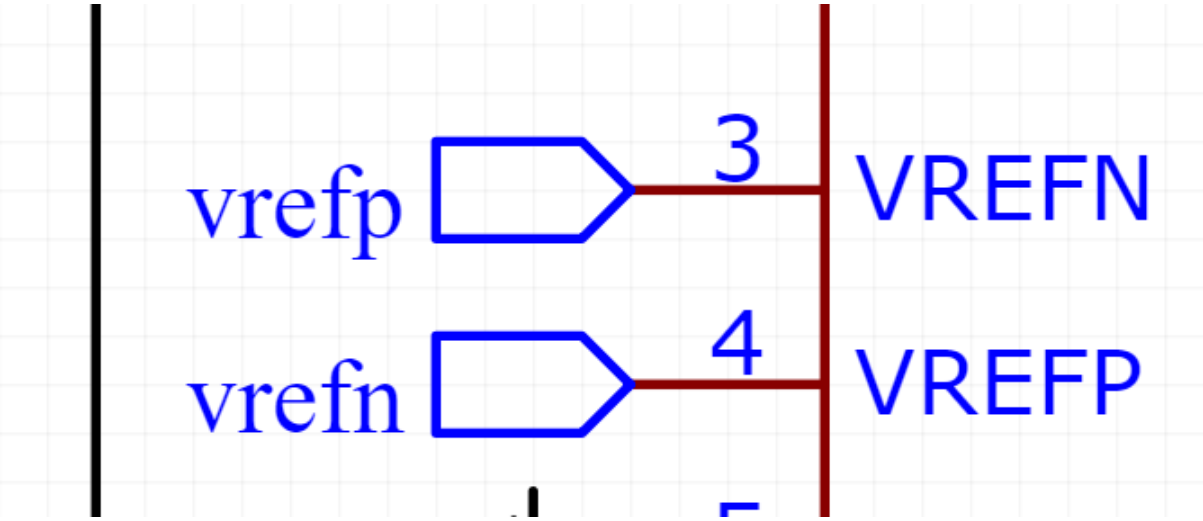
Picture of fix

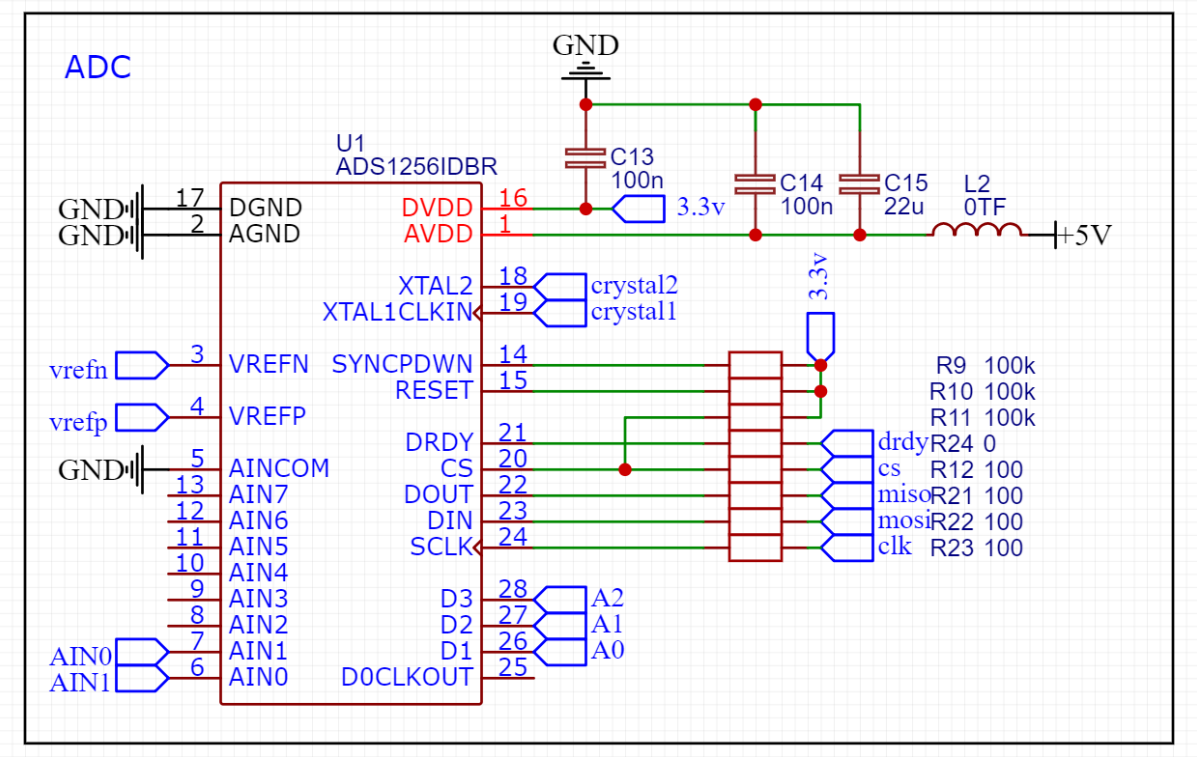
Problem 3

Swapped positive and negative voltage reference

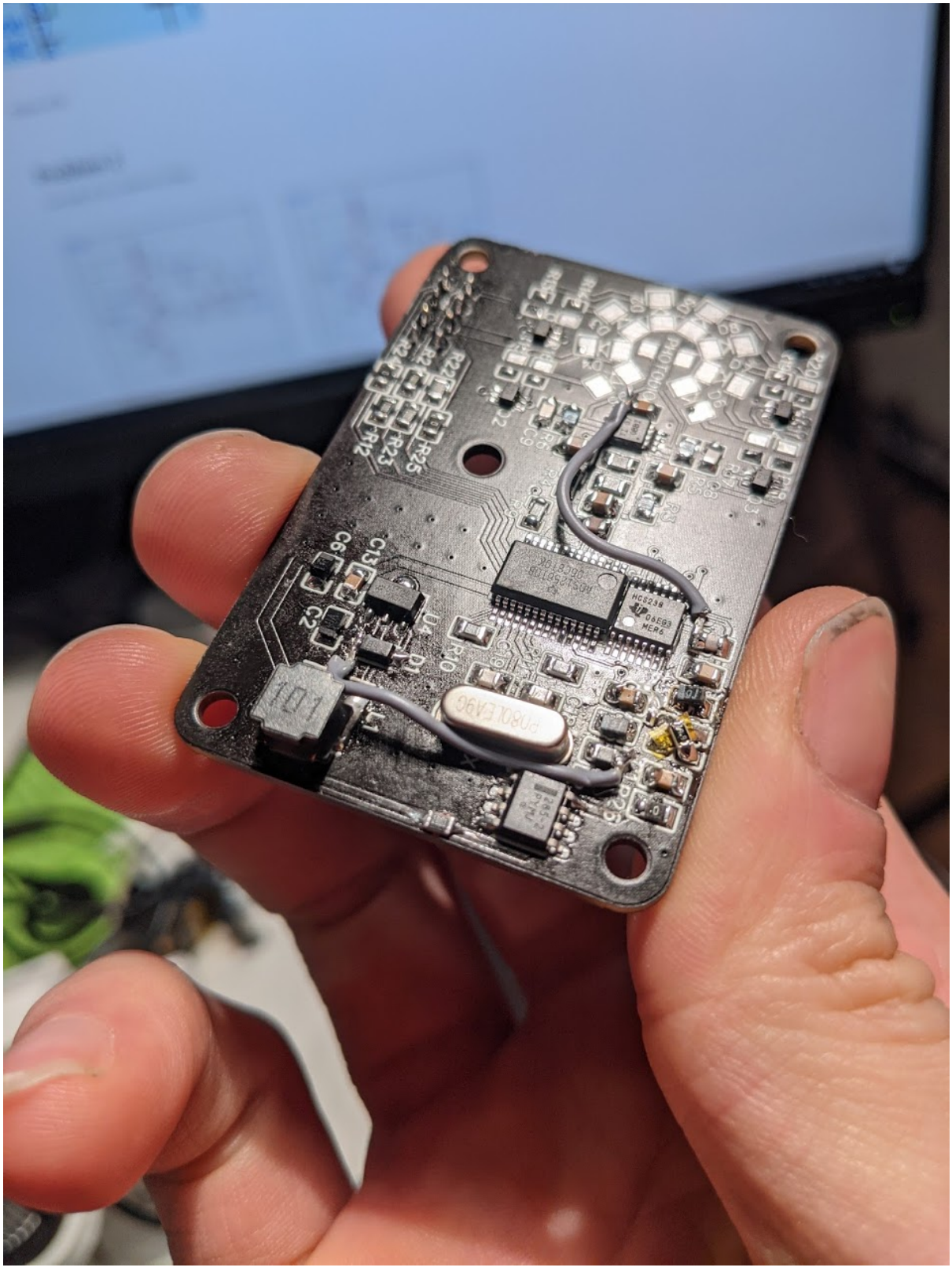


Old situation

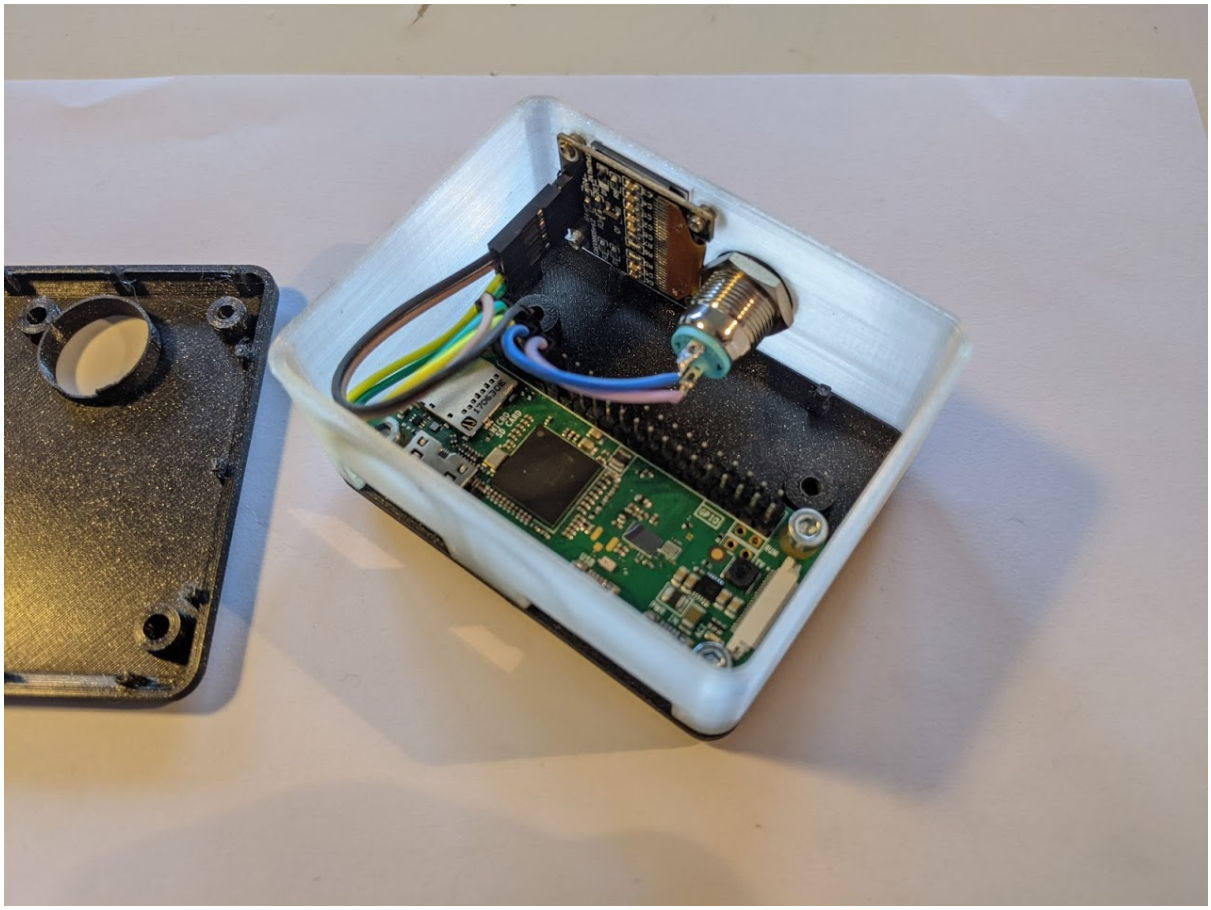


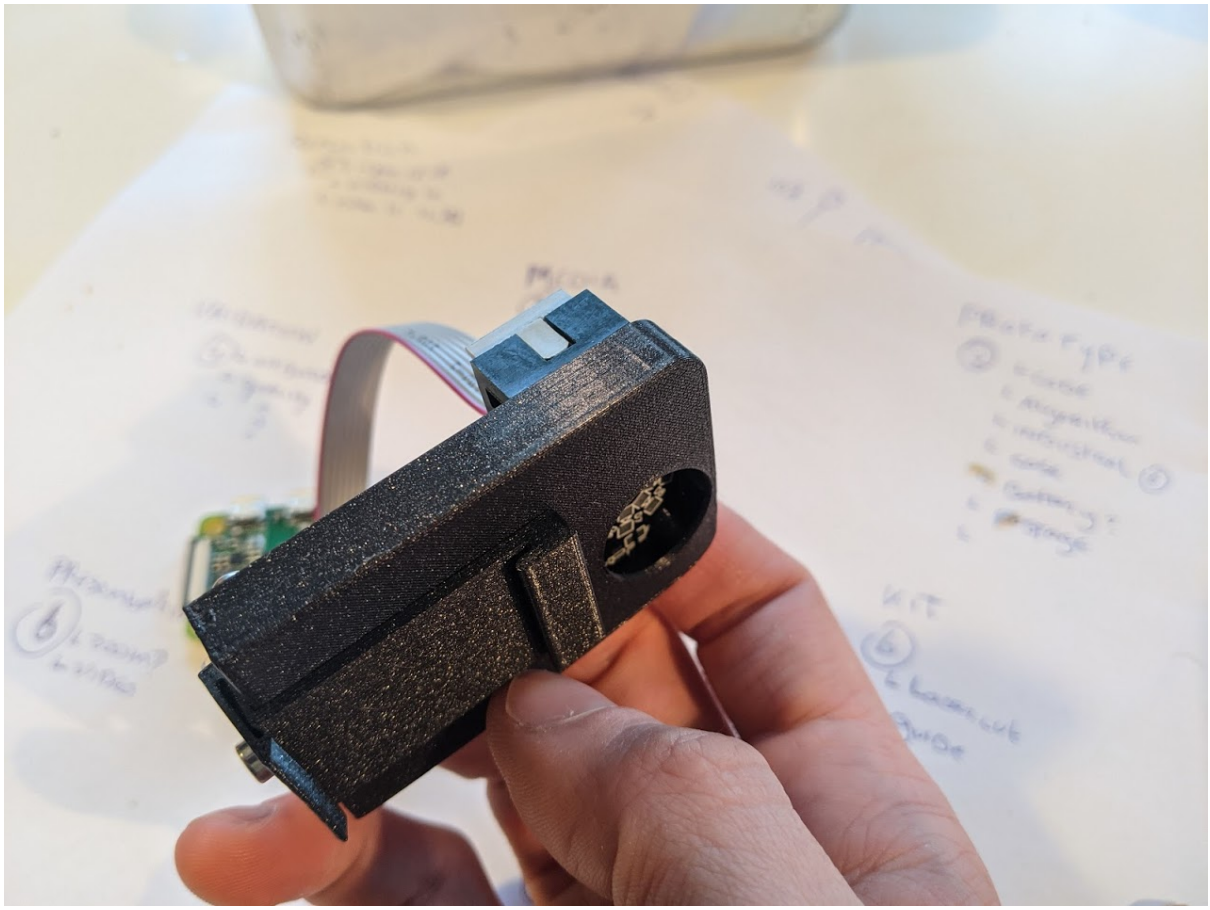


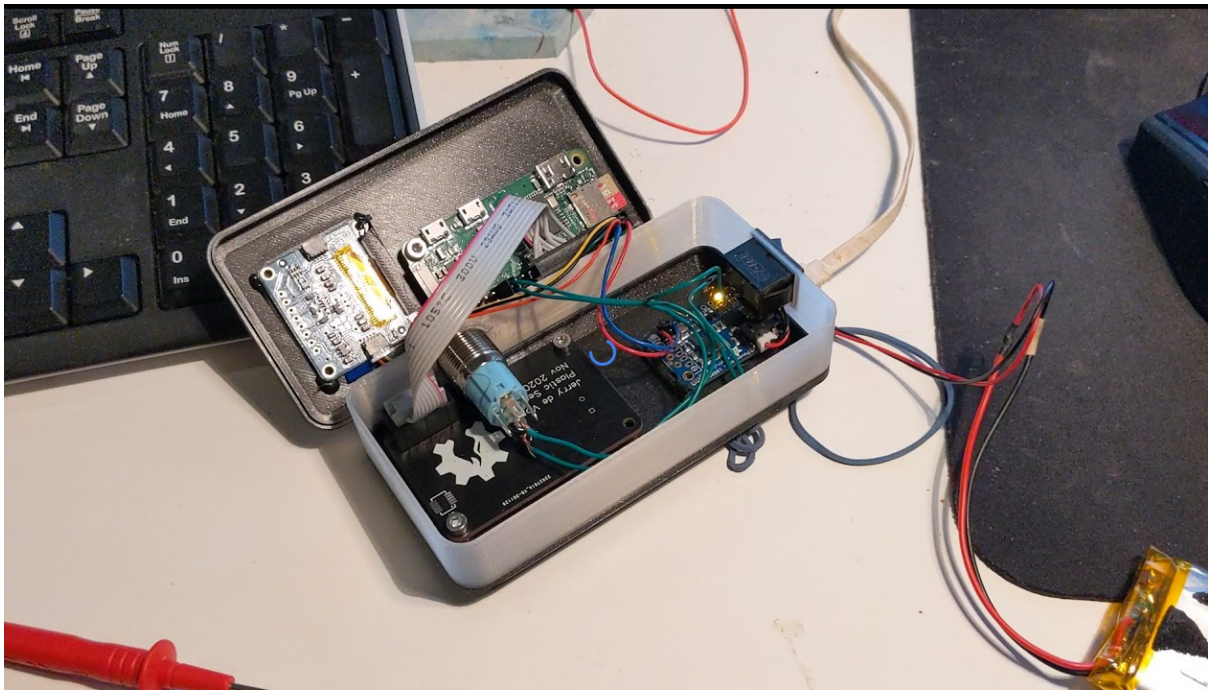
New situation

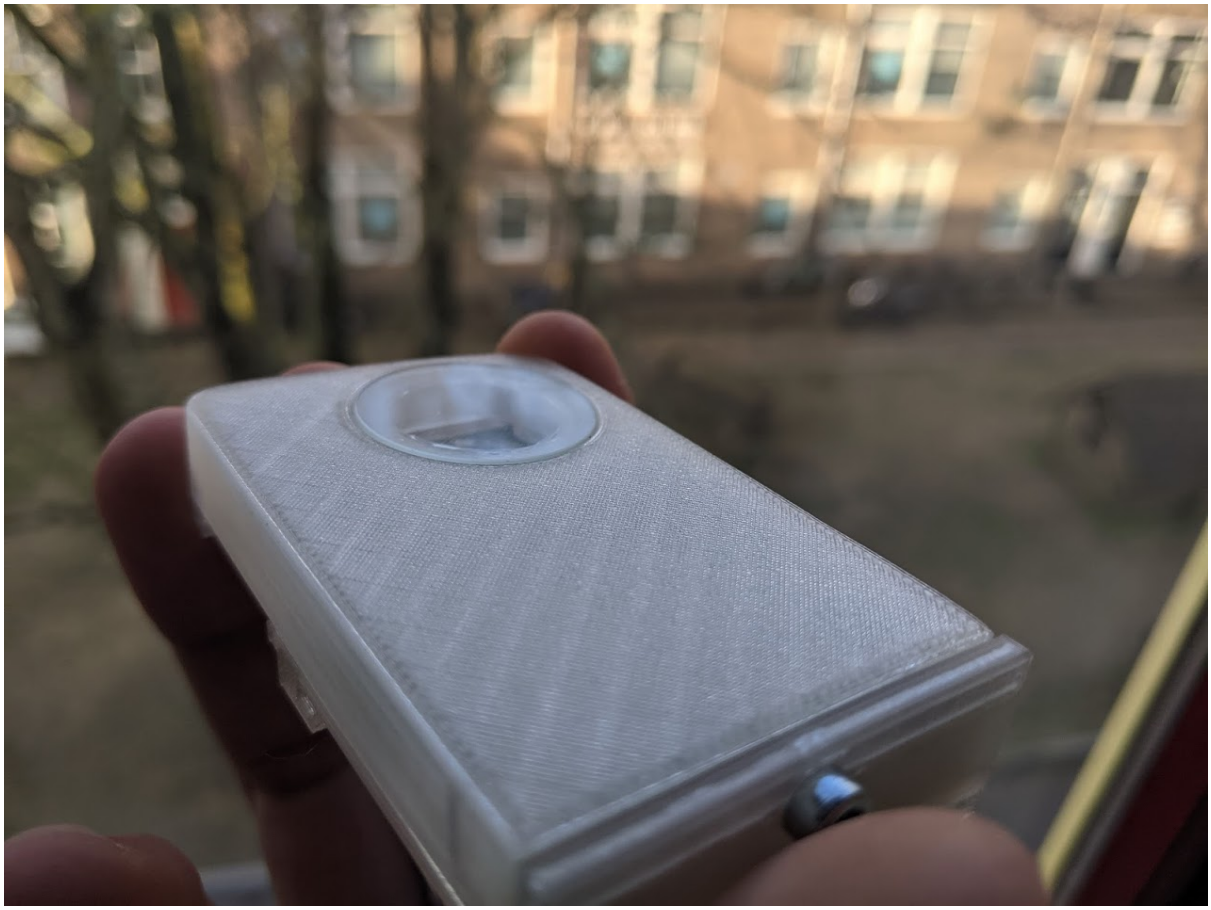


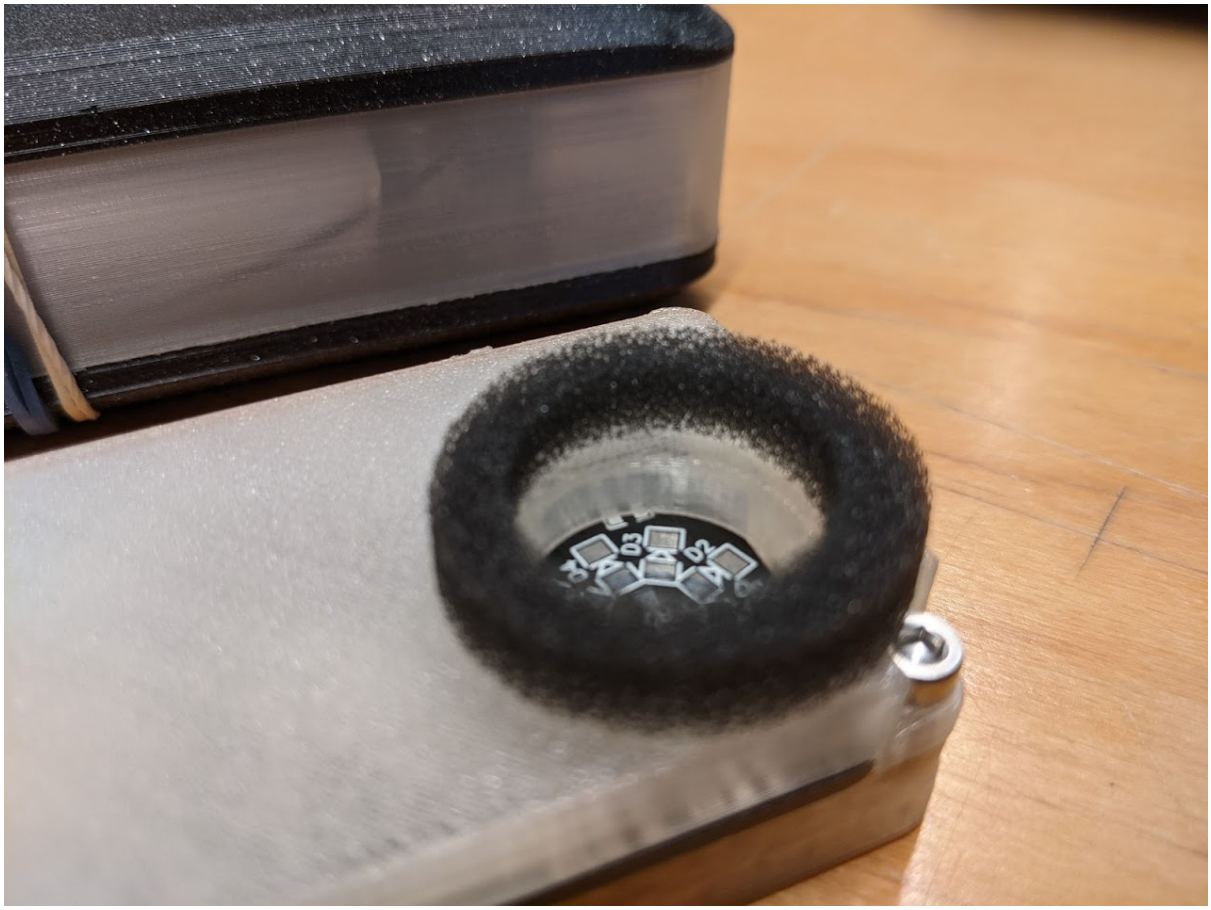
Part four - plastic scanner to finish

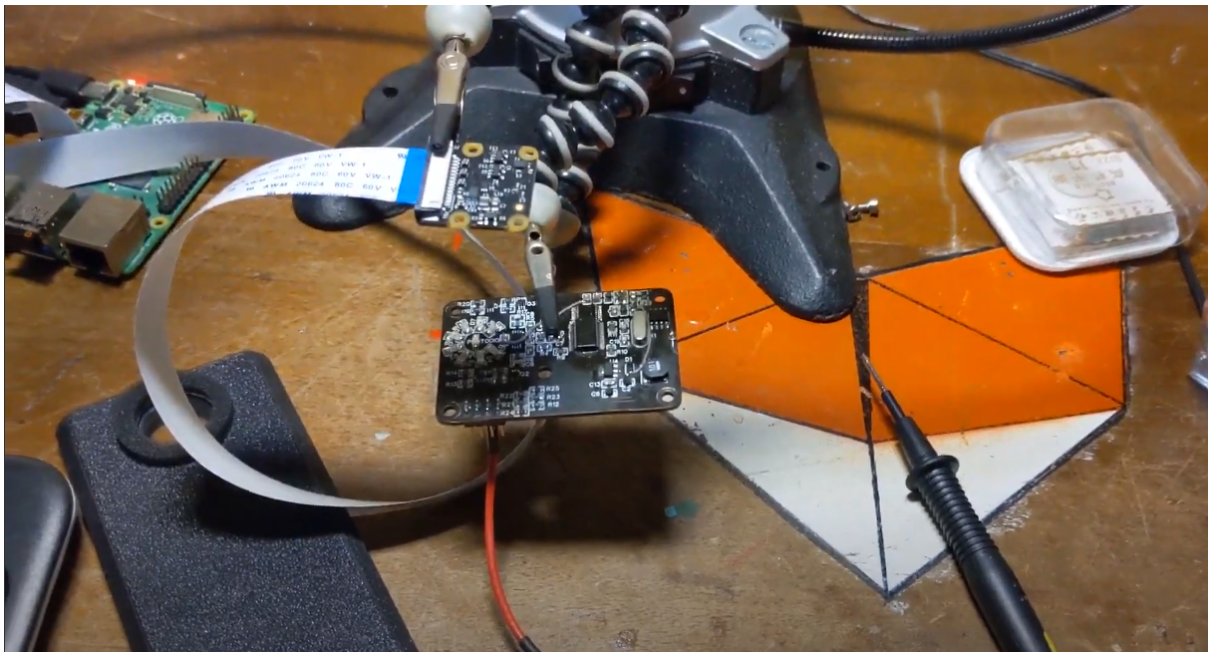


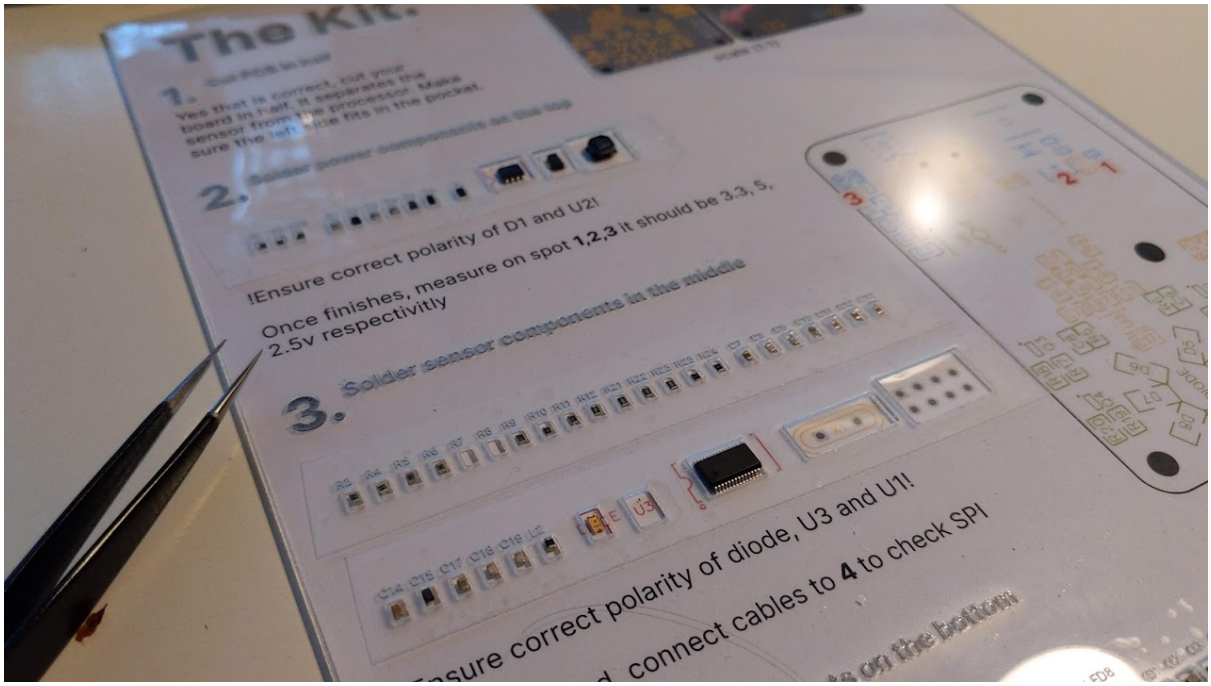












Manufacturing stages

Based on this this it's possible to propose 5 manufacturing options:

Open source - Kit- Basic - Pro - Product service system

each of this option will be explained in more detailed below

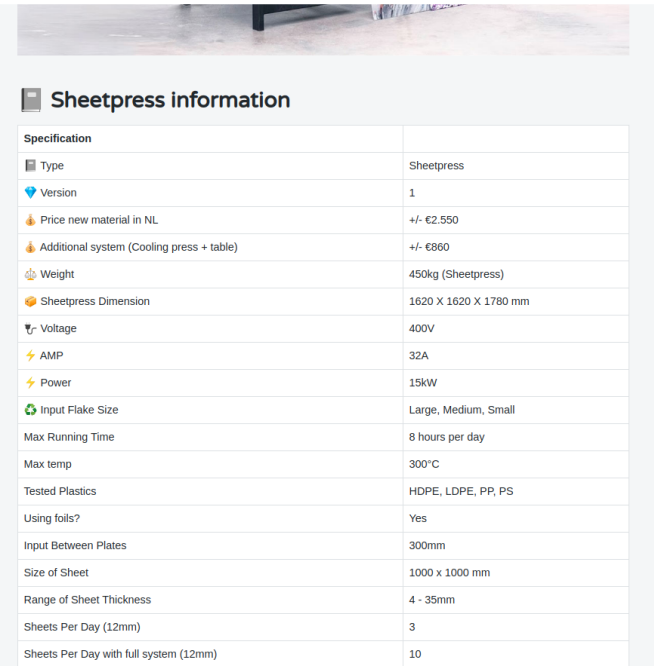
Otto DIY

documentation: 100% level: ☆☆☆☆☆ 1 hour version: 10 buy

instruction manual code with blockly arduino codes 3D files papercraft download

Background information:

Otto is truly Opensource; it means the hardware is easily discerned so that others can make it, is also Arduino



Sheetpress information

Specification	
Type	Sheetpress
Version	1
Price new material in NL	+/- €2.550
Additional system (Cooling press + table)	+/- €860
Weight	450kg (Sheetpress)
Sheetpress Dimension	1620 X 1620 X 1780 mm
Voltage	400V
AMP	32A
Power	15kW
Input Flake Size	Large, Medium, Small
Max Running Time	8 hours per day
Max temp	300°C
Tested Plastics	HDPE, LDPE, PP, PS
Using foils?	Yes
Input Between Plates	300mm
Size of Sheet	1000 x 1000 mm
Range of Sheet Thickness	4 - 35mm
Sheets Per Day (12mm)	3
Sheets Per Day with full system (12mm)	10

Open Source

Documentation will be delivered as is, user needs to source the parts themselves, solder components on PCB, assemble and test the product.

Envisioned target audience: Makerspaces, in house innovation labs, interested individuals.

Time required ★★★★★

Cost ★★

Skills ★★★★

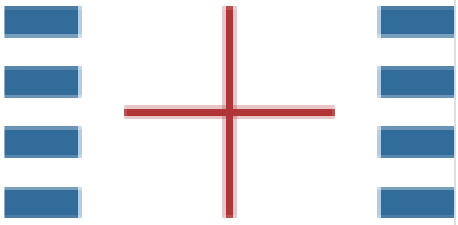
Example product

Open pick and place machine is an great example of an open source project that is open online free for all, well documented but also with a high startup cost

openpnp/openpnp

Open Source SMT Pick and Place Hardware and Software OpenPnP is a project to create the plans, prototype and software for a completely Open Source SMT pick and place

https://github.com/openpnp/openpnp



The Good

Allows for local manufacturing

People can contribute to the project

The Bad

Ordering single components everywhere can be expensive.

Building local makes it difficult to compare sensor data across the world.

Kit

A kit is provided for the project, people can buy or sell these kits and users know get the correct parts in one go. User orders the kit with all components, but needs to solder, assemble and test the product.

Envisioned target audience: Makerspaces, In house innovation labs, interested individuals, universities

Time required ★★★★

Cost ★★★

Skills ★★★

Example product

The Onze lucht project provides a kit to build your own air quality sensor in the north of the netherlands

Onze lucht

In het project Onze lucht meten burgerwetenschappers in heel Noord-Nederland de luchtkwaliteit, met zelfgebouwde fijnstofmeters. Zo krijgen de deelnemers inzicht in de

https://onzelucht.nl/

The Good

User gets the right parts, a one stop shop

Existing platforms like Etsy

The Bad

user is dependent on reseller

Basic

With a basic version of the plastic identification tool, the user buys a product from the reseller, the resellers provides product that is assembled, user needs to go through an one time setup and is afterwards able to use the product out of the box. The product is not calibrated.

Envisioned target audience: Plastic recycling companies, universities, companies involved in processing plastic

Time required⭐⭐⭐

Cost⭐⭐⭐⭐

Skills⭐⭐

Example product

Arduino provides programmable microcontrollers, after installing the software on the computer they can be used out of the box.

Arduino - Home

Open-source electronic prototyping platform enabling users to create interactive electronic objects.

https://www.arduino.cc/

The Good

User gets a product the is working

The Bad

User is not involved in making the product

might need to ship all over the world

Pro

With the pro version of the plastic identification tool, the users gets a product that is fully assembled and calibrated from the factory. The user can start using the product straight away.

Envisioned target audience: Plastic recycling companies, companies involved in processing plastic

Time required⭐⭐

Cost⭐⭐⭐⭐⭐

Skills⭐

Example product

WikiHouse

WikiHouse is a digitally-manufactured building system. It aims to make it simple for anyone to design, manufacture and assemble beautiful, high-performance homes that are

https://www.wikihouse.cc/

The Good

The Bad

Service

User signs contract for the service of identifying plastic, get the latest and greatest product, if the product is broken it will be replaced within the contract.

Envisioned target audience: Companies who want a product that "Just works"

Time required

Cost⭐⭐⭐⭐⭐⭐⭐

Skills

Example product

Red Hat is an consultancy agency that helps companies to use open source tools.

The world's open source leader

Red Hat is the world's leading provider of open source solutions, using a community-powered approach to provide reliable and high-performing cloud, virtualization, storage,

https://www.redhat.com/en

The Good

The Bad

Appendix

VII

Bill of Material

Bill of materials Handheld scanner

Part number	Part Description	Quantity	Price	Link
1	Breakout board	1	€176.97	https://wikifactory
2	Raspberry Pi Zero	1	€10.00	https://www.adafı
3	SD card	1	€10.30	https://www.digik
4	Powerboost 1000	1	€19.95	https://www.adafı
5	1.3 inch oled screen	1	€19.95	https://www.adafı
6	switch	1	€0.31	https://www.digik
7	button	1	€2.50	https://www.adafı
8	battery	1	€14.95	https://www.adafı
9	glass protector	1	€1.20	https://nl.aliexpre
10	m3 5mm	8	€0.11	Cilinderschroef m
11	IDC cable	1	€2.00	https://www.adafı
12	qwicc cable	1	€0.95	https://www.adafı
13	heat insers m3 3mm	4	€0.12	https://www.digik
14	3D print Top	1	€0.80	
15	3D print Middle	1	€0.10	
16	3D print Bottom	1	€0.67	
	Total price Handheld scanner		**€261.99**	

Bill of materials Breakout Board

	Part number	Part Description	Identifier	Quantity	Price	Link
PCB	1.00	printed circuit boa	n.a.	1	€1.00	https://easyeda.c
ADC	1.01	ADS1256	U1	1	€15.30	https://www.digik
Volt ref	1.02	2.5ref volage	U2	1	€0.85	https://www.digik
Opamp	1.03	Opamp 237	U3	1	€3.08	https://www.digik
Demultiplexer	1.04	Demux	U6	1	€0.35	https://www.digik
5V PSU	1.05	5v power	U4	1	€0.17	https://lcsc.com/p
Photodiode	1.06	InGaAs sensor	Photodiode	1	€13.80	https://www.digik
Inductor	1.07	inductor	L1	1	€1.50	https://www.digik
Diode	1.08	diode	D1	1	€1.40	https://www.digik
Crystal	1.09	crystal	X1	1	€0.75	https://www.digik
Connector	1.1	8 pin header	H1	1	€0.96	https://www.digik
Transistor	1.11	Transistor	Q1,Q2,Q3,Q4	4	€0.55	https://www.digik
Ferrite bead	1.12	ferrite bead	L2	1	€0.09	https://www.digik
LEDs	1.13.1	1650nm	D2	1	€17.18	https://www.digik
	1.13.2	1200nm	D3	1	€20.16	https://www.digik
	1.13.3	1050nm	D4	1	€17.84	https://www.digik
	1.13.4	1450nm	D5	1	€20.16	https://www.digik
	1.13.5	1550nm	D6	1	€11.79	https://www.digik
	1.13.6	1300nm	D7	1	€20.16	https://www.digik
	1.13.7	950nm	D8	1	€12.21	https://www.digik
	1.13.8	850nm	D9	1	€12.21	https://www.digik
Resistor	1.14.1	240k	R5,R6	2	€0.03	https://www.digik
	1.14.2	301	R3,R4	2	€0.03	https://www.digik
	1.14.3	1k	R7, R26	2	€0.06	https://www.digik
	1.14.4	100k	R9,R10,R11	3	€0.02	https://www.digik
	1.14.5	100	R8,R12,R21,R22	5	€0.03	https://www.digik
	1.14.6	0	R24,R25	2	€0.08	https://www.digik
	1.14.7	49.9	R1,R2	2	€0.06	https://www.digik
	1.14.8	43	R13,R14,R15,R1	6	€0.04	https://www.digik
	1.14.9	39	R19	1	€0.04	https://www.digik
	1.14.10	36	R20	1	€0.03	https://www.digik
Capacitor	1.15.1	47n	C7	1	€0.15	https://www.digik
	1.15.2	1n	C10	1	€0.03	https://www.digik
	1.15.3	100n	C11,C12,C17,C1	7	€0.03	https://www.digik
	1.15.4	47pf	C8,C9	2	€0.14	https://www.digik
	1.15.5	22u	C15,C5	2	€0.18	https://www.digik
	1.15.6	18p	C18,C19	2	€0.06	https://www.digik
	1.15.7	100p	C3	1	€0.04	https://www.digik
	1.15.8	100u	C2	1	€0.68	https://www.digik
	1.15.9	47u	C6	1	€0.89	https://www.digik
			Total price Breakout board		**€176.97**	

Appendix

VIII

Expensis

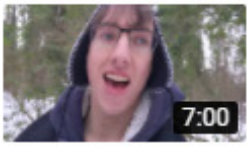
Expensis

Name	Company	amounth	receipt	date	note
LEDs	RS components	€161.12			by applied labs
Components	DigiKey	€122.70	INVOICE_76758577.pdf INVOICE_76567829 (1).pdf		
PCB	JLCpcb	€20.79	content (2).pdf		
Taxes	ups	€22.68			
Taxes	ups	€7.12			
Esp32	Tinytronics	€24.50	TinyTronics-Factuur-INV-2020-43672-161410.pdf		
filament	Tinytronics	€45.00	TinyTronics-Factuur-INV-2020-43672-161410.pdf		
charger	bol.com	€25.00	15292126875_2521774830_20201116.pdf		
components	RS components	€80.00			By applied labs
components	DigiKey	€106.03	INVOICE_77401468.pdf		
taxes	ups	€26.00			
PCB	JLCpcb	€19.07	content (1).pdf		
components	lcsc	€35.56	20201202MF9O_invoice.pdf		
components	Okaphone	€13.75			
Components	DigiKey	€279.79	INVOICE_77854421.pdf		
Tax	ups	€134.25			
IR sensor	Antratek	€61.41	Factuur_100041570.pdf		
Moeren	Fabory	€56.00	920438215.pdf		
Toolkit	iFixit	€40.84	RE 202100923839 (1).pdf		for armins work
Components	Tinytronics	€60.60	TinyTronics-Factuur-INV-2021-5181-178618.pdf		

Appendix

IX

Reflection

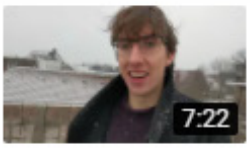


Graduation Reflection Week 21&22
Beschrijving toevoegen

https://youtu.be/QZVInysoox4

Graduation Reflection Week 19&20
Beschrijving toevoegen

https://youtu.be/m-Vsv6jlK60



Graduation Reflection Week 17&18
Beschrijving toevoegen

https://youtu.be/PrhaGf1NOk4

Graduation Reflection Week 15&16
Beschrijving toevoegen

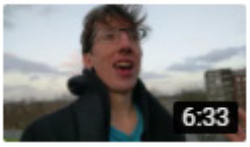
https://youtu.be/kFeEZcPEm7Q

Graduation Reflection Week 13&14
Beschrijving toevoegen

https://youtu.be/tOAk2DCb-pc

Graduation Reflection Week 13&14
Beschrijving toevoegen

https://youtu.be/bPsp124c9tQ

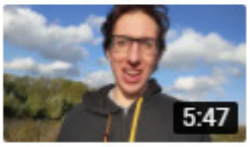


Graduation Reflection Week 11&12
Beschrijving toevoegen

https://youtu.be/lB6BAKlQv8I

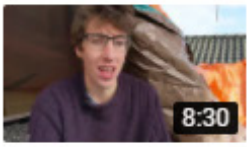
Graduation Reflection Week 9&10
Beschrijving toevoegen

https://youtu.be/gPWJu1vB8zw



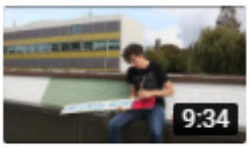
Graduation Reflection Week 7&8
Beschrijving toevoegen

https://youtu.be/41EbfEpWIxc



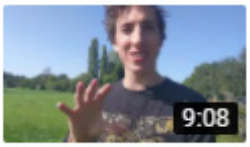
Graduation Reflection Week 5&6
Beschrijving toevoegen

https://youtu.be/bx5tIGXURNU



Graduation Reflection Week 3&4
Beschrijving toevoegen

https://youtu.be/mh_S4Xut0Fw



Graduation Reflection Week 1&2
Beschrijving toevoegen

https://youtu.be/wjYkeD_cECM