Dynamic Load Controller

And its uses in First Person camera applications

Contents

Introduction

The controls of robots have been an ever-evolving phenomenon over the years. While at first, we were tethering them to a bunch of wires, with only a joystick to control; we now can let them do the most advanced tasks on their own.

Vision still is one of the hardest hurdles to overcome when it comes to robotics. Many robots are past the point of the need for human eyes. Though a niche group of robots still rely heavily on them. This group can be described best as a group of “competitive” robots. Like sports robots, or racing robots.

Our sports robot still has a need for human eyes. Commonly, these eyes are from the side of the field. However, we would like to upgrade our eyes, to a first-person perspective. Essentially being a football player on the field, through the eyes of the robot.

Planning

To keep track of work done, I made a planning which I can adhere my progress to.

6 dec:
Assigned new problem in group.

13 dec:
Form idea of which metrics are important and which aren’t.

20 dec:
Present current findings and progress to Bryce and Edwin.

10 jan:
Have prototype working to present to Edwin

17 jan:
Have fine tuned product to show Bryce and Edwin.

Problem
To fetch our camera livestream to utilise it for first person driving, we use the internet. Internet has many benefits, though downsides also are abundant. One of the downsides to internet is, that it can become unstable very quickly.
This poses a risk to our camera stream, since it could likely be negatively impacted by an unstable network.

Luckily, there are systems in place to lessen the load a camera stream puts on a network; though this is not yet in place in our system.

Proposition to solve problem
Create a system which reduces the load the camera stream puts on a network. This can be done in various ways, though the underlying outcome is that the amount of data sent over a set period needs to decrease in contrast to the amount of data sent previously.

Both the and the adjustment of the amount of data sent should be in a feedback loop. This ensures that the system is always online and can work without any manual input.

Process
When orienting how to solve this problem, it is determined that we can best split the problem into two sub-problems.

1. How to measure a slower stream/network?
2. How to change the stream resolution dynamically?

How to measure a slower stream/network?

The quality of the stream and its speed are roughly determined by three major factors:

1. The speed of the stream algorithm
2. The speed of the hardware
3. The speed of the internet/bandwidth capabilities

The only factor which can influence the speed of a stream unpredicted, is #3.

Measuring network statistics to determine if a stream is slowing down or speeding up is therefore a smart choice when it comes to predicting stream speed.

However, there is another way to measure the speed of a stream. FPS.

The client of a stream receives the frames of said stream in quick succession; how quick this succession is, determines the framerate of a stream.

We can measure the amount of frames received per second on a specific client, this way; we can measure exactly how fast the stream is received on the client. Especially since we know our target FPS.

To summarize, there are two main ways to predict/measure a stream's performance:

1. Predicting how a stream would behave in the future by measuring network performance
2. Measuring the amount of frames received on the client side to determine the streams performance

We utilized both these solutions to make the final product as diverse as possible. Below is the timeline of progress on both these solutions.

Measuring network statistics

There are various network metrics which are relevant to our stream, all of which have influence on the performance of the stream. These are listed below shortly.

Latency

Network latency is a term used to describe the time it takes one data-packet to go to its destination, and back. The time it takes this packet is described in milliseconds.

This information is not always useful but can negatively impact communication protocols which wait for an ACK-signal to progress in their control loop.

Latency cannot be measured over the entire network. We cannot say "The networks latency is x". This is because latency is always between two points, the sender and receiver.

We measure latency by sending a pre-determined amount of bytes to a certain destination. When we start sending the first packages, we start a timer. We stop this same timer when the receiver of the bytes lets us know they have received said bytes.

The time measured is called, latency.

Packet Loss

Previously we already mentioned packets, in those contexts; we assume that all packets make the target destination. Though in some cases, they do not. This is called packet loss.

While previously, those packets would always more or less arrive, though just with a delay; in this case they do not at all. Which means it has more drastic effects on the application in need of that data.

To measure packet loss, we send a predetermined amount of packets (bytes) to a receiver. On the receiver, we check how many packets we received. Since we know the start amount, we also know how many we should receive.

For example, we send 100 packets to receiver X. X measures how many packets it receives, in this instance; it receives 78. This means that the packet loss is 100 – 78 = 12%.

Throughput

Throughput refers to the amount of data flowing **through** a pipeline (both in and out!), in our case this pipeline is our network. This means you can measure throughput at many different parts of the network.

Measuring throughput is simple, but often hidden in hardware registers. It relies on counting the RX and TX bytes of a network adapter/router/network pipeline etc. Usually this is done in seconds. Observe all the traffic coming and going, and that is the throughput.

For example, a pipeline sends 16mb of data and receives 25mb of data per second. The throughput of the TX is 16mb/s, the throughput of the RX is 25mb/s.

Bandwidth

Bandwidth is a very common term. It refers to the total amount of data a network can transmit in a set amount of time. Usually, the bigger the bandwidth, the more data can be pushed through the network.

Bandwidth cannot be measured, since it is a parameter which exists outside of the control of the users. Bandwidth is “given” to a network by either its internet provider or the hardware which the network is set up with. Available bandwidth CAN be measured, though the bandwidth must be known prematurely to processing network data; which is not always the case.

Conclusion

All that becomes apparent is that most of the network statistics need certain data to be sent in order to recognize and calculate a significant number.

Ideally, we do not want to risk measuring a metric which might endanger our stream; by endangering our stream. That is why we want to focus our attention on the *Throughput* metric. Sadly, this does have one downside, which is that throughput can only be measured at very specific points in a network. And that its output to the first eye seems very insignificant.

To measure throughput, we have made a network measuring tool in CPP. It takes a look at the RX and TX buffers of our network adapter. After this, it measures the total amount sent; the average and the current amount sent. This can be found under the Code folder.

How to change the streams quality dynamically

Changing the quality of a picture with the goal of downsizing its memory size can be done in multiple ways. Most conventionally, there are two ways to do this:

1. Downscaling the resolution of the image
2. In case of a non-raw picture, downscale the quality of the compression and/or encoding algorithm

Since we utilize this stream as a source of data when controlling the robot either manually or, in the future, via self-driving interfaces; changing the resolution constantly is not viable. A constantly changing image size when wearing vr-glasses for example, is a self-explanatory example as to why changing the resolution is not preferred.

Changing encoder settings

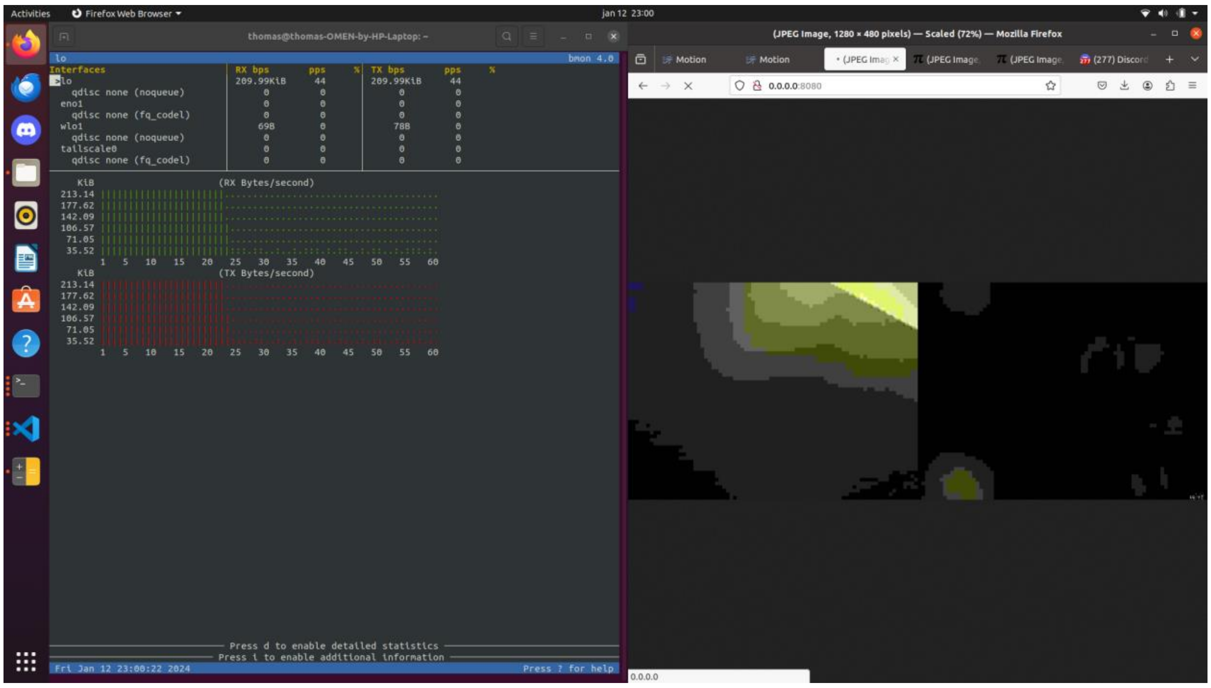
This leaves us with one other option to alter the quality of the stream, changing the compression and/or encoding algorithm. Most encoders allow for tuning of their algorithm parameters. Though we found that the best encoder, does not.

The best encoders are usually found not in software, but in the hardware alongside the camera. Many usb cameras have their own dedicated hardware encoder which is predesigned to output a specific compression rate. This means that if we want to change the image, we need to either have a camera which allows for reprogramming of their hardware encoder; or we need to post process the signal with a different encoder.

With processing speed as a primary scope, processing two times (first with hardware, secondly with software); almost always introduces redundancy and delays onto the system. Furthermore, most encoders rely on a raw signal; rather than an already processed image.
This means that when the hardware encoder does not allow for configuration; it is almost always better to switch to a software encoder.

In our case, the hardware encoder did not support configuration; thus we switched to a software encoder. With this software encoder, we can tune various parameters; one of which includes image quality.

Different quality settings are shown below for visualization purposes, the resolution is 1280x480.

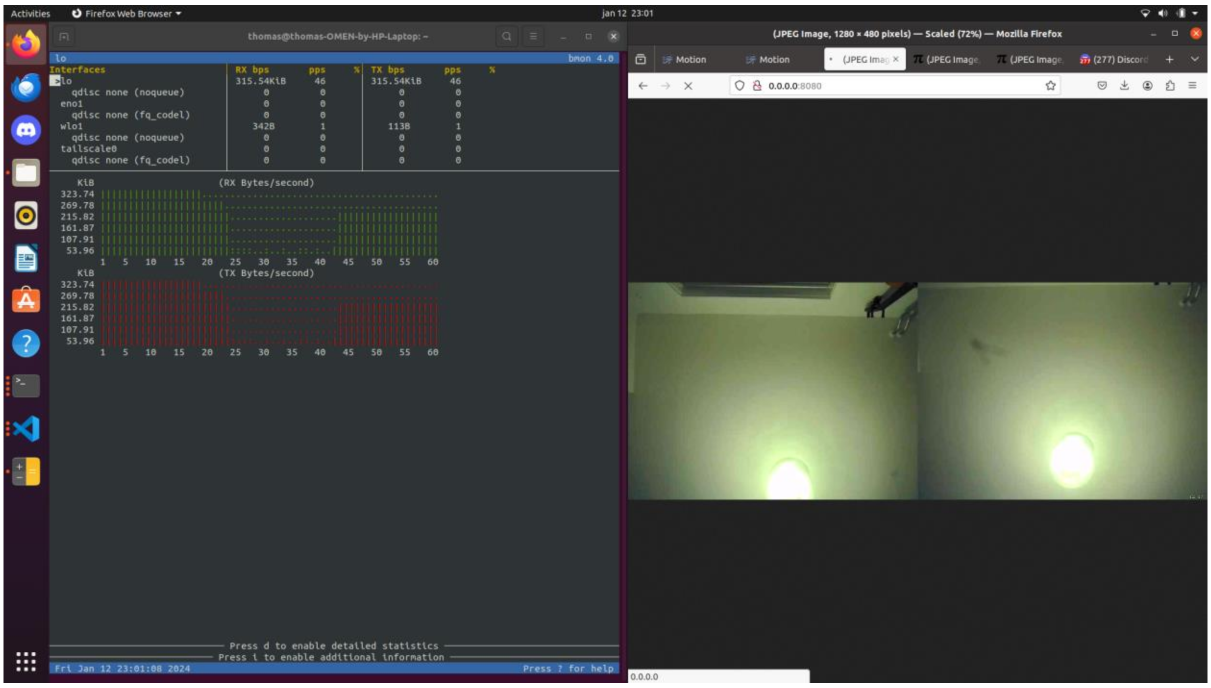


```
lo                                                                   bmon 4.0
Interfaces                 RX bps        pps     %  TX bps        pps     %
>lo                        209.99KiB      44        209.99KiB      44
   qdisc none (noqueue)           0        0                0       0
  eno1                            0        0                0       0
   qdisc none (fq_codel)          0        0                0       0
  wlo1                          69B        0              78B       0
   qdisc none (noqueue)           0        0                0       0
  tailscale0                      0        0                0       0
   qdisc none (fq_codel)          0        0                0       0

     KiB                   (RX Bytes/second)
  213.14
  177.62
  142.09
  106.57
   71.05
   35.52
          1   5   10   15   20   25   30   35   40   45   50   55   60
     KiB                   (TX Bytes/second)
  213.14
  177.62
  142.09
  106.57
   71.05
   35.52
          1   5   10   15   20   25   30   35   40   45   50   55   60

                      Press d to enable detailed statistics
                    Press i to enable additional information
 Fri Jan 12 23:00:22 2024                                       Press ? for help
```

(JPEG Image, 1280 × 480 pixels) — Scaled (72%) — Mozilla Firefox

0.0.0.0:8080

Quality: 1

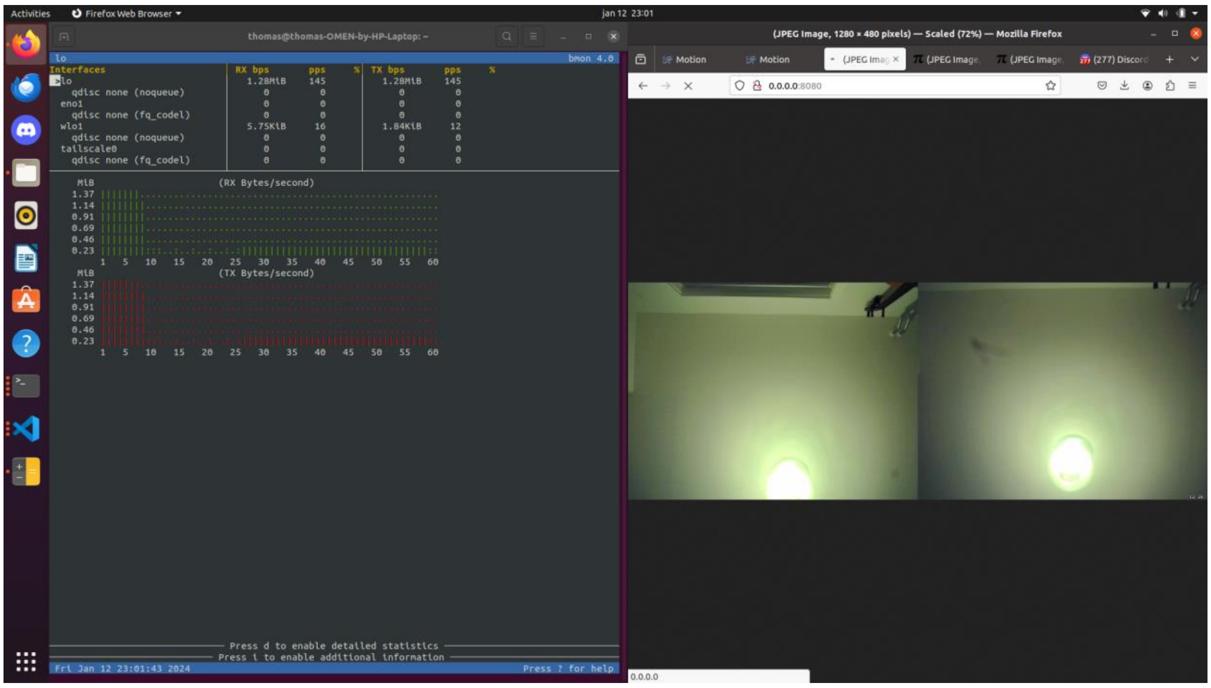


```
lo                                                                   bmon 4.0
Interfaces                 RX bps        pps     %  TX bps        pps     %
>lo                        315.54KiB      46        315.54KiB      46
   qdisc none (noqueue)           0        0                0       0
  eno1                            0        0                0       0
   qdisc none (fq_codel)          0        0                0       0
  wlo1                         342B        1             113B       1
   qdisc none (noqueue)           0        0                0       0
  tailscale0                      0        0                0       0
   qdisc none (fq_codel)          0        0                0       0

     KiB                   (RX Bytes/second)
  323.74
  269.78
  215.82
  161.87
  107.91
   53.96
          1   5   10   15   20   25   30   35   40   45   50   55   60
     KiB                   (TX Bytes/second)
  323.74
  269.78
  215.82
  161.87
  107.91
   53.96
          1   5   10   15   20   25   30   35   40   45   50   55   60

                      Press d to enable detailed statistics
                    Press i to enable additional information
 Fri Jan 12 23:01:08 2024                                       Press ? for help
```

(JPEG Image, 1280 × 480 pixels) — Scaled (72%) — Mozilla Firefox

0.0.0.0:8080

Quality: 30



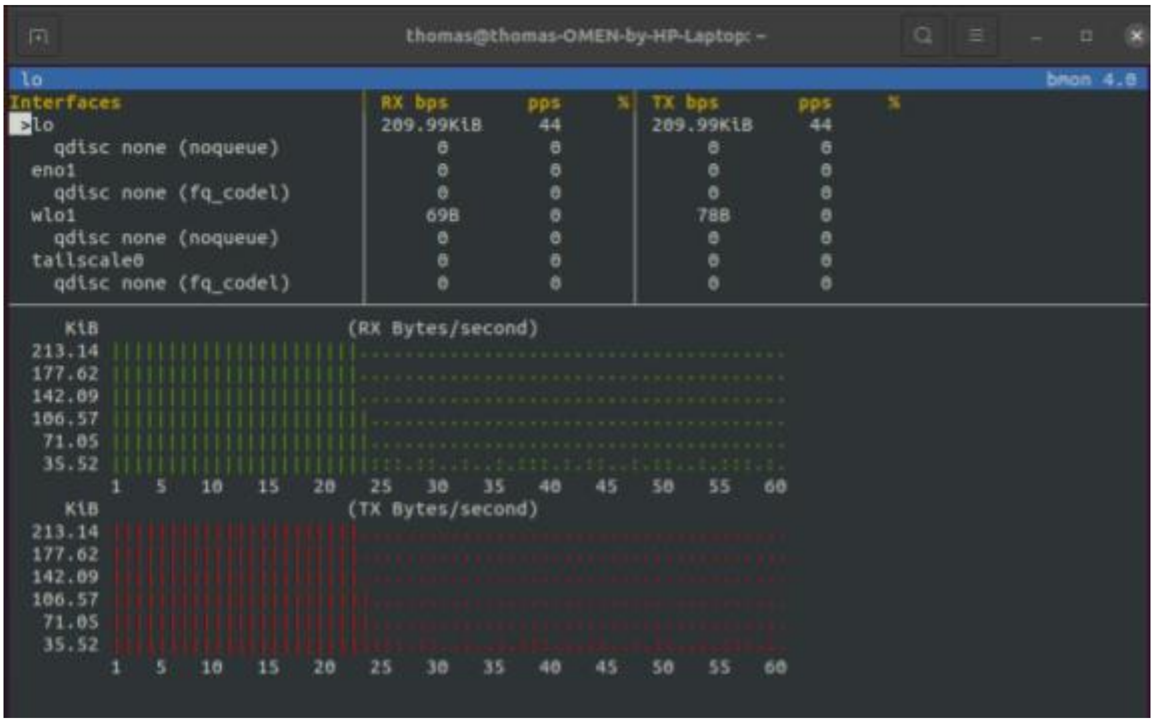
```
lo                                                              bmon 4.0
Interfaces                 RX bps      pps     %  TX bps      pps     %
>lo                         1.28MiB     145        1.28MiB     145
   qdisc none (noqueue)           0       0              0       0
  eno1                            0       0              0       0
   qdisc none (fq_codel)          0       0              0       0
  wlo1                      5.75KiB      16        1.84KiB      12
   qdisc none (noqueue)           0       0              0       0
  tailscale0                      0       0              0       0
   qdisc none (fq_codel)          0       0              0       0

                  Press d to enable detailed statistics
                  Press i to enable additional information
Fri Jan 12 23:01:43 2024                                  Press ? for help
```

Quality: 90

Relevancy of sacrificing quality for data compression

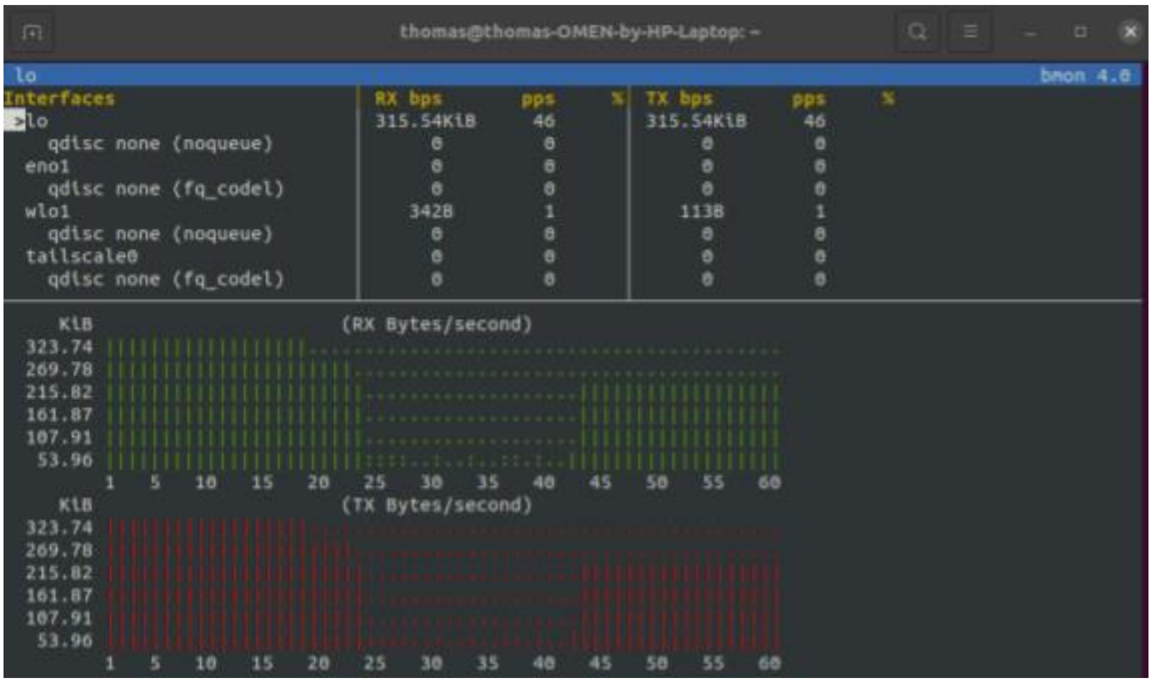
Since up until now, it was assumed that reducing the quality of a stream reduces its data output. Though this was never proven. We can use a tool called" bmon" to measure the used bandwidth on certain network adapters. Using this tool, we can prove that impeding the quality of a stream means it transmits less data.

We can see it in the left window of the provided screenshots above. Most specifically, we want to look at the "lo" adapter, the systems local network adapter.



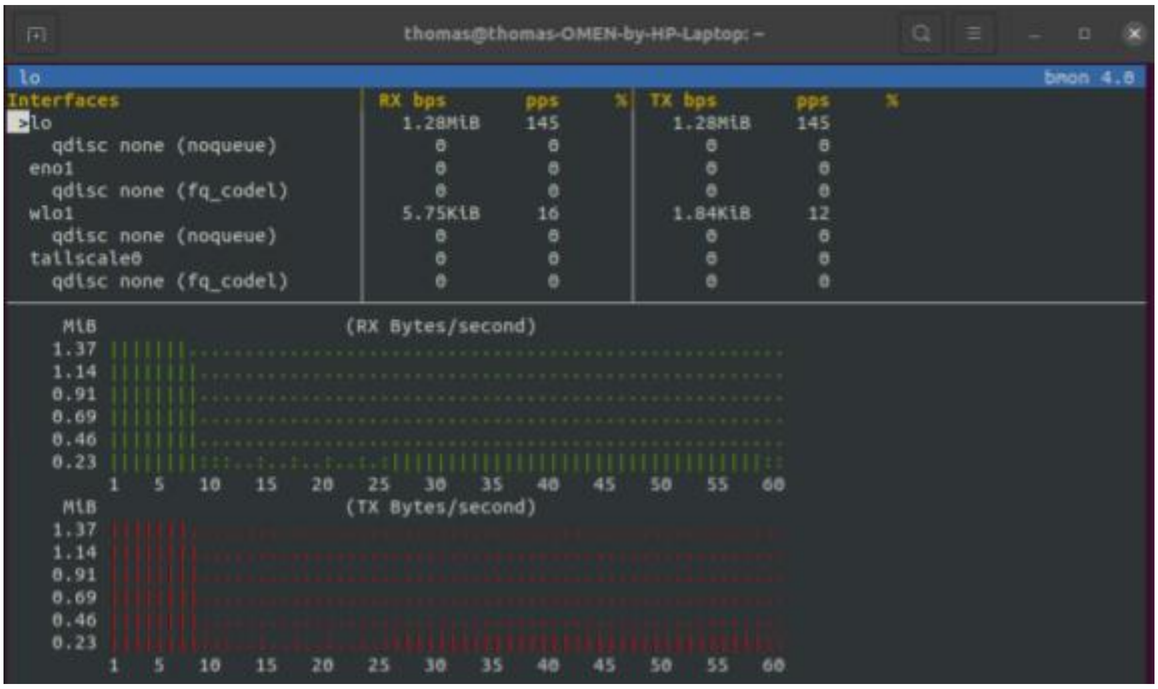
```
lo                                                              bmon 4.0
Interfaces                 RX bps      pps     %  TX bps      pps     %
>lo                       209.99KiB      44      209.99KiB      44
   qdisc none (noqueue)           0       0              0       0
  eno1                            0       0              0       0
   qdisc none (fq_codel)          0       0              0       0
  wlo1                          69B       0            78B       0
   qdisc none (noqueue)           0       0              0       0
  tailscale0                      0       0              0       0
   qdisc none (fq_codel)          0       0              0       0
```

We can see that for the 1 quality preset, we barely transmit 300 kilobytes. Though as seen, we cannot use that output stream.



```
thomas@thomas-OMEN-by-HP-Laptop: ~
lo                                                                          bmon 4.0
Interfaces                      RX bps        pps     %  TX bps        pps     %
>lo                             315.54KiB      46        315.54KiB      46
   qdisc none (noqueue)                 0       0                0       0
  eno1                                  0       0                0       0
   qdisc none (fq_codel)                0       0                0       0
  wlo1                               342B       1             113B       1
   qdisc none (noqueue)                 0       0                0       0
  tailscale0                            0       0                0       0
   qdisc none (fq_codel)                0       0                0       0

     KiB                      (RX Bytes/second)
  323.74
  269.78
  215.82
  161.87
  107.91
   53.96
         1   5   10   15   20   25   30   35   40   45   50   55   60
     KiB                      (TX Bytes/second)
  323.74
  269.78
  215.82
  161.87
  107.91
   53.96
         1   5   10   15   20   25   30   35   40   45   50   55   60
```

If we update to a 30 quality preset, we can see that the transmitted bytes barely differ. Though our output becomes quite usable.



```
thomas@thomas-OMEN-by-HP-Laptop: ~
lo                                                                          bmon 4.0
Interfaces                      RX bps        pps     %  TX bps        pps     %
>lo                               1.28MiB     145          1.28MiB     145
   qdisc none (noqueue)                 0       0                0       0
  eno1                                  0       0                0       0
   qdisc none (fq_codel)                0       0                0       0
  wlo1                            5.75KiB      16          1.84KiB      12
   qdisc none (noqueue)                 0       0                0       0
  tailscale0                            0       0                0       0
   qdisc none (fq_codel)                0       0                0       0

     MiB                      (RX Bytes/second)
    1.37
    1.14
    0.91
    0.69
    0.46
    0.23
         1   5   10   15   20   25   30   35   40   45   50   55   60
     MiB                      (TX Bytes/second)
    1.37
    1.14
    0.91
    0.69
    0.46
    0.23
         1   5   10   15   20   25   30   35   40   45   50   55   60
```

If we use almost max quality, we can see that the data quickly begins to ramp up. Remember, we are shooting with 30 fps. That means 30 times the data of one very high quality frame.

As we can see, even with a slight decrease in quality; we can save over 60% of bandwidth previously taken up. Naturally, there are sweet spots in between the three measurements provided.

Control loop

Now that we can change the encoder settings, and thus the quality, and we can measure network performance. We can use these two products to create a control loop.

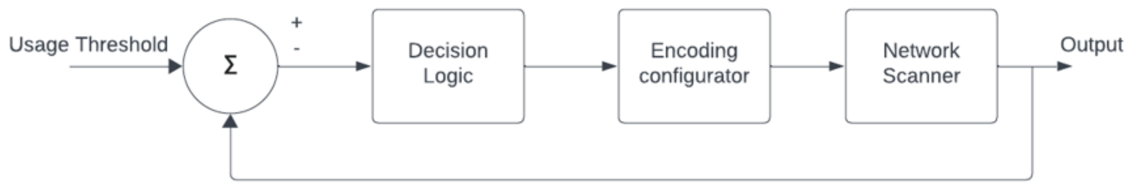
Rather than focussing on the highest possible quality, we want to focus on the highest speeds. Or at least, ensuring that this speed can stay stable. Because of this, we scale down according to the internet usage.

We do this by constantly polling the network usage, according to this information; we can compare it to a threshold we have set. Over this difference, we calculate a usage percentage.

For example, we have a network usage of 3000000 (3Mb/s) bytes, our allowed threshold is 4000000 (4Mb/s). We calculate: (3000000 * 100)/ 4000000 = 75% usage.

We can feed the control loop the usage percentage, and the control loop will ensure the usage percentage stays at a goal. This goal is the max allowed usage percentage the system is allowed to have.

If we have a 75% usage percentage, whilst our goal is 50%; we need to scale down the image quality whereas the usage percentage will settle around 50%.



We can visualize the control loop in a diagram like so.

Final product demo

Below is a short video which shows the product in action. We open a stream and view its contents. To increase the networkusage, we open another stream in our browser. We can see the program adjusting its quality levels, both in the console and on the stream this is noticeable.

Video added as dynamic_demo.mp4

Notice about the project

Currently the code is all written in a compilable way, however it cannot easily be implemented in the projects makefile. This is due to it being an automatically generated makefile, which is hard to manipulate. I have spoken to the teacher about this and this problem might be resolved. If not it will be clearly mentioned here.

Currently the code resides as local functions in the motion.c file.

Future Work

The future can bring some new work to this feature, namely extending the way bytes are read. Since the network registers do not only support the rx and tx bytes, but support way more. This way a more extensive networkscanner can be built.

Feasibility of planning

In order to validate my planning, I want to look at it again and provide insights into what stage I was in at those specific times.

To recall the planning:

6 dec:
Assigned new problem in group.

13 dec:
Form idea of which metrics are important and which aren't.

20 dec:
Present current findings and progress to Bryce and Edwin.

10 jan:
Have prototype working to present to Edwin

17 jan:
Have fine tuned product to show Bryce and Edwin.

6 dec:
No real comment.

13 dec:
Started researching network metrics and phasing out unimportant metrics. Started picking up on throughput here and trying to write a program which measures it.

20 dec:
Spoke with Bryce about my progress a lot, it wasn’t easy to explain at first; but after a while Bryce understood where I was and understood the network measuring demos I showed him. I understood what I was working with.

Also beforehand spoke to Edwin and asked some advice, he gave some pointers and approved or denied some of my questions regarding way of working.

10 jan:
Demoed my work to Edwin, he was very exited and surprised I made it work so well. We tried with a different camera aswell, to validate its generic usage. It all worked flawlessly.
Only real improvement was to port it to a raspberry, if I had time we would do it we agreed upon.

17 jan:
yet to be.