

This guide may be out of date! I now recommend using an Orange Pi 5 for ease of use and almost the same performance for lower power ([draft doc](#)). Link to all my coprocessor docs:  [Coprocesor](#)

Introduction

This document is intended to be a rough guide for anyone looking to set up a mini PC with Photonvision for Apriltag processing. Mini PCs, such as the Beelink N5095 used in this document, are very powerful tools that can be used to localize the robot accurately and with low latency. The total setup costs for this is under \$200 for a PC and a high-performance global shutter USB camera - much more affordable and powerful than existing COTS solutions such as the Limelight V2.

This guide is mostly derived from the tests conducted here: [Mini PC Photonvision Tests](#)

If you run into issues during setup, you can reach out to me directly (just request edit access with your question/comment) or join the Photonvision discord here: <https://discord.gg/g8t24yBDhQ>. You can ping @asid61 there to contact me.

Warning: do not attempt to power the Mini PC using PoE. It will kill it instantly.

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Hardware

The hardware used in this document is an N5095-based mini PC from Beelink. These computers are ubiquitous on Amazon and Aliexpress, making it a good choice for availability reasons. The N5095-based computers do FAR better than the slightly cheaper J4125 ones, about a 50-100% increase in performance. Beelink has other PCs with i3/i5/i7 processors in a higher price bracket, \$200-300 ish. N5105 PCs are also plausible but not yet tested, although they should be slightly more powerful than the N5095.

Computer

Brand: Beelink

Hard Drive: 128GB SSD

RAM: 8GB

OS: Windows 11

Processor: Intel Celeron N5095

Weight: 9oz (0.56 lbs)

Size: 4.5 x 4 x 1.6"

Power jack: 5.5 x 2.5mm, 11mm long ([example](#))

Power requirements: Technically rated for 12V 3A, but draws well under 2A in all tested configurations so far with up to 3 cameras. 2A peak observed with up to 3 cameras. ([Example power supply](#))

Cost: \$130 on Amazon or \$120 on Aliexpress. Search for "Beelink N5095" and scroll to find deals. Make sure not to buy a J4125-based version, they are way less powerful. Be especially careful on Aliexpress.

Cameras Tested

Lifecam 3000 (great for driver cam)

Generic webcam

AR0144 Camera w/ 100 deg low-distortion lens (highly recommended)

OV9281 Camera w/ 100 deg low-distortion lens (highest recommended)

OV2710 w/ 100 deg low-distortion lens (sort of recommended)

You may be able to use a separate M12 low-distortion 100deg lens for the OV9281 or AR0144 if you can't find one that has it already. [M27280M07S](#) should work. Research shows that this may be a 1/2.7" 2.8mm lens, so something like [this](#) may work. It's Amazon so just return it if you don't like it.

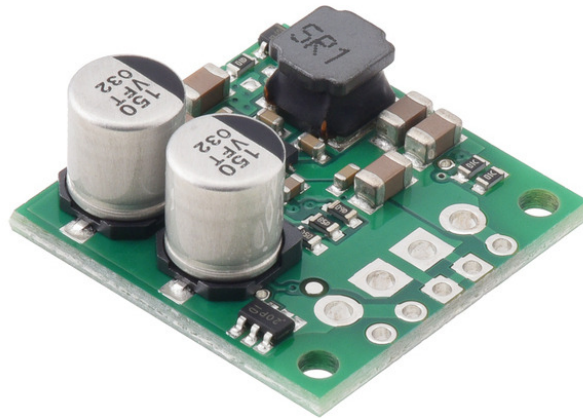
Do not use 2 of the same model camera at the same time. It will confuse Photonvision and not work properly. This may be fixed in later Photonvision releases. Buy 2 different cameras if you plan on running multiple, or rename the cameras in the Arducam renaming utility (for OV9281)

Power

For power, a robust buck-boost or converter is recommended. Pololu has a good 2.5A 12V buck-boost that works well for this. <https://www.pololu.com/product/4984>

They also have a 15V version if your coprocessor prefers that.

<https://www.pololu.com/product/4985>



General specs, measured with 1 AR0144 and 1 Lifecam-3000 camera plugged in, running Photonvision on Ubuntu Server, Ethernet and WiFi communication:

Specification	Value	Unit
Peak Power (on boot)	21.7	W
Operating Power	17.0	W
Supply Voltage	12	V

That's less than 2A in all cases!

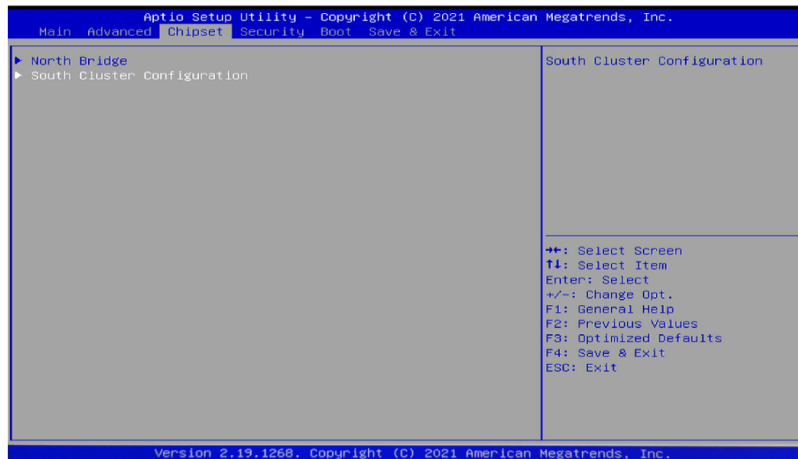
Headless Ubuntu (Debian) Server Setup

First, you should set up automatic power-on with a BIOS setting:

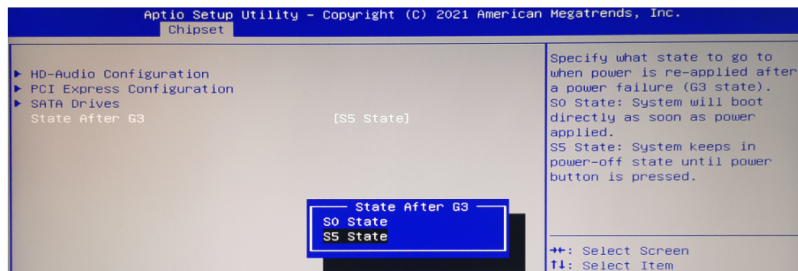
<https://www.bee-link.com/cms/support/kldetail?id=82>

Method 1

1. Select to enter Chipset, select "South Cluster Configuration".



2. Enter "State After G3" and set it to "S0 State".



Ubuntu Server LTS is easy to install by following the Ubuntu install documentation. You will need an 8GB USB drive to boot from. I flashed 22.04.1 LTS Server Edition (Jammy Jellyfish) onto an 8GB USB stick using Balena Etcher and booted the Beelink from there. Insert the USB stick, power on PC, and hold down or repeatedly long-press F7. Select the USB UEFI Boot option. When the network connection screen came up, I selected my home WiFi and entered the password. Or use an ethernet cable to plug into a router or wifi extender. I allowed it to find the most recent installer from the web and download it. Then I allowed it to use the entire SSD for installation. Install the normal version, not the minimal version. I elected to install the OpenSSH server from the list of packages during setup. Installation completed successfully. I did have to restart it after the first boot after it got stuck on some random line for >5 minutes. But it booted up fine the second time.

I would recommend naming the PC “photonvision”. Anything else seems to lead to intermittent issues with connections from my laptop. I also named the user photonvision and set it as the password as well.

Once everything is set up, you should be able to boot into the PC! You can also disconnect the display at this point and use “ssh <user>@photonvision.local” to log in remotely from a computer on the same network. <user> is the username you set up during the installation.

To find the IP address during debugging, you can use “ip -brief addr show”.

Run “sudo apt-get update” and then “sudo apt-get upgrade” to update everything before continuing. The “sudo reboot now” to restart.

To install Photonvision, follow the instructions about “other Debian-based coprocessors” found here: https://docs.photonvision.org/en/latest/docs/installation/sw_install/other-coprocessors.html

To update Photonvision later, make sure to use your username instead of “pi” (the default in the above page example).

The scripts were installed successfully, but I had to run it a second time. “sudo service photonvision status” can be used to check if the install was successful and PV is running. Make sure to reboot after install to get it running.

“A start job is running for Wait for Network to be Configured” adds about 3 minutes to the startup time. The top of [these fixes](#) from the command line works to stop this from happening, permanently: “sudo systemctl disable systemd-networkd-wait-online.service” followed by “sudo systemctl mask systemd-networkd-wait-online.service”

You will be able to access the PV interface at <pcname>.local:5800 if you follow the above steps. I named my pc “photonvision” for easy setup, as mentioned before.
http://photonvision.local:5800 was available 32 seconds after the unit was plugged in.

Making a Read-only Operating System

Warning: Do this only after calibration is complete and all cameras are configured. Otherwise, you will need to unlock the file system to modify it. Basically, do this step after your entire setup is dialed in and you don't need to mess with it ever again, or get very comfortable [SSH'ing in and disabling this](#).

A read-only file system will ensure that the Operating System (OS) doesn't get corrupted when the PC is suddenly shut off (such as when you power off your robot). This is useful for reliability's sake, especially because such failures can happen unexpectedly and suddenly after being a non-issue for many reboots. To set up a read-only OS, Use this guide:

<https://web.archive.org/web/20220713015414/https://spin.atomicobject.com/2015/03/10/protecting-ubuntu-root-filesystem/>

Solution

Overlayroot has been available since Ubuntu 12.10, and has been back-ported to 12.04 LTS. It is quick to install:

```
apt-get install overlayroot
```

The configuration file is stored at `/etc/overlayroot.conf`, and contains a wealth of in-line documentation.

The only item to change is the `overlayroot` variable. By default, it is blank:

```
overlayroot=""
```

Don't Recurse

By default, overlayroot will mount all filesystems under `/` in the specified mode. This can be prevented by adding another option to the configuration:

```
overlayroot="tmpfs:swap=1,recurse=0"
```

I only edited the config to use "overlayroot="tmpfs:swap=1,recurse=0"". You can edit the config file by using "sudo nano /etc/overlayroot.conf".

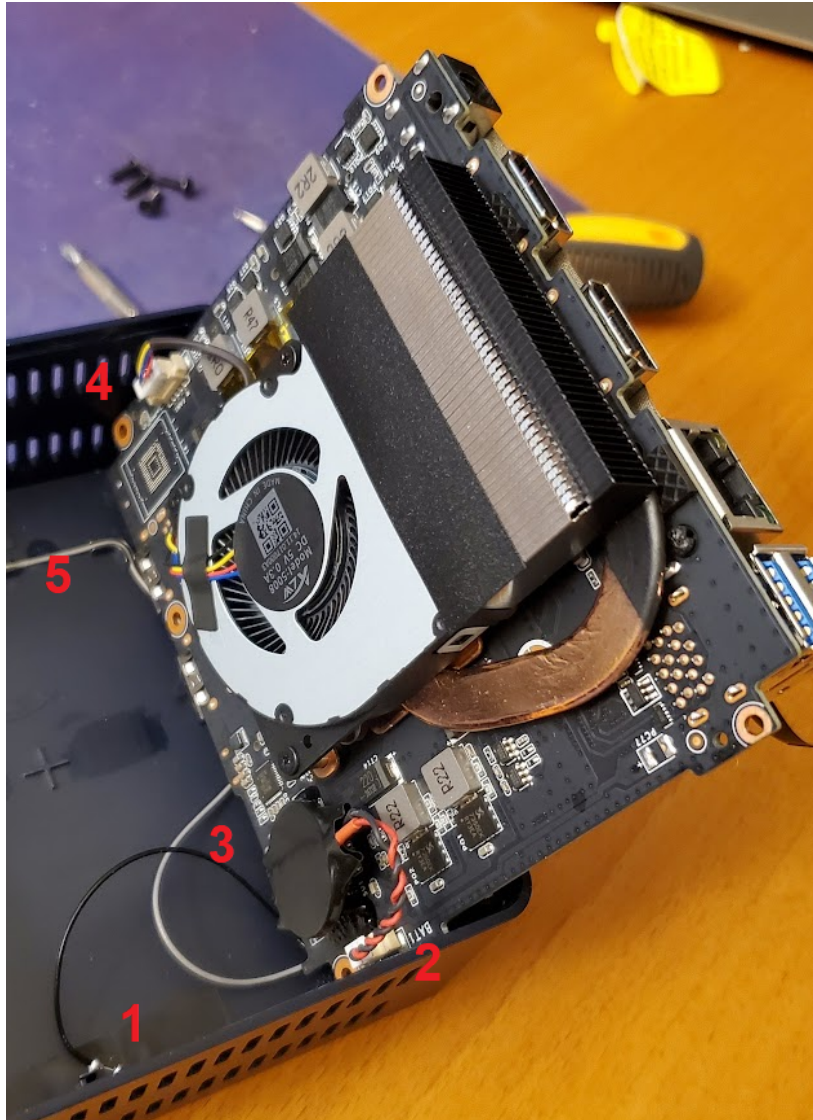
That seemed to just work. The output was exactly what was expected after reboot. Unsure of what else to do here, so... it's done? Extremely easy. On my test machine I have not done this, as I frequently modify it. To be perfectly safe, I would only run this like, before the elimination rounds at an event, or not at all.

Robustification

Following reports of a lack of mechanical robustness on the internals of the Beelink PCs, I opened mine up to check on things. I first used a small screwdriver to unscrew the 4 screws on the bottom of the case.



Note the fragile FFC cable labeled (1). You may need to unplug this to open the case completely, as I did. If you're not using the extra hard drive slot it connects to, it can be removed entirely and taped off to avoid it coming loose down the line. Or hot glued in place. I then dug a little deeper by removing the screws along the edges of the board (labeled 2-6). Some removable blue loctite on the screw holding down the SSD (to the right of 6) would be good to add. Also some hot glue on the antenna below 6. Make sure not to get hot glue directly on the antenna connector, just on the wire itself nearby to act as strain relief.



The antennas at 1 and 5 should be hot glued at a couple points to relieve strain. The connectors at 2 and 4 should be hot glued to stay plugged in. The battery at 3 should also be carefully glued to hold it down. Don't go too wild with the glue, as you may want to unplug things for some strange reason later. But probably not.

When putting it back together, I noticed that the screws came apart too easily. For that reason I would also recommend adding loctite to all screws removed to this point. Removable blue loctite is probably best.

And that's it! Everything else looked pretty decent, so I would be surprised if anything really bad happened. A foam mount might help.

Setting a Static IP Address

I could not find a way to do this very easily for now, at least by Beta 7. The Setting page will pretend to set a Static IP, but won't actually do it. If you want to set up a static IP, you will need to follow a generic guide online like this one:

<https://www.linuxtechi.com/assign-static-ip-address-ubuntu-20-04-lts/>

Set an IP address consistent with what Photonvision recommends here:

<https://docs.photonvision.org/en/latest/docs/getting-started/installation/networking.html>

UPDATE 2/3/2023: Photonvision has not fixed this yet. There are some commands that sort of work, but the presence of 2 network adapters in the PC makes it not work properly. I will list the custom commands here to fix it eventually.

Distance Tests With 36h11 Tags and Lifecam

This is an older test I ran some time ago to help people decide what resolution to use. Distance testing was performed to see the effects of webcam resolution and decimation on detection distance. This testing was performed on the Photonvision beta, dev-v2023.1.1-beta-5-10-g4a54d70, using 36h11 tags.

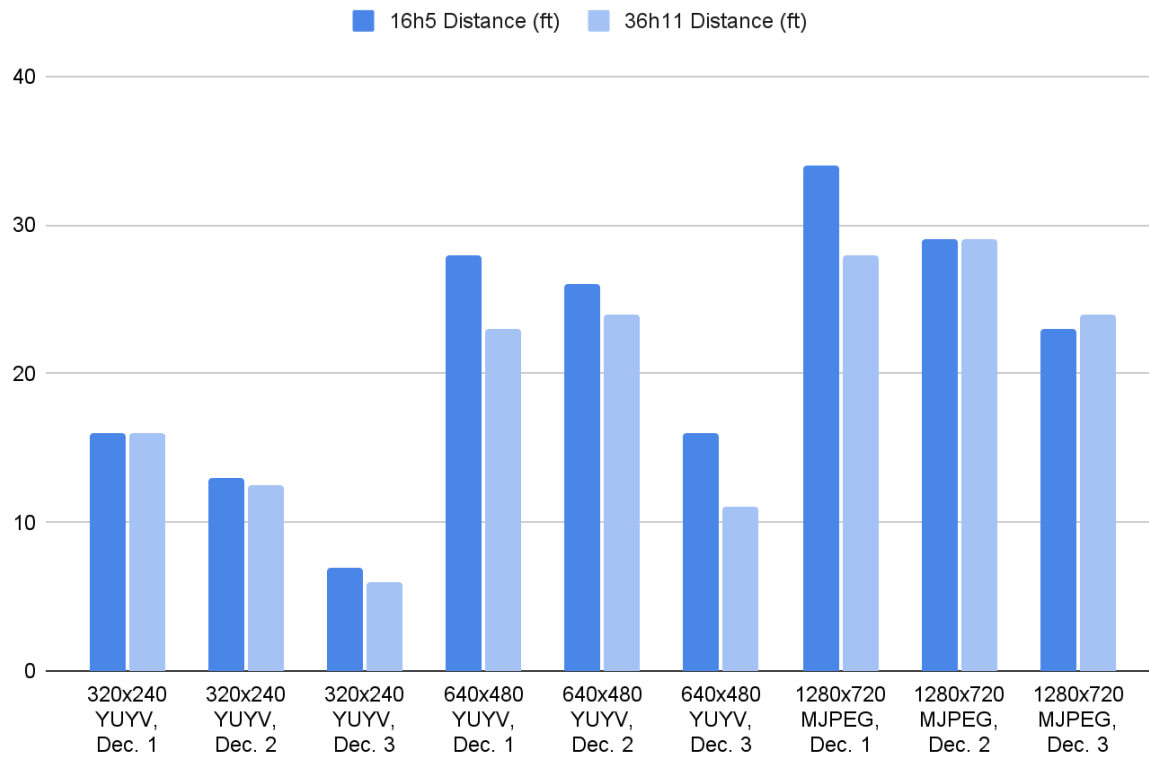
Hardware used was a Lifecam-3000, 3 threads, 30 decision margin, 50 pose iterations, exposure 25, brightness 50. All tests were performed at 30fps, except for 1280x720 tests, performed at 15fps.

Results

Resolution	Decimate	Max range (ft)	Latency (ms)
320x240 YUYV	1	16	5
320x240 YUYV	2	12.5	5
320x240 YUYV	3	6	1
640x480 YUYV	1	23	17
640x480 YUYV	2	24	17
640x480 YUYV	3	11	6
1280x720 MJPEG	1	28	52
1280x720 MJPEG	2	29	52
1280x720 MJPEG	3	24	32

The tests are shown summarized graphically below:

16h5 and 36h11 Distance vs. Decimate and Resolution



The measured distance matches the theoretical fairly well for low decimate, while increasing the decimate only slightly decreases detection distance. However, processing speed does not increase enough to justify any decimate above 1, except possibly in edge cases or when trying to eke out the last bit of camera FOV with a higher resolution. The OV9281 with Decimate 2 on a 640x480 resolution will run at up to 120fps with decent range, making it a great choice as a primary vision camera.

Camera Tests

Tags detected were Tag16h11 family using Photonvision v2023.1.1-beta-6, to provide 1:1 comparisons across operating systems and resolutions. **Unless otherwise noted, 2D detection was used, with 3 threads, 1 decimate, 0 blur, 15 decision margin, and 50 pose iterations.** Note that detection distance will be increased ~20% when using 16h5 tags.

Beta 7 or later will see performance improvements.

Full camera results are available in the [Mini PC Photonvision Tests](#) document.

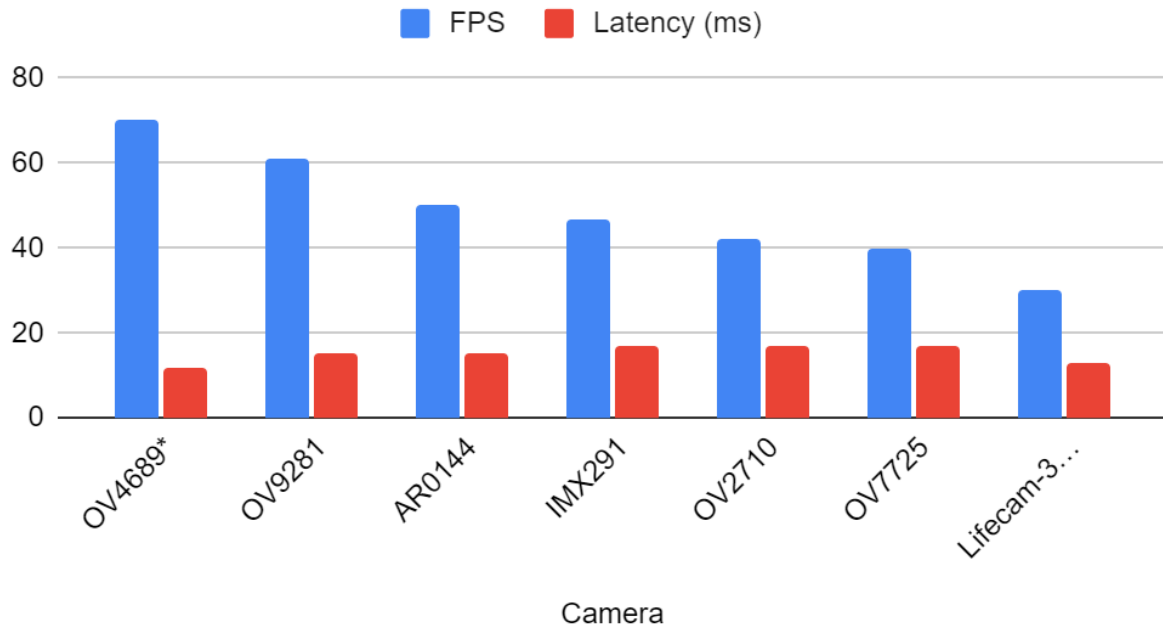
List of tested cameras and a rating:

- Lifecam 😊
- AR0144 😊
- OV9281 😊
- OV2710 😊
- OV4689 😊
- IMX291 😊
- OV7725 😊

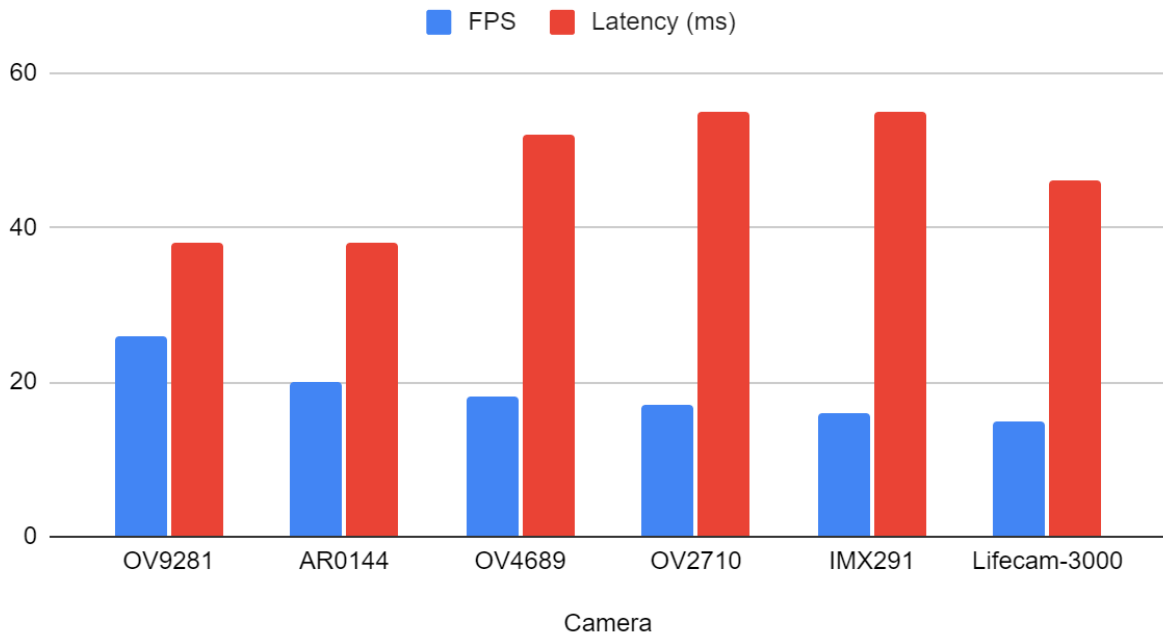
Note that OV9281 works much better these days (2024-2025 season) as PV has stabilized somewhat.

Camera Summary

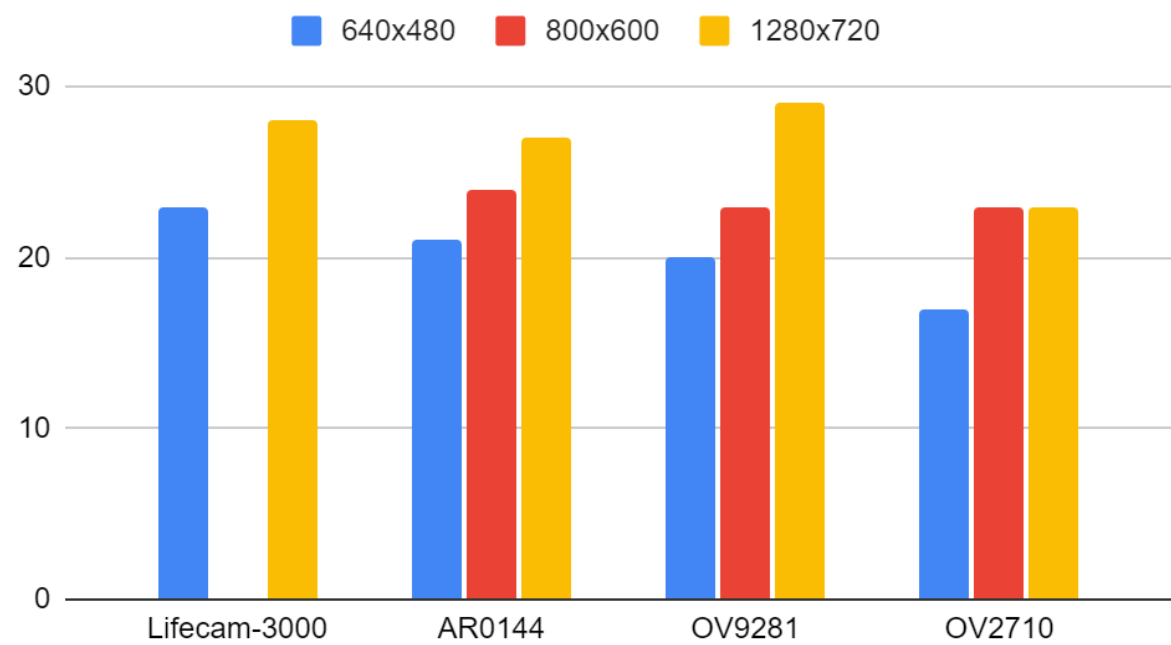
640x480 Performance



1280x720 Performance



Range vs. Camera



Conclusions

I can't be bothered to write a real conclusion, so here's some key takeaways:

- Get an N5095 or better (N5105, i5 10th gen, etc.) mini PC
- If you want multiple cameras, avoid cameras with the same name.
- Running 2 or 3 cameras is perfectly feasible, especially if one is a driver camera.
- 800x600 or 1280x720 resolution is best for long-distance detection. Dual 640x480 cameras may also be good.
- A buck-boost converter with a 2A or higher rating is recommended. Only run the VRM as a converter if you are running 1-2 cameras to avoid overheating. Ensure that your converter operates down to ~5V. XL6009-based converters should work well, but make an enclosure for it or buy an enclosed version.
- Keep a spare Mini PC on hand in case of failure (I have not had one yet)
- Keep that USB stick with the Ubuntu installer on it on hand (for emergency resets)

Future plans / To-do list:

- Bug Photonvision people to fix static IP setting
- Bug Photonvision people to fix OV9281 (maybe cscore issue?)
- Bug Photonvision people to fix multiple AR0144 issues
- Create an OS image that can be flashed onto any Beelink N5095-based Mini PC, or simply booted from without even setting up an OS on the Mini PC.
- Test more cameras (open to requests!) (OV4689, [OV7725](#) and [IMX291](#) in progress)
- Design a shock-proof mount