Utilizing Simple Technology to Create an Instrument for Accessibility-Friendly pH Measurements

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Abstract

The pH of a solution is an indicator of the acidity (or basicity) of a scientific sample.[1] It is a fundamental concept that is impactful to biological, chemical, industrial, and environmental systems.[1] Therefore, several methods have been designed to measure pH with varying levels of accuracy and precision. In the undergraduate laboratory, one of the most widely used qualitative methods of pH measurement is via paper that has been coated with pH responsive dyes. The dye changes color in response to a given solution, and this color can be matched to a scale with corresponding pH values.[2] This method is quick, easy, and affordable, but has the major pitfalls of being inaccessible to visually impaired students and susceptible to producing measurements that have been impacted by the paper itself or skewed by differences in human perception. The aim of this project is to create a practical and convenient instrument that uses a fully accessible output to provide a standardized reading of the color value of a pH responsive dye. The device will utilize an Adafruit QT Py computing system, simple circuitry, Computer-Aided Design, 3D printed components, and Python coding. This project also serves as an example of multidisciplinary research and demonstrates a proof-of-concept that effective chemical instrumentation can be made on obtainable, small scales.

Background

- pH paper is created by saturating small strips of paper with dyes that change color in response to the proton concentration in a sample of solution.[2]

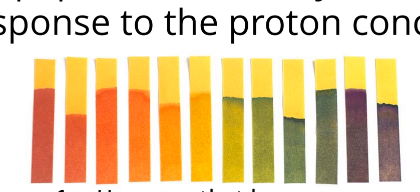


Figure 1: pH papers that have responded to solutions of varying pH

  - Easy to use, quick, durable, and affordable (~$10 per roll)[3]
  - Accuracy is reduced by human interpretation error, chemicals present in papers, and degradation
  - Inaccessible to blind and colorblind users
- pH probes are electrical devices that translate the voltage difference between a reference and test electrode to a pH value and report it digitally.[4]

Figure 2: A typical pH probe.

  - More accurate and accessible than pH paper
  - Delicate, bulky, difficult to use, and time intensive., and expensive (~$70 and upwards per probe)[5]
  - Both pH paper and pH probes are not designed for use in aqueous mediums
- The typical chemistry lab setting can be challenging for individuals with disabilities, particularly in regards to those with visual impairments.
  - Reading graphs or charts, analyzing structures, and making observations are an essential component of lab work[6]
  - Recent work has aimed to provide alternative methods such as tactile models, computer simulations, web-based aids, adapted procedures, and simple instruments so that visually impaired individuals can carry out effective lab work[6, 7, 8, 9]
- The design, construction, and implementation of simple instrumentation is a booming subject in the field of chemistry. It improves accessibility in lab settings, offers opportunities to explore sustainable research, and reduces costs.[10, 11]
  - Qutieshat et al.'s standardized pH paper reader does not account for the complications introduced from paper or provide a fully dark environment[12]
  - Dos Santos et al.'s concept for a smartphone-based spectroscopy device is revolutionary, but not practical due to component variation[13]

Materials

A Prusa 2M 3D printer was utilized for all 3D prints and a Sparkfun soldering iron with lead-free solder was used to solder all components. All materials and resources for Prototype 1 follow:

Total Project Cost: < ~$400

Prototype 1 Materials Cost: $82.17

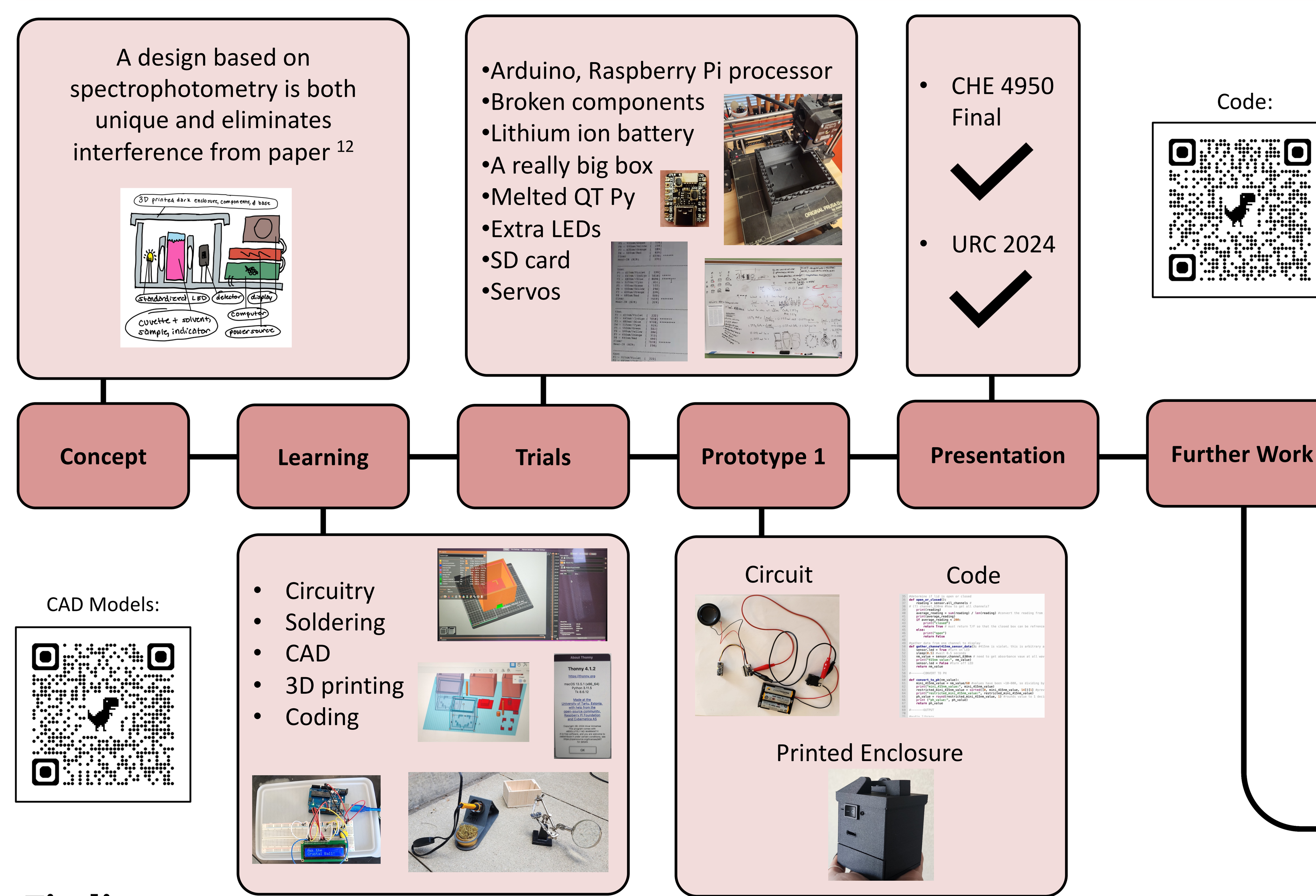
Prototype 1 Price Per Unit: $44.77

Compare to:

Vernier GoDirect Spectrophotometer: $460[14]

PerkinElmer ScanLambda 650: ~ $20000[15]

Methods



Findings

Figure 3: A simplified diagram of the final circuit for Prototype 1.

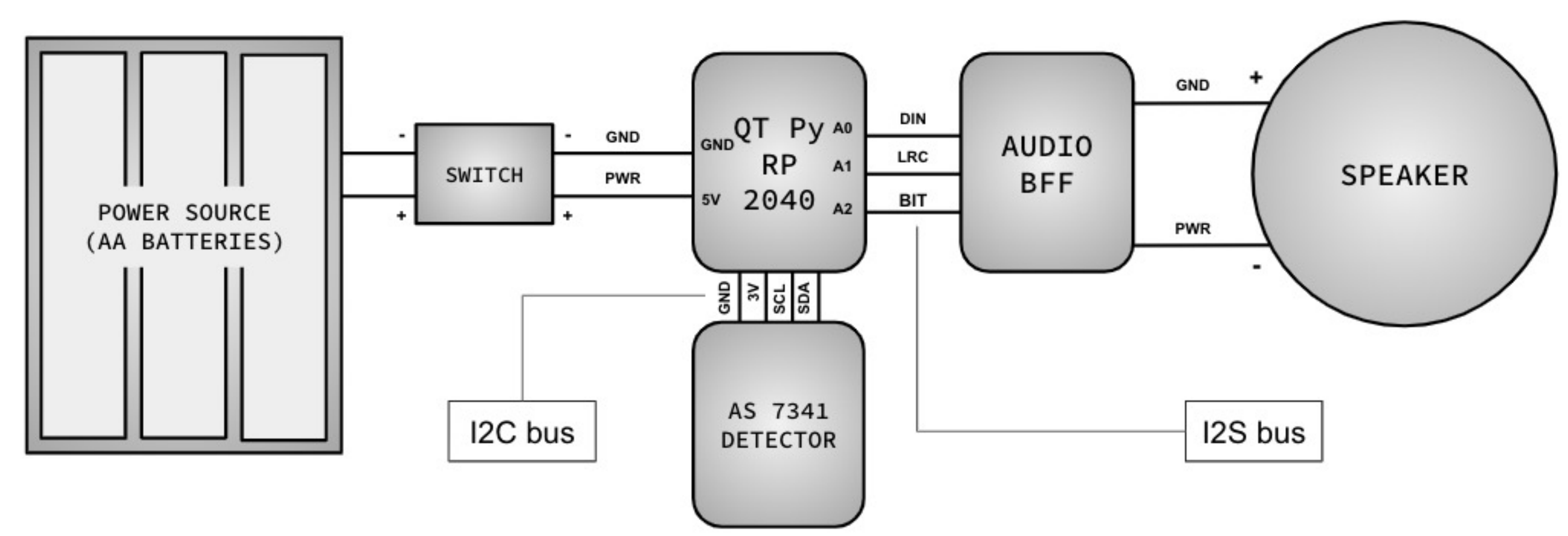
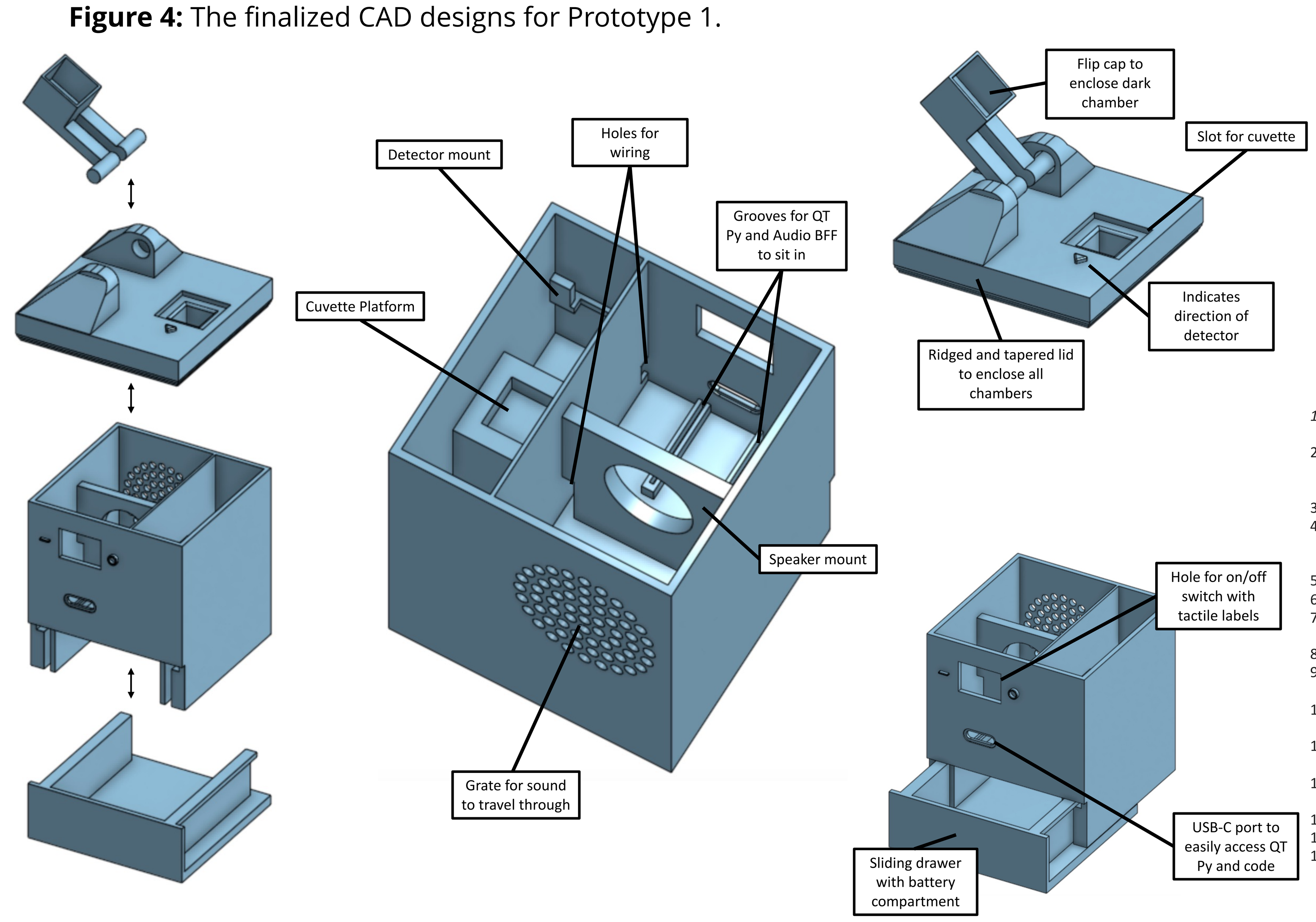


Figure 4: The finalized CAD designs for Prototype 1.



The code for this project is written function-wise. A Main Loop calls upon a series of functions that drive the entire instrument's operations. There are three major categories of functions, each of which are composed by more specific functions:

- Operate detector
  - Determine if the chamber cap is open or closed via a darkness threshold
  - If cap is closed, gather a reading from the detector in arbitrary units
- Convert readings to pH value
  - Convert the detector value to an appropriate pH value*
    * This code is not yet complete because the calibration is not finished
- Play an audio output
  - Retrieve, organize, and format audio files from a library
  - Match the determined pH value to the prepared audio files
  - Play audio files on speaker
- The Main Loop repeats them every 5 seconds when the device is connected to power

```
#--------MAIN LOOP

while True:
    sleep (5) #wait 5 seconds then repeat
    if open_or_closed(): #if sensor is in the dark
        nm_value = gather_channel590nm_sensor_data() #gather the detector reading from 590nm channel
        ph_value = convert_to_ph(nm_value) #use 590nm value to calclulate a ph value
        play_ph(ph_value) #use ph_value to play corresponding audio
        (ph_value)
```

Figure 5: The Main Loop of Prototype 1's code. This code retrieves data for the detector's 590nm (Yellow) channel.

Next Steps

Pitfalls to Correct:
- Filament that is soluble in organic solvents
- Imperfect dark chamber and light source
- Junctions where liquids may enter instrument
- Print that uses supports

Areas of Focus:
- Calibration
- Tactile display

Figure 6: The detector produces a 10-variable output for each pH reading inputted. A series of pH solutions can be used to calibrate the instrument, and a mathematical model that can convert any detector output back to a pH value will be established. Multioutput regression and machine learning methods will be considered.[16]

Objective Model

Additional Work:
- Added code features (battery indicator, other languages, etc.)
- Manufacturing a circuit board and further design refinement
- Calibrate for organic solvents
- Sample testing
- Try the instrument in classic lab experiments
- Exploration into other small-scale instrumentation projects

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Resources

1) *8.6: The pH Concept*. Chemistry LibreTexts. https://chem.libretexts.org/Bookshelves/Introductory_Chemistry/Chemistry_for_Allied_Health_(Soult)/08%3A_Properties_of_Solutions/8.06%3A_The_pH_Concept (accessed 2024-04-25).
2) 6. Acid-Base Indicators. Chemistry LibreTexts. https://chem.libretexts.org/Bookshelves/Physical_and_Theoretical_Chemistry_Textbook_Maps/Supplemental_Modules_(Physical_and_Theoretical_Chemistry)/Equilibria/Acid-Base_Equilibria/6._Acid-Base_Indicators (accessed 2024-04-25).
3) Amazon.com. https://www.amazon.com/Hydrion-paper-93-Dispenser-Color/dp/B005FYGXUC (accessed 2024-04-25).
4) pH Electrodes. Chemistry LibreTexts. https://chem.libretexts.org/Bookshelves/Analytical_Chemistry/Supplemental_Modules_(Analytical_Chemistry)/Analytical_Sciences_Digital_Library/Courseware/Analytical_Electrochemistry%3A_Potentiometry/05_pH_Electrodes (accessed 2024-04-25).
5) pH Electrode BNC. Vernier. https://www.vernier.com/product/ph-electrode-bnc/ (accessed 2024-04-26).
6) Schnepp, Z.; Watson, R. Making Chemistry Accessible for Learners with Vision Impairment. Commun Chem 2023, 6, 232. https://doi.org/10.1038/s42004-023-01033-x.
7) Aristov, M. M.; Moore, J. W.; Berry, J. F. Library of 3D Visual Teaching Tools for the Chemistry Classroom Accessible via Sketchfab and Viewable in Augmented Reality. J. Chem. Educ. 2021, 98 (9), 3032–3037. https://doi.org/10.1021/acs.jchemed.1c00460.
8) American Printing House for the Blind; Hoffmann, R. The SALS App: Making Chemistry Accessible With iOS Devices. JSESD 2019, 22 (1), 1–5. https://doi.org/10.14448/jsesd.11.0005.
9) Patchett, R.; Watson, R.; Davies, J.; Schnepp, Z. Carbon for Water Treatment: A Chemistry Experiment That Is Accessible for Vision Impaired People. J. Chem. Educ. 2022, 99 (1), 494–499. https://doi.org/10.1021/acs.jchemed.1c00396.
10) Kovarik, M. L.; Clapis, J. R.; Romano-Pringle, K. A. Review of Student-Built Spectroscopy Instrumentation Projects. J. Chem. Educ. 2020, 97 (8), 2185–2195. https://doi.org/10.1021/acs.jchemed.0c00404.
11) Chen, Y.; Wu, Y.; Li, Z.; Zheng, Y.; Yan, B.; Cheng, Y. A Raspberry Pi Pico Based Low-Cost, Research-Grade, Open-Source Thermal Conductivity Cell Detector for Chemical Laboratory Analysis. J. Chem. Educ. 2023, 100 (9), 3477–3483. https://doi.org/10.1021/acs.jchemed.3c00488.
12) Qutieshat, A.; Aouididi, R.; Arfaoui, R. Design and Construction of a Low-Cost Arduino-Based pH Sensor for the Visually Impaired Using Universal pH Paper. J. Chem. Educ. 2019, 96 (10), 2333–2338. https://doi.org/10.1021/acs.jchemed.9b00450.
13) ED2023-0025.pdf. https://quimicanova.sbq.org.br/pdf/ED2023-0025 (accessed 2024-04-26).
14) Go Direct® SpectroVis® Plus Spectrophotometer. Vernier. https://www.vernier.com/product/go-direct-spectrovis-plus-spectrophotometer/ (accessed 2024-04-26).
15) Perkinelmer scan lambda 600 cost - Google Shopping. https://www.google.com/search?q=Perkinelmer+scan+lambda+600+cost&sca_esv=3eb2b7adee194e22&sca_upv=1&rlz=1C5CHFA_enUS853US868&biw=979&bih=770&tbm=shop&sxsrf=ACQVn09PjepxkuZlu2wuv8MXChdCu3Pp2A%3A1714050904844&ei=WFcqZpzeMsiC0PEP7P-wgA0&ved=0ahUKEwic6ryaud2FAxVIATQIHew_DNAQ4dUDCAg&uact=5&oq=Perkinelmer+scan+lambda+600+cost&gs_lp=Egtwcm9kdWN0cy1jYylgUGVya2luZWxtZXIgc2NhbiBsYW1iZGEgNjAwIGNvc3QyBBAjGCcyBBAjGCdItQlQxAdYxAdwAXgAkAEAmAFioAHAAaoBATK4AQPIAQD4AQGYAgOgAsoBmAMAiAYBkgcDMi4xoAf0BQ&sclient=products-cc (accessed 2024-04-26).
16) Li, X.; Wang, Y.; Zhang, Z.; Hong, R.; Li, Z.; Wang, M. RMoR-Aion: Robust Multioutput Regression by Simultaneously Alleviating Input and Output Noises. IEEE Transactions on Neural Networks and Learning Systems 2021, 32 (3), 1351–1364. https://doi.org/10.1109/TNNLS.2020.2984635.