Science Fair Logbook

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Contents

June 12, 2023

Possible subjects for CYSF

- Wireless energy through magnetic induction (Innovation)

Pros:
- Very innovative, can become a kickstarter (Phone charger)
- Cool to do tests on - coil size, frequency, distance

Cons:
- Limited range (under 2 meters)
- High energy consumption, low efficiency, and could be dangerous (radiation).

- Using machine learning to predict the stock market (Innovation)

Pros:
- It is useful to have or find patterns in the market
- Ties into AI and big data

Cons:
- There are more factors to stock prices than just numbers, the AI will have to understand the news (Very hard and might not be possible).
- Accuracy will take a long time to get right, and a massive amount of data will be needed.

★ Smart pen that digitizes physical notes (Innovation)

Pros:
- It is convenient to have, can become a kickstarter eventually
- Can have many implications such as online learning in a pandemic

Cons:
- VERY complex and could take alot of time to finish
- Custom tech requires custom parts (expensive / hard to manufacture).

- Testing effective ways to produce/extract hydrogen (experimental)

Pros:
- Hydrogen combustion is more efficient than oil (and more sustainable)
- I already know about electrolysis (Splitting water to hydrogen and oxygen).

Cons:
- Rather than doing existing ideas would be hard as ill have to find a new way to form a reaction with little experience.

June 14, 2023 2

Problem & Research Question

As the world shifts into digital means, pen and paper writing is becoming increasingly less popular. However, research indicates that traditional writing offers significant advantages over typing, particularly in memory retention.* Because rather than transcribing lectures, students paraphrase it to something that makes sense to them.

→ The pen is mightier than the keyboard Pam A. Mueller and Daniel Oppenheimer.

- Why can't we have both?

This project seeks to merge the digital convenience of typing with the cognitive benefits of handwriting by developing a pen that digitizes writings without external components - like a screen or encoded notebook found in other smart pens (eg) livescribe.

↘ very inconvenient and costly to buy their specialized notebooks

- No external components = More practicality and accessibility, encouraging widspread adoption.

- Research Question:

How can a pen without external components effectively digitize handwritten notes in real time.

- What about iPads? Not enough evidence and copy-paste tools likely lower effectiveness of note taking.

Hypothesis

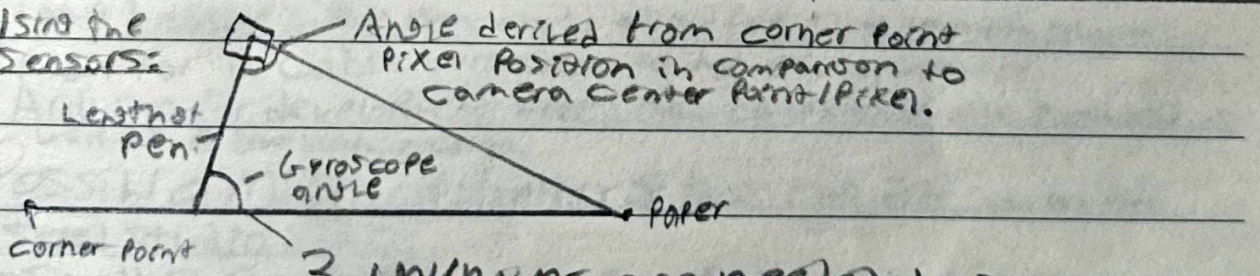
It is hypothesized that the synergy of low-cost sensors embeded in a pen along with costumized and open source algorithems can ensure an accurate digital replica of handwriting on paper/drafting page. Without external components.

- How will the pen work?

What internal components/sensors could be used?

-Accelerometer + Inaccurate	Acceleration in direction
- Gyroscope	Angular velocity (rotation)
- Compass	Direction based on Poles
- Mouse sensor (laser or optical)	To detect movement on paper
- Camera/optical sensor	Could compare writings/corners to track position or frame.
- ~~Proximity sensors~~ - will need alot of them/ not very useful, only for distance to the page	not where
- Microcontroller	TO process the sensor data and derive the location
- Battery	To facilitate a wireless flow of power
- Bluetooth module	To transmit the data or Coordinates for output/ further processing.

Using the Sensors:



3 unknowns are needed to solve a triangle (at least one must be a length, and 1 must be an angle)

I then constructed a 3d pyramid using skewer sticks and a give em for further brainstorming of the formulas.

* Further brainstorming can be found towards the end of the logbook (It is viewed from many angles and I did not want space to be a limitation).

The Design

- Components needed for positioning:

Camera: To detect the page's corner points

Compass and gyroscope: To track the pen's 3 dimensional orientation to the paper

Microcontroller: To process the data collected by the sensors

Bluetooth module: To send the digitized replica to an external device for output or further processing.

Battery: To allow for wireless usage of the pen.

- Compass vs. Gyroscope:

A compass determines the pen's direction along the x-axis, this displacement can also be detected by a gyroscope, however compasses are less prone to have bias/drift in their output over time as they are comparing their orientation to Earth's poles rather than angular velocity displacement based on previous outputs.

- Goals for design #1

- Good visibility from the camera (At the top)
- Similar dimensions as a normal pen. 15cm tall and a maximum 1.5 cm width.
- Easy to 3d print the frame
- Enough space for components, like the mouse sensor
- The microcontroller's size should be as big as possible to maximize its speed and ability to run the programs. A clamp holder in the pen could allow for slightly more space
- Room for a cable connection to the microcontroller
- Arduino for development speed and compatability is preferred, as well as a bluetooth module.

- Possible microcontrollers that can fit into the pen

1. Seed studio xiao.
   - Smallest, cheapest but not powerful nor has many ports/connectors
2. Arduino micro
   - Little power and no bluetooth.
3. Arduino Nano
   - Large and old, so not as powerful as other Arduinos
4. Arduino Nicla vision, ★ Best (so far)...
   - Expensive but contains a gyroscope, compass, and camera and is also quite powerful. However these parts are not accurate as others in the market and the camera will have to be away from the microcontroller (on the top of the pen).

June 19, 2023

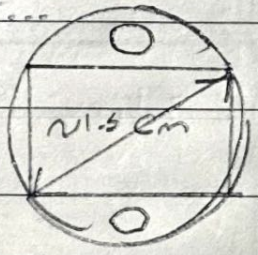
Design #1

1:1 scale

- Multiple cameras for maximum POV

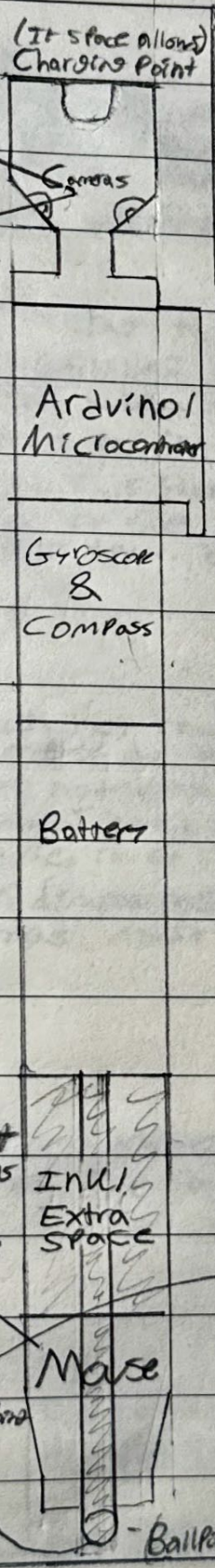
☆ Reflection
- Multiple cameras is a good idea however combining the images will be difficult because of added destortion in this very large image taken by multiple locations.

- Most components will be flat...



Therefore, extra space can accomodate for the wires.

- Ways for mase to work
1. Sensor facing down beside ballpoint
2. Mechanical components to detect movement on the ballpoint like a trackball mouse
3. Sensor, probably lazer to detect more contrast facing the pen's ballpoint

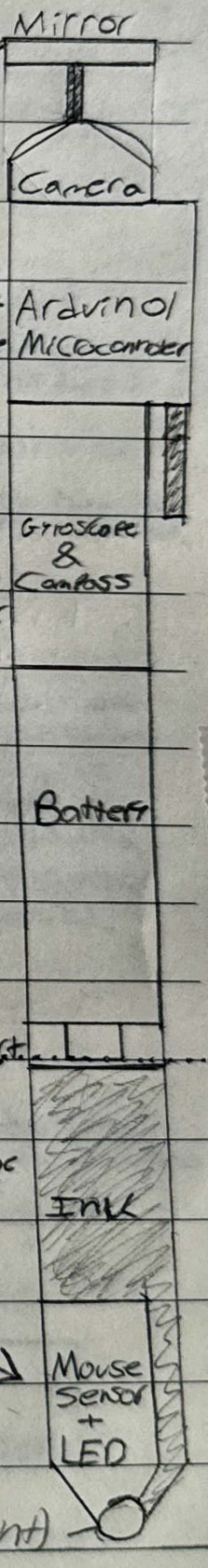


Design #2

1:1 scale

- Might need to be convex for larger POV.

☆ The mirror exists because putting one singular camera facing down on the center of the pen would not be possible due to the wires and support obstructing the view. The mirror is more of a short term theoretical solution that would work if distortion is accounted for. However, a commercial product's camera would look more like design #1.



- Detaches magnetically to construct the pen, change the battery, and refill the ink.

- Due to time and manufacturing constraints, (e.g.) custom Mouse sensor), the pen wont look like this but it's a general goal to work towards.

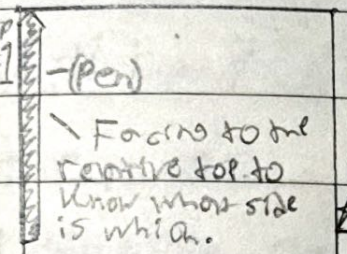
July 23-25, 2023

Software

- Initialization

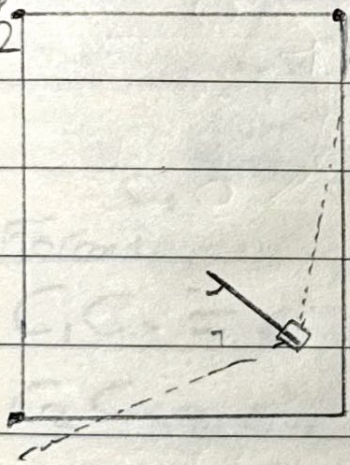
In order for the gyroscope to provide a useful orientation between the pen and drafting page, it has to be measuring its displacement from the paper.
Therefore, before any writing, the orientation of the paper must be measured.

Step #1



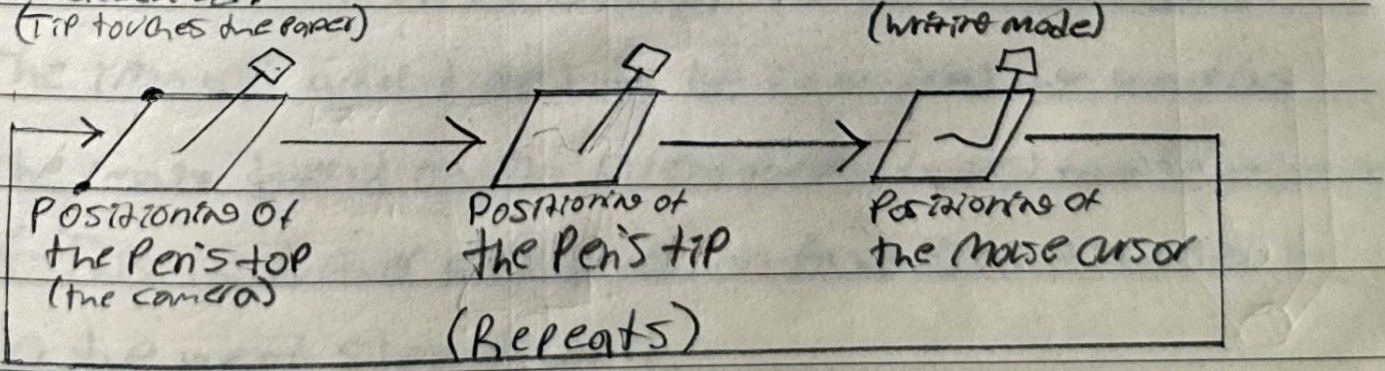
By placing the pen as shown, the gyroscope can be initialized. (The 3 axis values on the gyroscope will be subtracted by the gyroscope outputs during writing to find the displacement)
Edit: This step will also be used to identify the color of the page for corner detection through a photo taken by the camera when this step is happening.

Step #2



Though not recommended (because this measurement is used in most of the formulas for positioning), if the user does not know the dimensions of the page, the formulas used for the positioning of the pen's tip (outlined in the formula section) can be used to find the dimensions of the page, however 3 corner points must be visible (rather than 2).

- Once the initialized values are determined (above), the pen is ready for digitization. The following diagram shows how the positioning is executed.



September 22-30, 2023

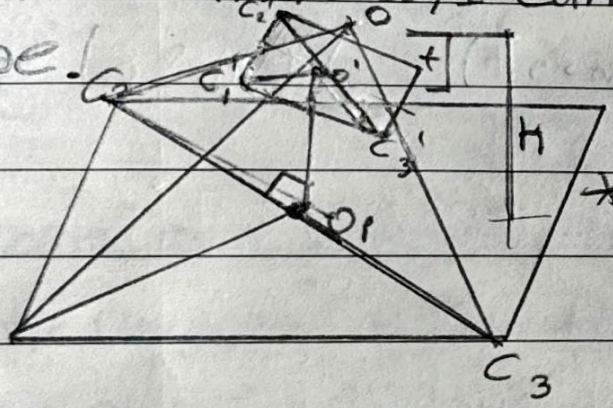
* Brainstorming towards the end of the logbook due to space/organization.

Determining the dimensions of the drafting Page

- When the Pen is Perpendicular

Given the camera's focal length f positioned at a height h from the drafting page pointing perpendicular to Point O_p, the tree corner points C_1, C_2, and C_3 will be projected onto points C_1', C_2', and C_3' in the image.

Using similar triangles, I can derive the dimensions of the page.



* I've made a more clear depiction in a digital format (on the CKSF Portion)
* The camera will need to face down on the center of the Pen for this to work. (A mirror world work as it reprojects it downwards)

Formula

$$C_1C_2 = C_1'C_2'\frac{h}{f}$$

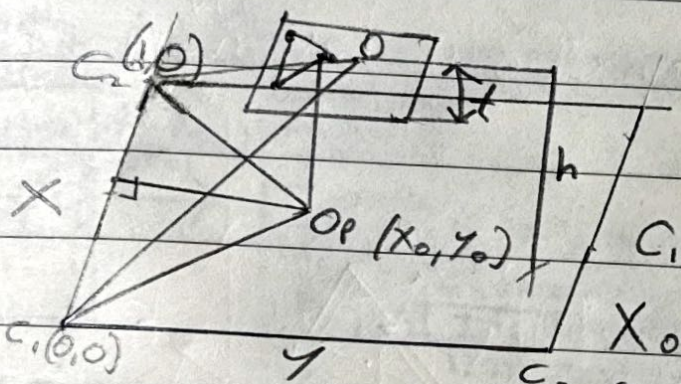
$$C_2C_3 = C_2'C_3'\frac{h}{f}$$

- In general the Pen is not perpendicular to the page during handwriting. In order for the scanner to work the image will need to be rectified by warping the image based on the orientation derived from the gyroscope.

* This is further explained on Page 10 as it is relevant to the next step as well.

Positioning of the Pen's top

From the formula diagram in the initialization phase one can determine the coordinate of the pen's top using 2 points given that the dimensions of the base are known.



Formula

$C_1O_1 = C_1O' \frac{h}{f}$

$C_2O_1 = C_2O' \frac{h}{f}$

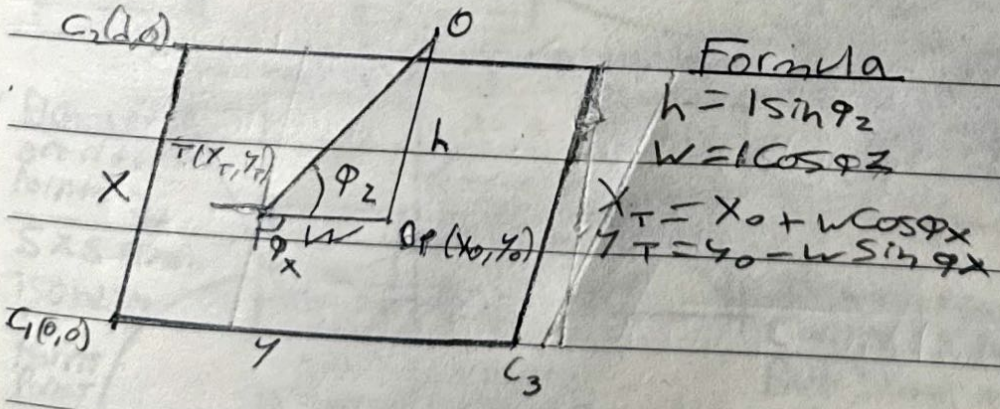
$C_1 = a\cos\left[\frac{C_2O_1^2 - C_1O_p^2 - d^2}{2 C_1O_p d}\right]$

$X_0 = C_1O_p \sin C_1$

$Y_0 = C_1O_p \cos C_1$

Positioning of the Pen's tip

Given the projection of the camera's center point on the base $O_p(X_0, Y_0)$, and the adjusted tilt provided by the gyroscope φ_2, the coordinates of the pen's tip (X_T, Y_T) can be determined.



Formula

$h = l \sin \varphi_2$

$W = l \cos \varphi_2$

$X_T = X_0 + W \cos \varphi_x$

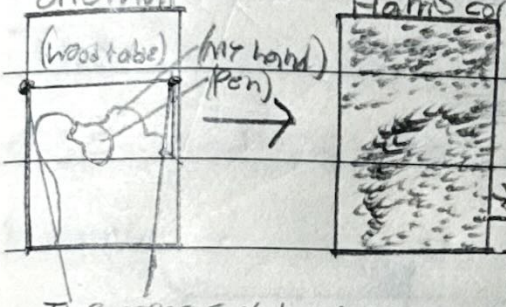
$Y_T = Y_0 - W \sin \varphi_x$

December 8-25, 2023

Corner detection Program

To accurately detect the corners of the Page, the image captured by the camera must be processed and filtered down to 2-3 best Points (depending on the formulas explained earlier). I will develop this Program on a google colab python notebook.

Test 1. Only Harris corner detection



53,241 detected corners

*Reflection

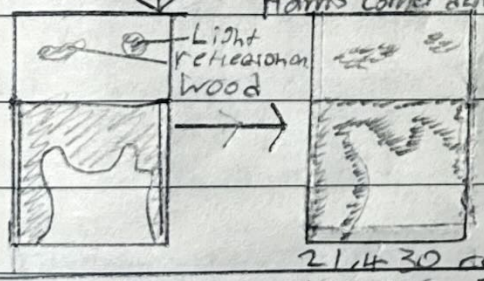
I'll need to eliminate the noise on the non Paper surface. What is different about it?

- Color
- Texture (can't really be identified)

Test 2. Random walker segmentation + Harris corner detection

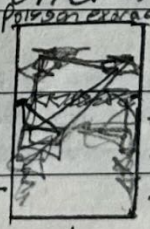
(Some image used)

RGB range: (White)
[220 220 220, 255 255 255]



Is this enough to find the corners?

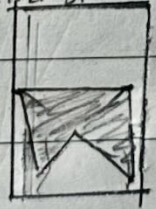
- I'll try to extract Polygons using function available on open CV library.



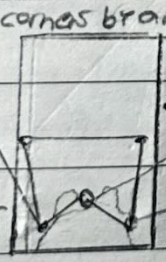
NO, too many Polygons form

*But most of them are small, I'll try filtering by size 100 Pixel sq

21,430 corners detected



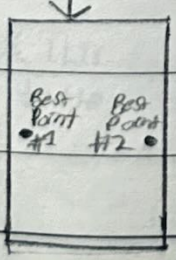
It works but does not know which Corner is the Page's corner(s). But some angles are very big/small.



* = still best points
O = Not valid Points

* How can I get rid of this Point?

5x5 Pixel isolation to Harris Points



The Paper is assumed to be a rectangle, therefore Corners will have less Corners detected by Harris

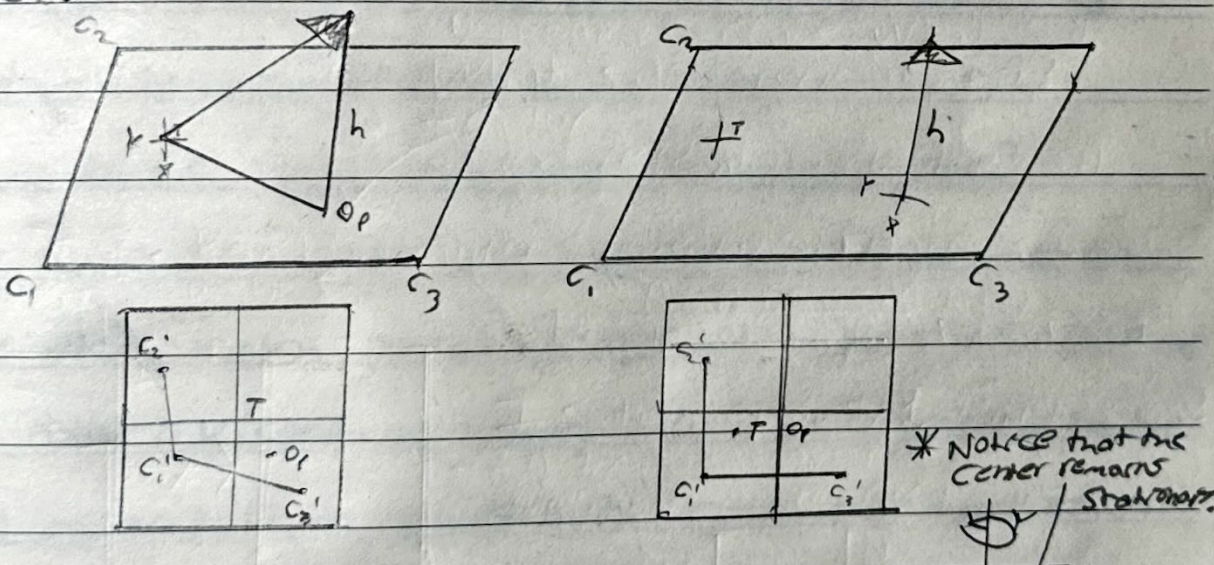
Compared to noise like my more curved (More Points) hand. True corners are also very isolated from the rest of the Page so after segmentation it will be very isolated.

December 8-25, 2023

Warp Perspective transformation

In order to maintain the formulas in the initialization and Pen Positioning Phases, the image captured by the camera must be rectified into a flat paper geometry through the displacement derived from the pen's gyroscope.

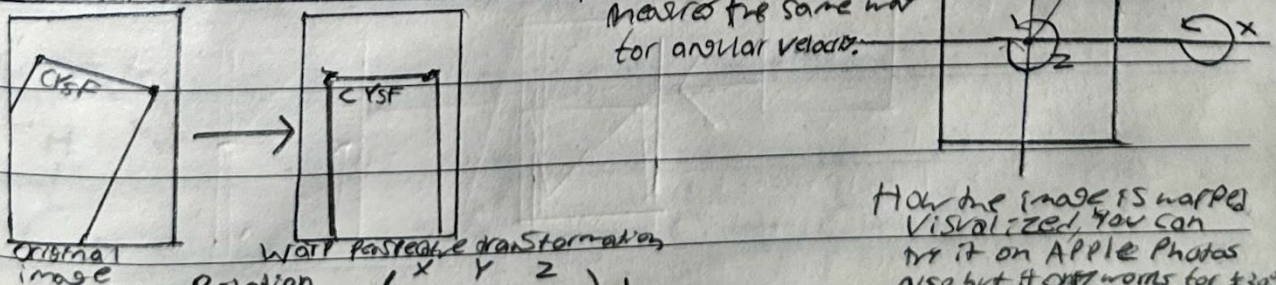
The diagram below shows the geometry of the corner points C_1, C_2, and C_3 projected as C_1', C_2', and C_3' on the rectified image.



* Notice that the center remains stationary.

Implementation (Program)

* A 3-Axis gyroscope measures the same way for angular velocity.



How the image is warped visualized, you can try it on Apple Photos also but it only works for ±30° in each direction.

* This Program is attached to the CYSF Platform

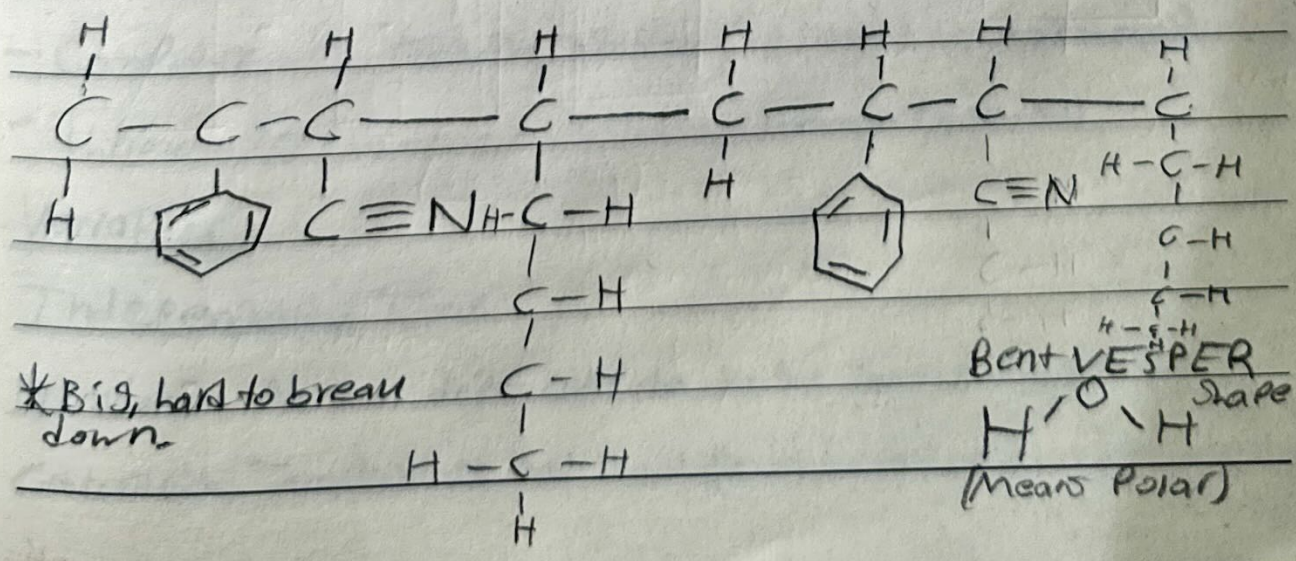
However, because the image is flat (2 dimensional) rather than 3d, this is done through streaming the image, interfearing with the dimensions, however the camera measures angles for the pen so that is not a concern.

Positioning of the mouse cursor

When the pen is gliding on the Page (writing mode) the pen's ball rotates through friction, releasing ink from the cartrage. This rotation is detected by the optical mouse sensor that will send this displacement data to the microcontroller for further processing. In order for this to work, both the Physical size of the drawing Page and mouse sensor's resolution are required according to "The optical mouse sensor as a two-dimensional displacement sensor. No, I.e. ~~what if the mouse sensor gets obstructed by ink?~~

In theory if the pen was made of a nonPolar material like ABS seen in Lego bricks, and the pen's ball was Polar, the Polar ink (contains water) would be attracted to the ball causing it to rotate with it - And the mouse sensor detecting that movement.

* This was further illustrated on Page 5.



Febuary 15, 2024

Testing gyroscope accuracy

A gyroscope measures angular velocity rather than directly measuring angles. By integrating angular velocity data over time one can determine the angular displacement.

Accurately measuring the gyroscope's precision using manual methods, such as a protractor introduces a significant margin of error.

Therefore this experiment will not focus on the immediate accuracy of angular displacement measurements but will assess the long term drift of my chosen gyroscope - Arduino Nicla vision's gyroscope (LSM6DSOXTR gyroscope from ST microelectronics).

This experiment will provide insight to a gyroscopes stability reliability for a pen of this precision.

Materials

- Arduino Nicla vision LSM6DSOXTR 3-axis gyroscope
- Computer with OpenMV installed (to record the measurements)
- Thermometer (to ensure a consistant temperature environment)

Variables

Independent: Time

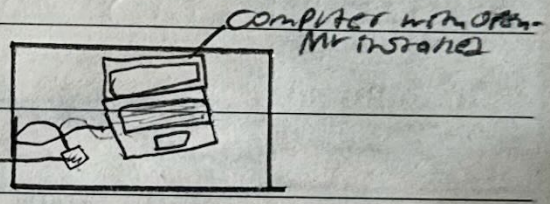
Dependent: Angular drift outputs in the 3-axis gyroscope

Controlled: Temperature and stability of the device (gyroscope and cable)

Testing Gyroscope accuracy

Setup

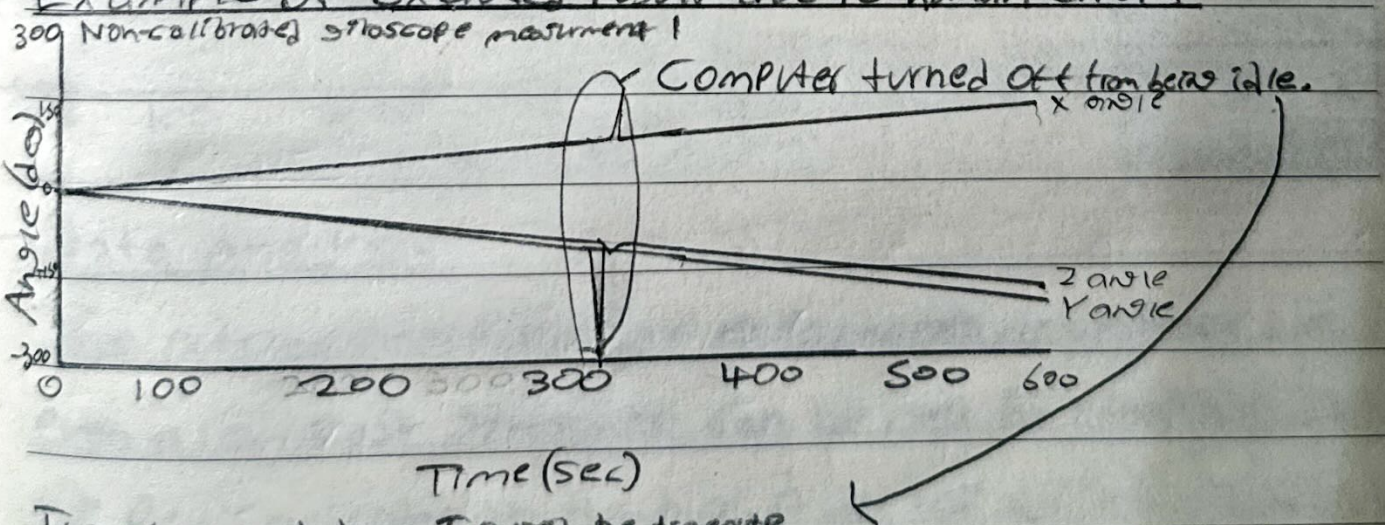
I secured the Nicla vision on a stable, non moving surface to eliminate any external influences on its orientation. I also monitored the room's temperature as I knew it can effect the gyroscopes performance and left it undisturbed to measure its orientation.



Data collection

I performed the experiment 5 times to ensure a consistent and reproducible result of the 6000 3 dimensional rotation values over 10 minutes (10 readings per second) - a fast freuency in relation of the fast movements of the users hand during handwriting.

Example of excluded result due to human errors



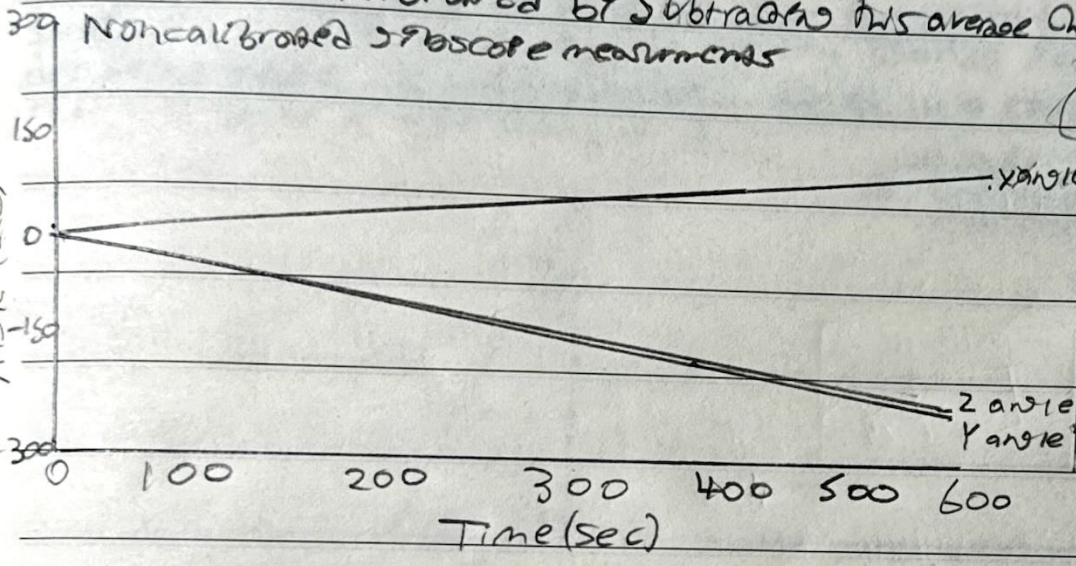
Therefore next time, I raised the timeout settings on my computer not to turn off from being idle in the data frame.

Febuary 15, 2024

Testing gyroscope accuracy/drift

Before calibration

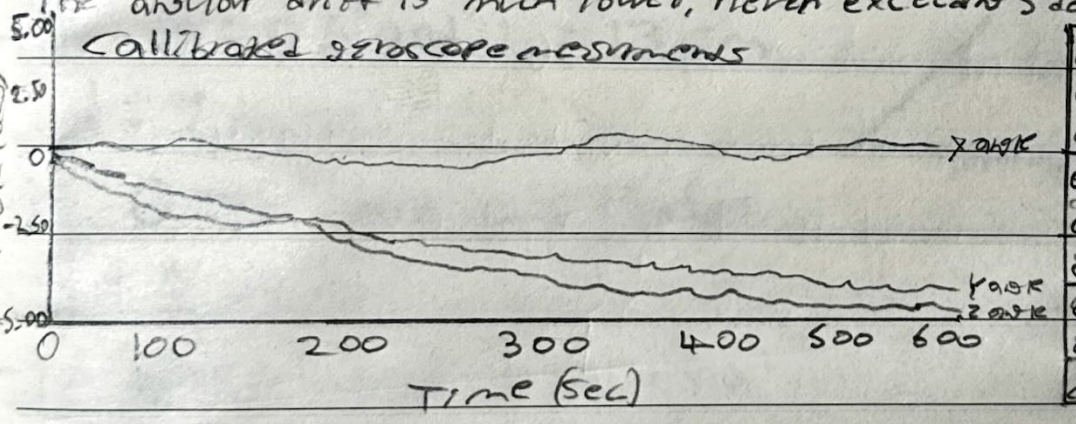
I was not expecting this level of drift, I expected around 5 degrees as this is how much drift relatively priced gyroscopes have. The graph seems very linear/constant in error, it turns out gyroscopes have to be calibrated by subtracting this average change to the outputs.



dx-ave	0.021
dy-ave	-0.039
dz-ave	-0.036
dx-max	0.031
dy-max	-0.036
dz-max	-0.030
dx-min	0.012
dy-min	-0.055
dz-min	-0.043

After calibration

The angular drift is much lower, never exceeding 5 degrees after calibration



dx-ave	0.000
dy-ave	-0.001
dz-ave	-0.001
dx-max	0.016
dy-max	0.003
dz-max	0.006
dx-min	-0.021
dy-min	-0.004
dz-min	-0.008

Data analysis

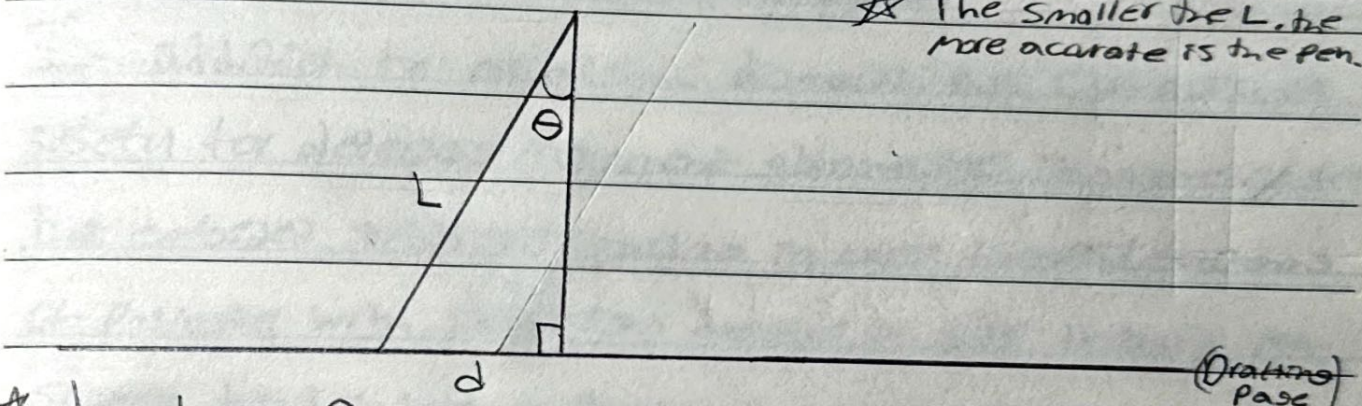
The outcomes of the above experiments demonstrate that even a low-cost gyroscope can be used to effectively control the pen's orientation. However, it will need to be calibrated during initialization to keep angular errors at a minimum.

Estimated accuracy.

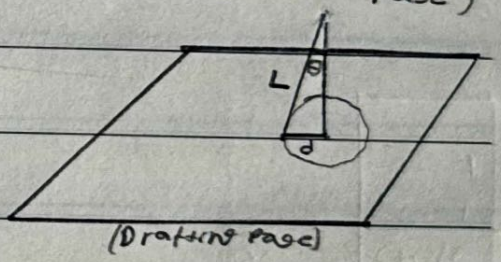
- Gyroscopes are prone to angular errors in all 3 axes.
- I need to estimate the displacement of the pen caused by an angular error θ.

Let L be the height of the pen from the tip to the camera. For simplicity, I will assume that the pen stands perpendicular to the drafting page. I will also assume θ in a random direction that will cause a displacement d.

d is proportional to L:
☆ The smaller the L, the more accurate is the pen.



★ $d = L \cdot \sin\theta$



- if $\theta = 0.5°$ and $L = 13\,cm$
  $d = 1\,mm$
- if $\theta = 1°$ and $L = 13\,cm$
  $d = 2\,mm$
- if $\theta = 5°$ and $L = 13\,cm$
  $d = 11\,mm$

Implications

Beyond the implication of improved memory retention from writing notes letter by letter compared to typing on a keyboard. This Project improves online learning in remote communities through instantaneous sharing and collaborating notes between students and educators.

In addition to academic domains, this can also be useful for detecting movement abnormalities in handwriting data, the embedded gyroscope-aiding in early diagnosis/monitoring of patients with Parkinsons desease or those recovering from severe head injury or stroke.

December 2, 2023 and February 3, 2024

Interview: Spiros Ratsiatos (computer scientist)

Contact information: +30 699-342-4860

Q: "My camera captures an image that includes the pen, page, and part of the table. How could I create a new image that will only show the page?"

A: "This problem is known as 'image segmentation,' you can try the OpenCV Python library. Try an image segmentation algorithm"

Q: "After I get the image segmented, how could I find the location of the page's corner points?"

A: There are algorithms that do that in OpenCV library. Usually those algorithms generate many points, think of a way to filter them

Q: I now developed a Python Jupyter notebook that can do the image segmentation, rectification, and location of the corner points. How can I make it run on a microprocessor?

A: There is an image processing IDE called OpenMV that has equivalent libraries to OpenCV.

Q: "How do I collect the stroboscope measurements?"

A: There should be some example codes that do that, same for the camera

Interview: George Tritakis (MD)

Contact information: 403-475-5840

Q: "I am in the process of developing a pen that transcribes handwritten notes using a camera, mouse, and gyroscope. I need your guidance to see if there are any medical implications associated with the pen.

A: The gyroscope and mouse sensor could detect abnormal shakes in users hands like with those with Parkinsons desease - specifically large and recurring tremors in users hands. These illnesses are often takes time to be noticed by parents so diagnosis and treatment begins very late. This pen could speed up this process.

Q: "Are there any other cases where this pen could be used?"

A: Yes, People recovering from stroke and head injuries also suffer from abnormal movement in their hands. There are plenty of resources that describe these movements in further detail.

Limitations

Positional errors.

As described on Page 14, though the sensors in the pen can provide accurate measurements, they have some limitations that can lead to random or systematic errors.

Moving the drafting Page

It is assumed the drafting Page will remain stationary during handwriting as it is a reference Plane when finding the pens angular displacement/orientation.

Computational Power

The computational power of the microcontroller is limited, it takes seconds to run the image processing Program on a PC, real time capabilities will have to rely on some computation to be migrated to an external device.

Battery capacity and size of the pen.

Though not a top priority, all the high refresh rate sensors, data processing, and wireless communication will drain the battery. To reduce freqvent size, the value of the battery would need to be maximized, however this would come at the cost of the sleek ergonomics of the Pen.

The Paper used has to be a rectangular/square shape

This is because both the formulas and image processing methods assume this to determine the Position of the pen to the corners of the Page.

Conclusion

In conclusion, this project successfully demonstrates feasibility for a pen that digitizes handwritten notes on paper in real-time without external components, integrating low-cost sensors and algorithms accurately. Thereby combining the creative benefits of handwriting and digital convenience. It is worth noting that this project is currently under active development, with the primary emphasis on establishing proof of concept.

Things I learned

- Advanced trigonometry and different relationships between the geometry of rectangles, circles, and triangles.
- How gyroscopes, compasses, cameras, and mouse sensors work
- How to code image processing in Python/methods and algorithms for it

Short term tasks for the future

- The migration of the image processing modules (currently on openCV) to the openMV IDE so there is less dependency on external components
- More experiments on the sensors to understand them better and begin to combine them

Long term tasks

- Make a fully functioning prototype of the pen
- Testing, validation, and commercialization

June 12, 2023 – Febuary 19, 2024

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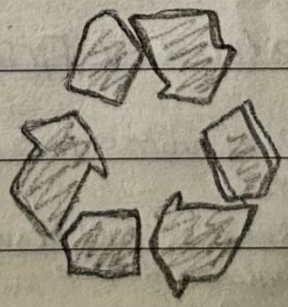
Risk and Safety

Safety will be taken with utmost consideration during the manufacturing and disposal of the pen and its materials. To ensure a safe work environment, proper use and handling of equipment (eg) soldering irons or box cutters) will strictly adhere to safety guidelines regarding precautions, personal protective equipment, and first aid measures. Furthermore, all activities will be conducted in a closed environment, therefore, proper ventelation will be a top priority, especially during soldering activities. Finally, materials requiring special disposal, such as batteries, wires, and plastics, will be recycled at local drop-off/recycling centers. Any remaining components that do not pose a risk will be disposed of in compliance with environmental standards and regulations.



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Scientific Method

Problem | What inspired me?

Hypothesis | Based on research

Collect Data | Conduct an experiment

Analize Data | What did I learn?

Conclusion | How does this connect to the hypothesis?

Apply and Share knowledge with others.

Variables

Independant: There should only be one per experiment
Variable that is changed to cause changes in the dependant variable.

Dependant:
Variable that changes when another variable is manipulated.

Controlled: A common source of error
Variables that are kept constant throughout the entire experiment.