AMBOTS CALIBRATION

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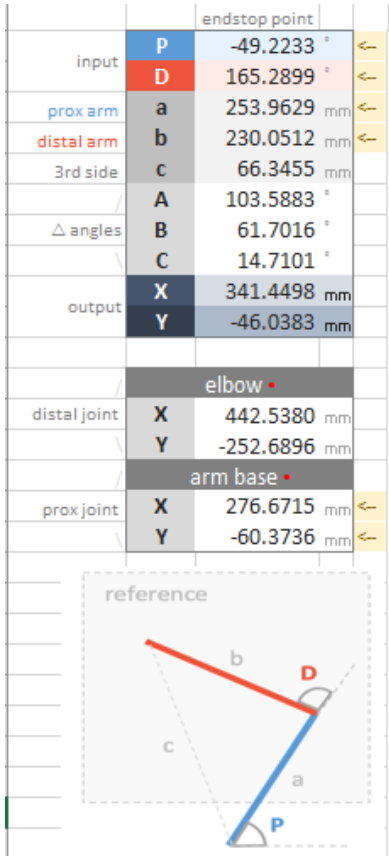
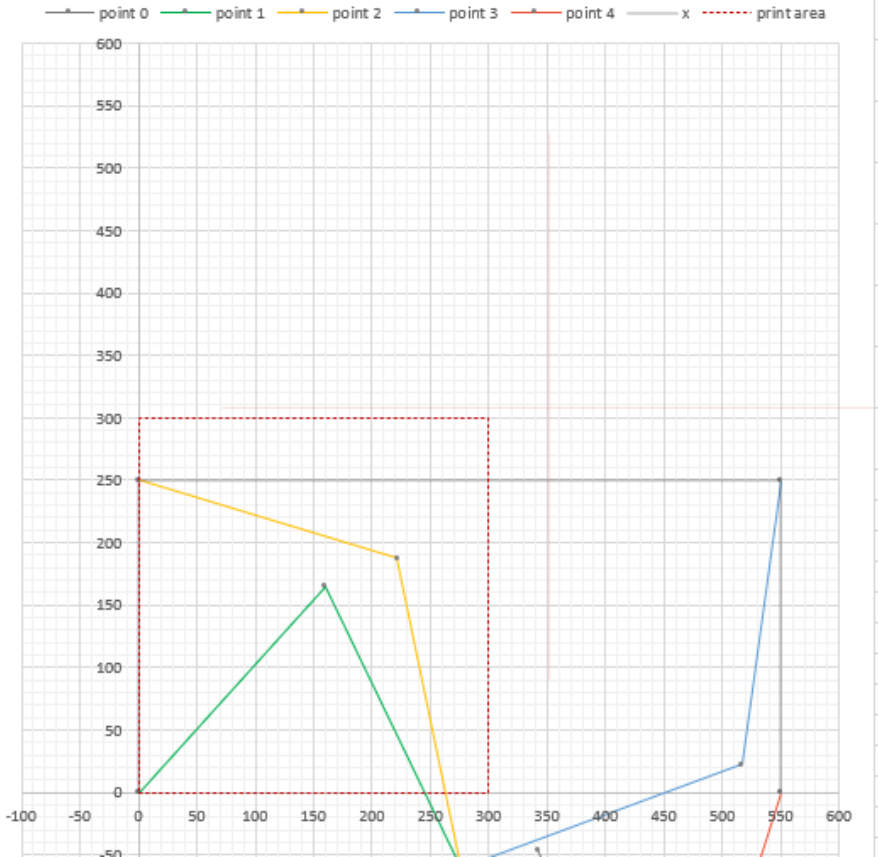
Former Calibration Process: How it worked

- Manually move print head to four corners of the build plate (Time consuming)
- Take those coordinates and plug into Excel spreadsheet to solve



		endstop point	
input	P	-49.2233	°
	D	165.2899	°
prox arm	a	253.9629	mm
distal arm	b	230.0512	mm
3rd side	c	66.3455	mm
	A	103.5883	°
△ angles	B	61.7016	°
	C	14.7101	°
output	X	341.4498	mm
	Y	-46.0383	mm
	elbow •		
distal joint	X	442.5380	mm
	Y	-252.6896	mm
	arm base •		
prox joint	X	276.6715	mm
	Y	-60.3736	mm



		point 1		point 2		point 3		point 4	
coordinates	X	0.0000	mm	0.0000	mm	550.0000	mm	550.0000	mm
	Y	0.0000	mm	250.0000	mm	250.0000	mm	0.0000	mm
Input	X	19.8000	mm	6.5000	mm	553.0000	mm	549.2000	mm
	Y	15.2000	mm	253.6000	mm	257.8000	mm	-3.9000	mm
modified input	X	19.8000	mm	6.5000	mm	553.0000	mm	549.2000	mm
	Y	15.2000	mm	253.6000	mm	257.8000	mm	-3.9000	mm
measured angles	P	117.1756	°	102.4576	°	18.8438	°	-38.4335	°
	D	113.7417	°	66.7711	°	67.8715	°	114.6609	°
new offset angles	P	117.3161	°	102.5982	°	18.9844	°	-38.2930	°
	D	108.5958	°	61.6253	°	62.7257	°	109.5150	°
elbow position	X	160.1281	mm	221.2791	mm	516.8206	mm	475.9948	mm
	Y	165.2694	mm	187.4748	mm	22.2432	mm	#######	mm
nozzle position	X	0.0668	mm	-0.1060	mm	549.9900	mm	550.0488	mm
	Y	0.0303	mm	250.0226	mm	249.8906	mm	0.0562	mm
error from target	X	0.0668	mm	-0.1060	mm	-0.0100	mm	0.0488	mm
	Y	0.0303	mm	0.0226	mm	-0.1094	mm	0.0562	mm
	error	0.186389	mm						

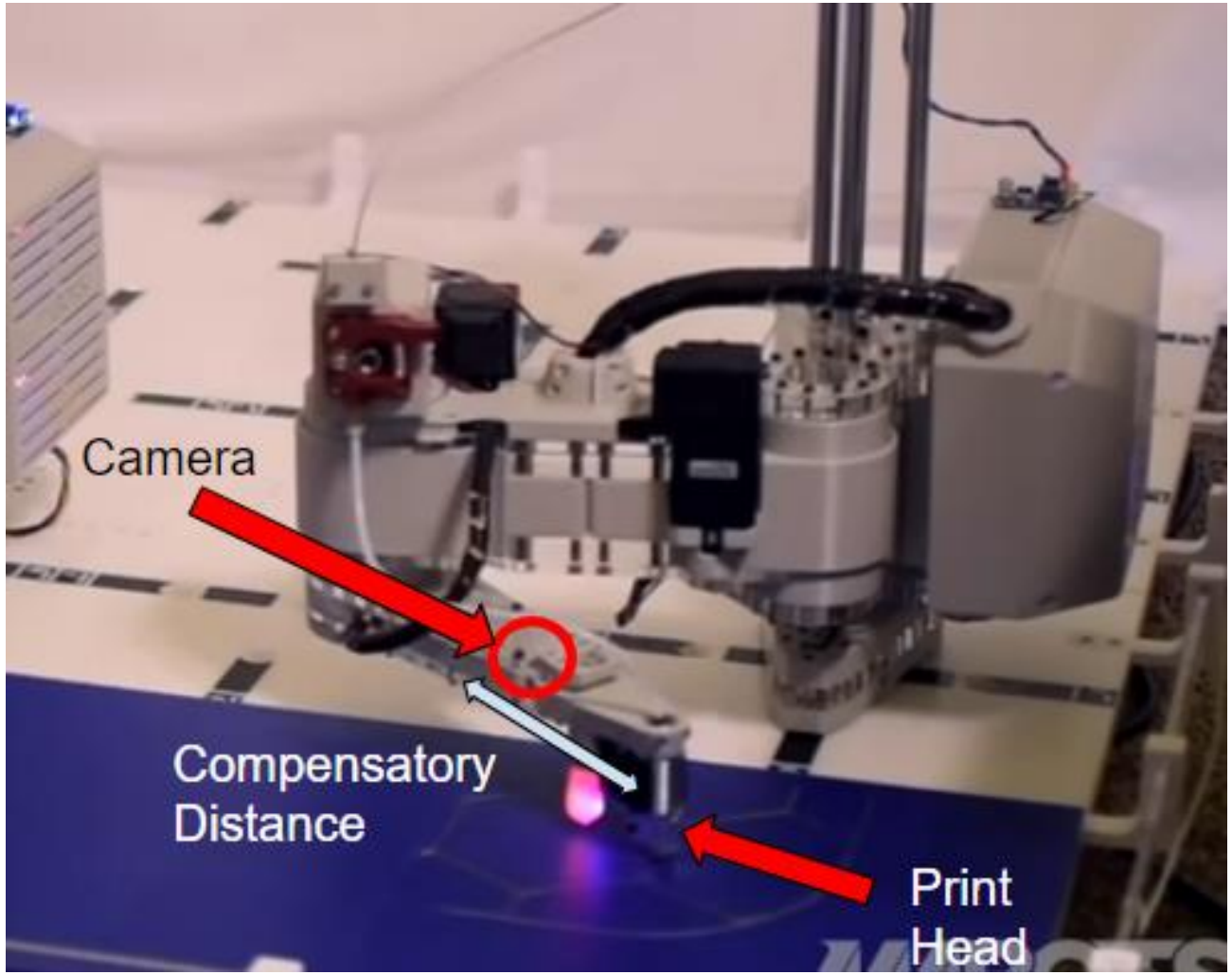
Input Config M669 K4 P270.64612 D223.12374 A-49.36381:130 B20:170.43576 X-284.07571 Y52.3731

		config value	
proximal arm length	P	270.64612	mm
distal arm length	D	223.12374	mm
proximal stop angle	A	-49.36381	°
distal stop angle	B	170.43576	°
proximal X position	-X	284.0757	mm
proximal Y position	-Y	-52.3731	mm

output M669 K4 P253.96288 D230.05124 A-49.22326:130 B20:165.28989 X-276.67148 Y60.37363

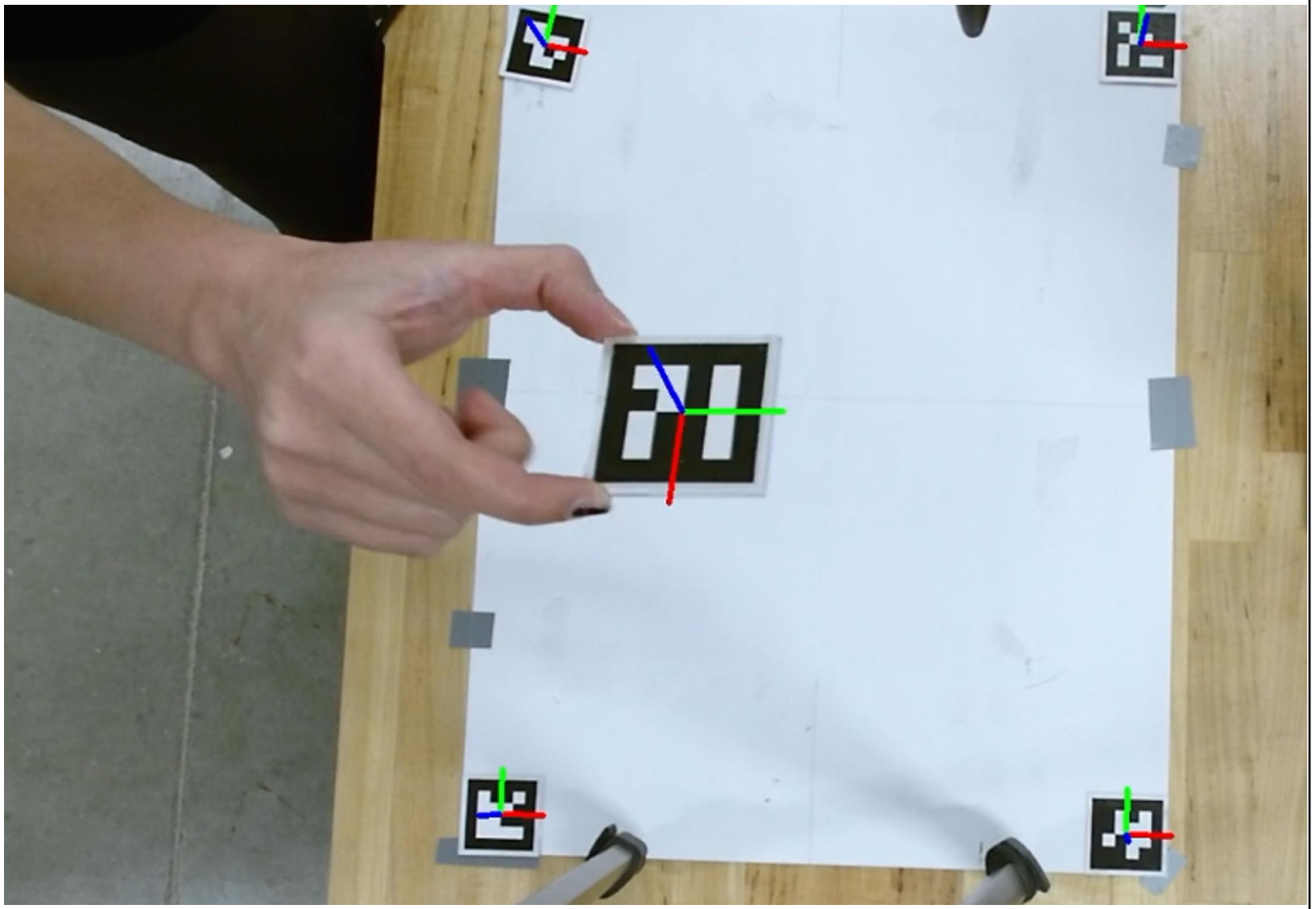
Our Plan

- Create a system that will automatically calibrate the print head.
- This is currently done manually which is inefficient.



Camera Operation

- We will use computer vision and ArUco markers to identify the exact position of the robot and compensate accordingly.
- The camera cannot have the exact POV of the print head, which we will need to account for.

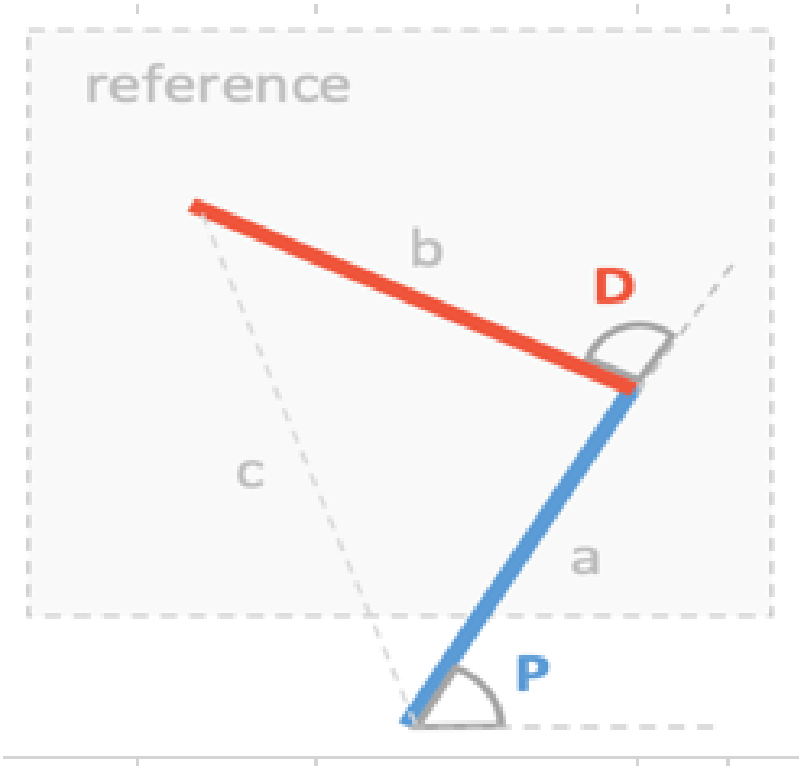


High-level Algorithm

1. Give initial configuration parameters and calibration points
2. Find physical data points using ArUco markers
3. Use solver algorithm
    1. Convert camera points to nozzle points
    2. Minimize error function
    3. Return new configuration
4. Repeat 2 and 3 with new configuration until converging

Problems exposed with our approach

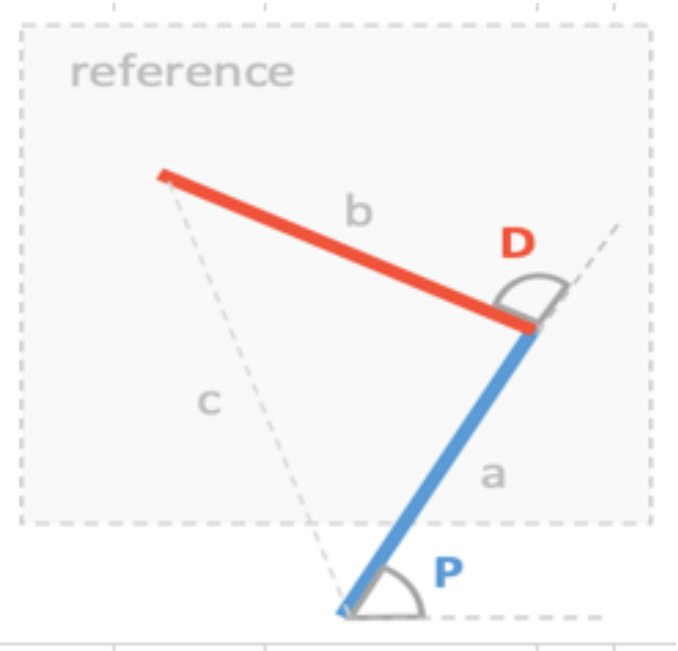
1. The data points we have are now from the perspective of the camera and not the print head
2. Conversion from camera to print head is nonlinear which can introduce error
3. ArUco markers need to be placed precisely



Solution 1

Problem: The data points we have are now from the perspective of the camera and not the print head.

Solution: Use math to do the conversion calculations using the equations



Formulas used:

$$c = \sqrt{(Y + baseY)^2 + (baseX - X)^2}$$

$$C = \cos^{-1}\left(\frac{a^2 + b^2 - c^2}{2ab}\right)$$

$$D = 180 - C$$

$$B = \cos^{-1}\left(\frac{a^2 + c^2 - b^2}{2ac}\right)$$

$$A = 180 - B - C$$

when X < baseX:

$$P = 180 - B - \sin^{-1}\left(\frac{Y + baseY}{c}\right)$$

when X > baseX:

$$P = \sin^{-1}\left(\frac{Y + baseY}{c}\right) - B$$

$$elbowX = baseX + a * \cos^{-1}(P)$$

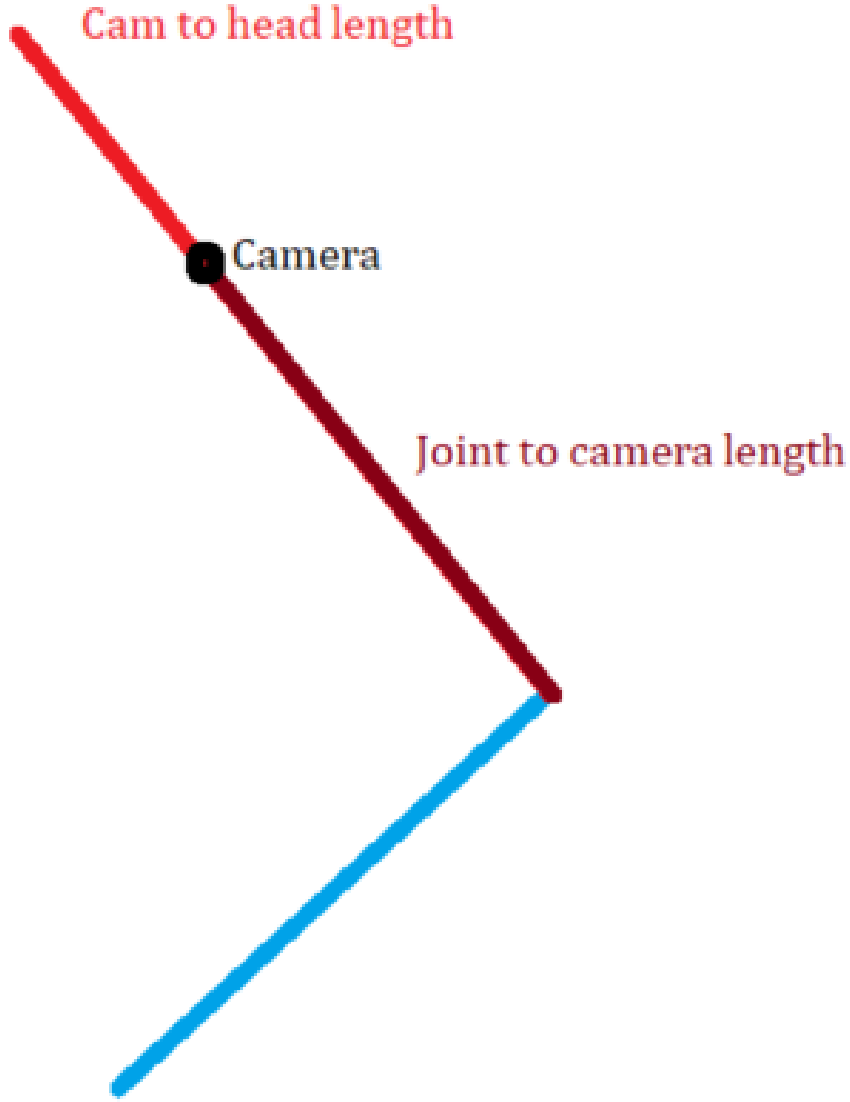
$$elbowY = a * \cos^{-1}(P) + baseY$$

Solution 2

Problem: Conversion from camera to print head is nonlinear which can introduce error.

Solution: Split distal length parameter into two, giving us a joint to camera parameter and camera to head parameter, and add a fifth point to the calibration.

Aside: The physical lengths of the parameters are not always the lengths that give the best results for the calibration.



Manual Testing

```
M669 K4 P270.64612 D223.12374 A-49.36381:130 B20:170.43576 X-284.07571 Y52.37313
        error: 219.967 -> 94.267        tolerance = 30
M669 K4 P240.64612 D244.22447 A-49.36810:150 B20:170.43576 X-254.07571 Y82.23731
        error: 92.334 -> 48.3908        tolerance = 30
M669 K4 P217.93967 D255.27140 A-49.36810:150 B20:170.43576 X-283.20797 Y52.23731
        error: 83.491 -> 23.9211        tolerance = 30
M669 K4 P221.83651 D255.27140 A-49.36810:150 B20:170.43576 X-277.57159 Y60.28333
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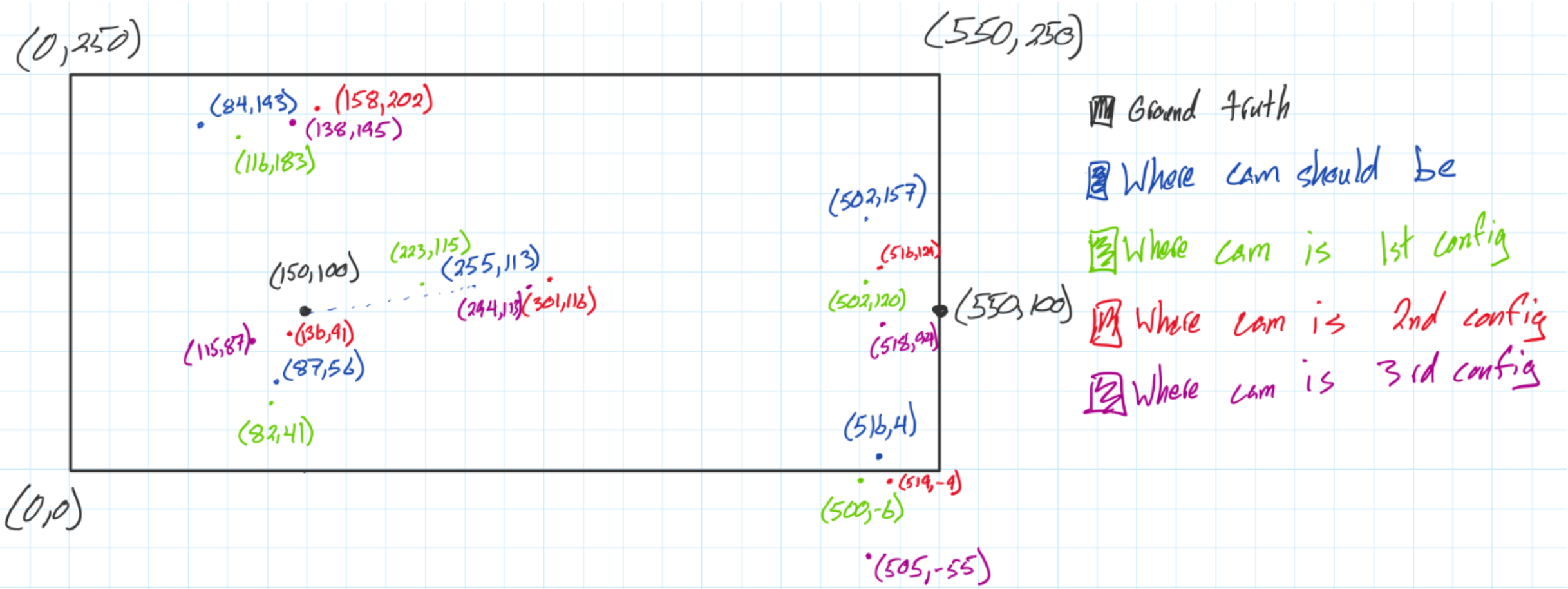

Solution 3

Problem: ArUco markers need to be placed precisely.

Potential Solution: Use a build plate with an accurate grid system to easily place ArUco markers

Results and Conclusion

- We have completed the implementation of the algorithm needed to automate the calibration
- There were issues with the camera hardware, so the automation is yet to be tested
- Handing off to AMBOTS and they will finish the full automation testing

Questions