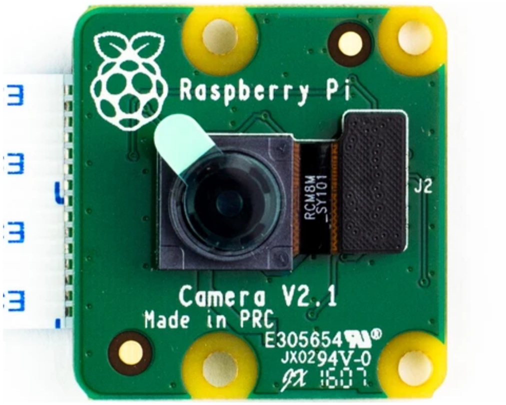
Raspberry Pi - Setup Camera and test the performance of different video encoders

Camera module on Raspberry Pi needs to be enabled manually before it can be used by applications. There are some methods to access to the camera with different encoders, but popular drivers include Video For Linux 2, and OMX H264 hardware encoder. This post runs some tests using FFmpeg and PiCamera package to measure the performance of different encoders.

#raspberry-pi #camera #v4l2 #ffmpeg #python #picamera

Last update: 2021-08-04 17:31:07

Table of Content



RaspberryPi Camera Module

This tutorial is for setting up the official Raspberry Pi Camera module which is attached with a CSI cable. Other types of USB Camera should work on Pi out-of-the-box.

1. Enable Camera module

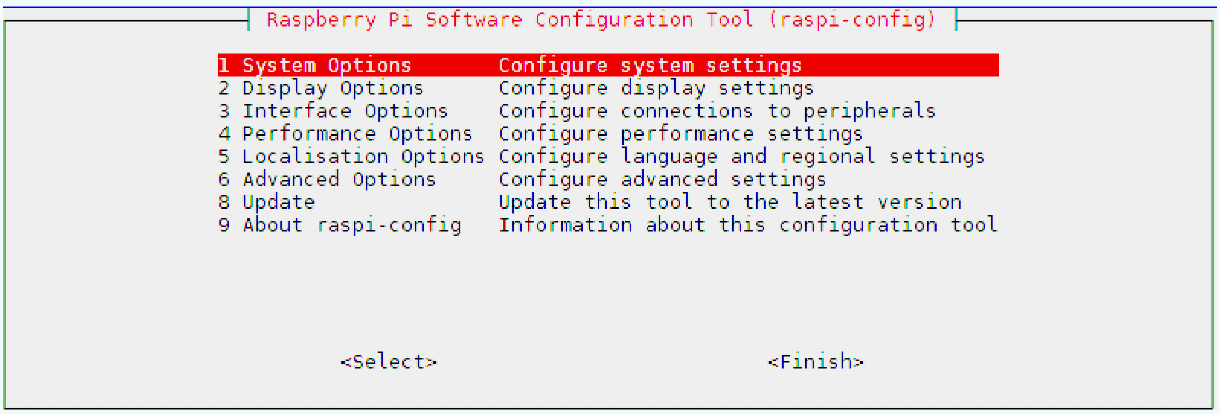
Run `raspi-config` configuration tool:

```
sudo raspi-config
```

then select **Interfacing Options** → **Camera** → **Yes**.

This method will automatically set `start_x=1` in `/boot/config.txt` file.

raspi-config is a Raspberry Pi configuration command-line tool, to enable or disable some features in Pi OS. This tool requires root permission, therefore, it must be run with the super user right using `sudo`.



User interface of `raspi-config`

2. Increase GPU memory

Some video encoders need a big buffer to process video encoding or decoding. To increase the memory reserved for video processor, in the `raspi-config` configuration tool, go to **Performance Options** → **GPU Memory** then fill in ***256*** and select **OK**.

This method does the same thing with setting up `gpu_mem=256` in `/boot/config.txt`.

3. Test Camera

Detect the camera connection by running the checking tool:

```
vcgencmd get_camera
```

which should print out `supported=1 detected=1` telling that the camera is supported and connected.

vcgencmd is a command line utility that can get various pieces of information from the VideoCore GPU on the Raspberry Pi. Check more detail in Raspberry Pi/vcgencmd

Raspicam commands has a set of tools to work with the camera module: `raspistill`, `raspivid`, and `raspiyuv`.

- Capture an image: `raspistill -o cam.jpg`
- Record an video: `raspivid -o vid.h264`

4. Video for Linux 2 - V4L2

Under Linux, the standard APIs for cameras (including webcams) is `V4L` (Video for Linux), and a number of applications have been written that support any camera with a V4L driver. An independent developer has now written an user space V4L driver for the Raspberry Pi camera but it is closed sourced, and can be a little slow because it runs as a user program rather than a kernel driver.

Recognizing that a V4L driver is needed, the Raspberry Pi Foundation reported that they were working with Broadcom to develop an official kernel V4L driver. As a kernel driver, it should be faster than the user space driver.

Finally, V4L2 was released under the name `bcm2835-v4l2` which is included Raspberry Pi OS by default. Use `v4l2-ctl` utility tool to capture from the camera.

4.1. List devices

```
v4l2-ctl --list-devices
```

```
bcm2835-codec-decode (platform:bcm2835-codec):
        /dev/video10
        /dev/video11
        /dev/video12

bcm2835-isp (platform:bcm2835-isp):
        /dev/video13
        /dev/video14
        /dev/video15
        /dev/video16

mmal service 16.1 (platform:bcm2835-v4l2):
        /dev/video0
```

4.2. Driver info

```
v4l2-ctl -d /dev/video0 --all
```

```
Driver Info:
    Driver name      : bm2835 mmal
    Card type        : mmal service 16.1
    Bus info         : platform:bcm2835-v4l2
    Driver version   : 5.4.79
    Capabilities     : 0x85200005
            Video Capture
            Video Overlay
            Read/Write
            Streaming
    ...
```

4.3. Supported formats

```
v4l2-ctl --list-formats
```

```
ioctl: VIDIOC_ENUM_FMT
        Type: Video Capture

        [0]: 'YU12' (Planar YUV 4:2:0)
        [1]: 'YUYV' (YUYV 4:2:2)
        [2]: 'RGB3' (24-bit RGB 8-8-8)
        [3]: 'JPEG' (JFIF JPEG, compressed)
        [4]: 'H264' (H.264, compressed)
        [5]: 'MJPG' (Motion-JPEG, compressed)
        [6]: 'YVYU' (YVYU 4:2:2)
        [7]: 'VYUY' (VYUY 4:2:2)
        [8]: 'UYVY' (UYVY 4:2:2)
        [9]: 'NV12' (Y/CbCr 4:2:0)
        [10]: 'BGR3' (24-bit BGR 8-8-8)
```

```
        [11]: 'YV12' (Planar YVU 4:2:0)
        [12]: 'NV21' (Y/CrCb 4:2:0)
        [13]: 'RX24' (32-bit XBGR 8-8-8-8)
```

Please take a note for `RGB3`, `JPEG`, `H264`, and `MJPEG`, which can be used in OpenCV, or streaming directly.

4.4. Capture JPEG Image

```
v4l2-ctl --set-fmt-video=width=2592,height=1944,pixelformat=3 && \
v4l2-ctl --stream-mmap=3 --stream-count=1 --stream-to=somefile.jpg
```

4.5. Record H264 Video

⚠ Note the value *height=**1088***, not 1080.

```
v4l2-ctl --set-fmt-video=width=1920,height=1088,pixelformat=4 && \
v4l2-ctl --stream-mmap=3 --stream-count=100 --stream-to=somefile.264
```

5. FFmpeg

The pre-built `ffmpeg` package of Pi already enables hardware accelerator support, with OpenMAX IL H.264 video encoder (`h264_omx`).

```
sudo apt-get install ffmpeg -y
```

An FFmpeg version with a specific library can be built by following this topic Compile FFmpeg with Hardware Accelerator.

5.1. Encoders

To see all available encoders:

```
ffmpeg -encoders
```

If interested in `h264` and `mjpeg`, use `grep` to search for the specific encoders:

```
ffmpeg -hide_banner -encoders | grep -E "h264|mjpeg"
```

```
 V..... libx264              libx264 H.264 / AVC / MPEG-4 AVC / MPEG-4 part 10 (codec
 h264)
 V..... libx264rgb           libx264 H.264 / AVC / MPEG-4 AVC / MPEG-4 part 10 RGB
 (codec h264)
```

```
V..... h264_omx             OpenMAX IL H.264 video encoder (codec h264)
V..... h264_v4l2m2m         V4L2 mem2mem H.264 encoder wrapper (codec h264)
VFS... mjpeg                MJPEG (Motion JPEG)
```

Check encoder options

Before using an encoder, check its options by `help` command in `ffmpeg`.

```
ffmpeg -h encoder=<format>
```

Here is the list of formats supported by OpenMAX IL H.264 video encoder (h264_omx):

```
ffmpeg -h encoder=h264_omx
```

```
Encoder h264_omx [OpenMAX IL H.264 video encoder]:
    General capabilities: delay
    Threading capabilities: none
    Supported pixel formats: yuv420p
h264_omx AVOptions:
    -omx_libname       <string>     ED.V...... OpenMAX library name
    -omx_libprefix     <string>     ED.V...... OpenMAX library prefix
    -zerocopy          <int>        E..V...... Try to avoid copying input frames if
possible (from 0 to 1) (default 1)
    -profile           <int>        E..V...... Set the encoding profile (from -99 to
100) (default -99)
        baseline        66          E..V......
        main            77          E..V......
        high            100         E..V......
```

5.2. Performance

Next, try to record some short video (60 seconds) with H264 format using different encoders. To measure the performance, use a small tool to check CPU and Memory Usage in monitor - Script to check performance.

Note that `ffmpeg` will use `v4l2` driver if user does not specify the driver!”

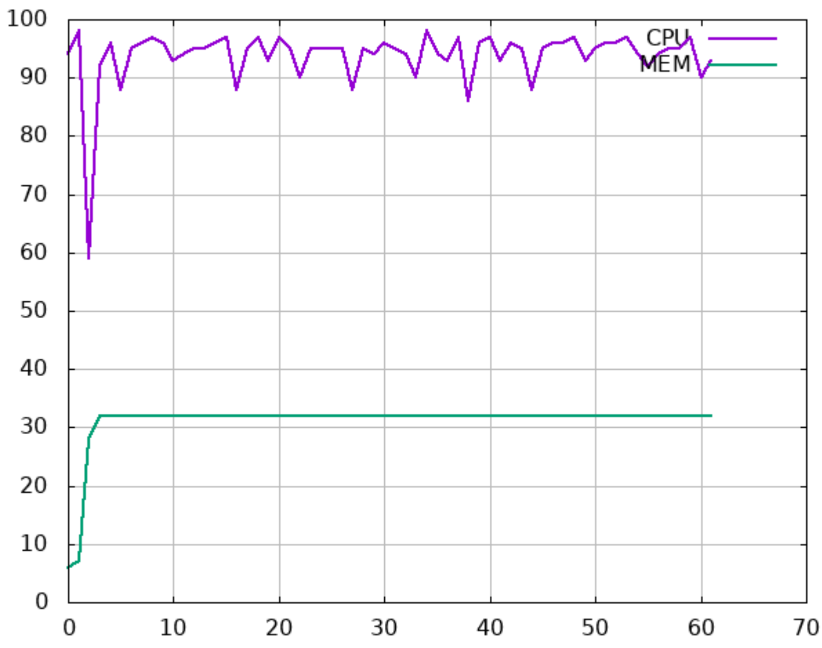
Video settings

Video side: **1024x768**
Framerate: **30** fps
Input Length: **60** seconds

5.2.1. Raw to MJPEG (.avi)

```
ffmpeg -y -hide_banner \
    -use_wallclock_as_timestamps 1 \
    -t 60 \
    -i /dev/video0 \
    -c:v mjpeg \
    raw_mjpeg.avi
```

- Performance:
  - Total time: 63 seconds
  - Average CPU: *93 (too high)*
  - Average MEM: 31
  - Input FPS: *4.8 (dropped input)*
  - Output FPS: 30
- Quality:
  - Format: JPEG
  - Codec ID: MJPG
  - Bit rate: 839 kb/s



Raw to MJPEG

5.2.2. Raw to H264_OMX @8Mbps (.mp4)

```
ffmpeg -y -hide_banner \
    -use_wallclock_as_timestamps 1 \
    -t 60 \
    -i /dev/video0 \
    -c:v h264_omx \
    -b:v 8M \
    raw_h264omx.mp4
```

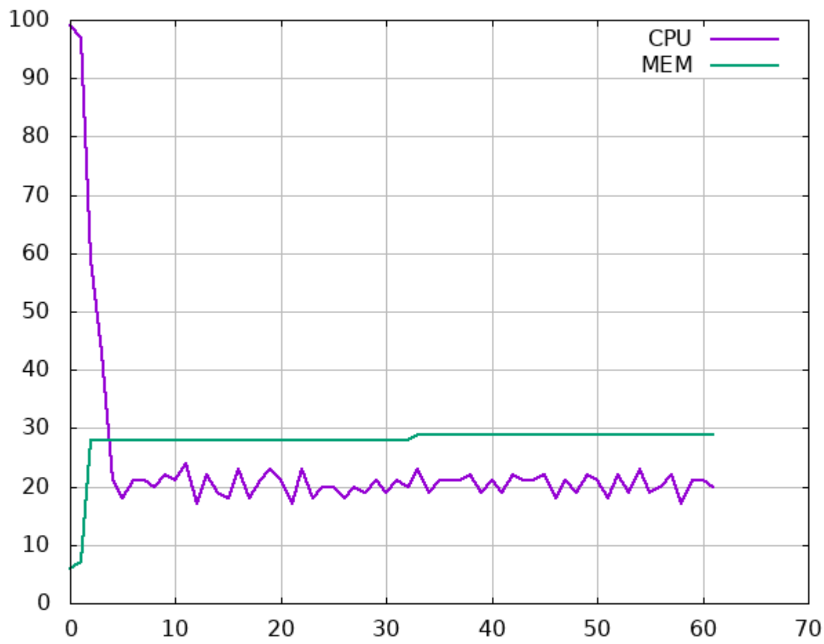
- Performance:
  - Total time: 63 seconds
  - Average CPU: *16 (OK)*
  - Average MEM: 27
  - Input FPS: 30
  - Output FPS: 30
- Quality:
  - Format: AVC (GOP: M=1, N=12)
  - Codec ID: avc1
  - Bit rate: 2 877 kb/s

Raw to H264_OMX @8Mbps

5.2.3. Raw to H264_V4L2M2M @8Mbps (.mp4)

```
ffmpeg -y -hide_banner \
    -use_wallclock_as_timestamps 1 \
    -t 60 \
    -i /dev/video0 \
    -c:v h264_v4l2m2m \
    -b:v 8M \
    raw_h264v4l2m2m.mp4
```

- Performance:
  - Total time: 62 seconds
  - Average CPU: 23
  - Average MEM: 27
  - Input FPS: 30
  - Output FPS: 30
- Quality:
  - Format: AVC (GPO: M=1, N=60)
  - Codec ID: avc1
  - Bit rate: 1 783 kb/s

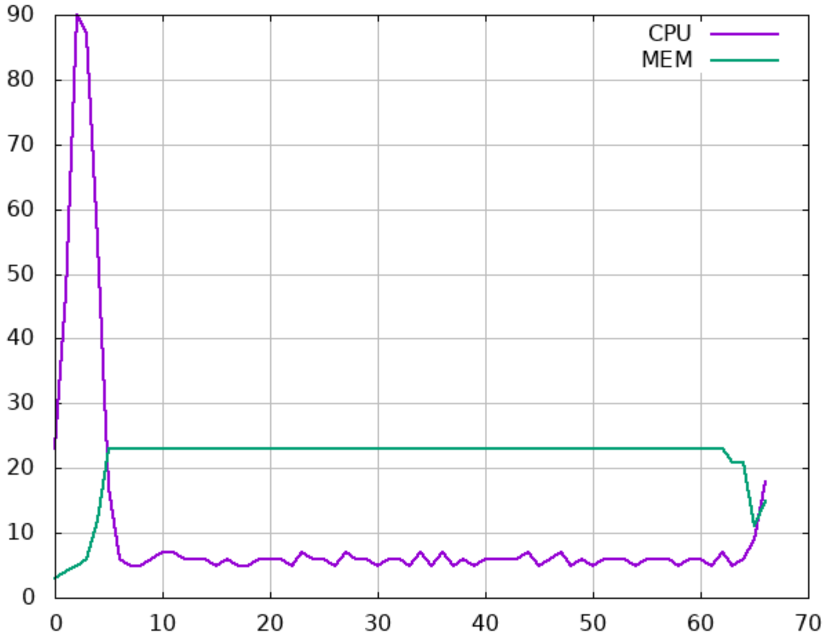


Raw to H264_V4L2M2M @8Mbps

5.2.4. V4L2 MJPEG direct copy (.avi)

```
ffmpeg -y -hide_banner \
    -use_wallclock_as_timestamps 1 \
    -t 60 \
    -input_format mjpeg \
    -i /dev/video0 \
    -c:v copy \
    -t 60 \
    mjpeg_avi.avi
```

- Performance:
  - Total time: 67 seconds
  - Average CPU: **10 (Good)**
  - Average MEM: 21
  - Input FPS: 30
  - Output FPS: 30
- Quality:
  - Format: JPEG
  - Codec ID: MJPG
  - Bit rate: *10.2 Mb/s (very high bandwidth)*

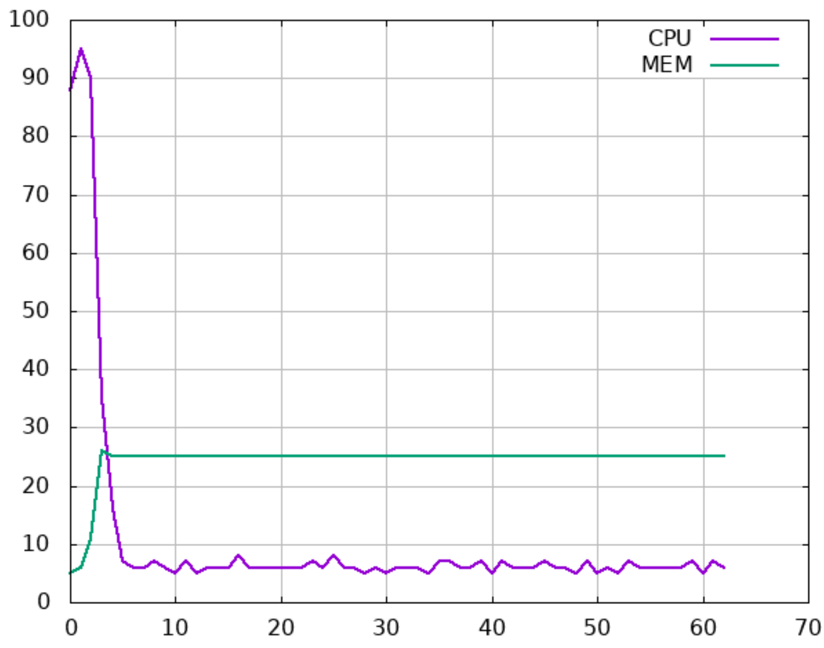


Save V4L2 MJPEG strem

5.2.5. V4L2 H264 direct copy (.mp4)

```
ffmpeg -y -hide_banner \
    -use_wallclock_as_timestamps 1 \
    -t 60 \
    -input_format h264 \
    -i /dev/video0 \
    -c:v copy \
    -t 60 \
    h264_mp4.mp4
```

- Performance:
  - Total time: 67 seconds
  - Average CPU: **10 (Good)**
  - Average MEM: 24
  - Input FPS: 30
  - Output FPS: 30
- Quality:
  - Format: AVC (GPO: M=1, N=60)
  - Codec ID: avc1
  - Bit rate: *5 506 kb/s (OK)*



Save V4L2 H264 stream

5.2.6. Conclusion

After above tests, it can be said that using compressed input format from `v4l2` is much more effective than compressing by an software encoder.

Let's add some timestamp to video by using `drawtext` filter with built-in expandable `localtime` variable in Text-expansion option.

```
ffmpeg -y -hide_banner \
    -use_wallclock_as_timestamps 1 \
    -t 10 \
    -i /dev/video0 \
    -vf "drawtext=text='%{localtime}':fontcolor=white:x=100:y=100" \
    -c:v h264_omx \
    -b:v 8M \
    raw_h264omx_text.mp4
```

Filter and stream-copy cannot be used together

Text needs inserted and each frame needs re-encoded, therefore, stream-copy is unavailable.

```
# this will not work
ffmpeg -y -hide_banner \
    -use_wallclock_as_timestamps 1 \
    -t 10 \
    -input_format h264 \
    -i /dev/video0 \
    -vf "drawtext=text='%{localtime}':fontcolor=white:x=100:y=100" \
    -c:v copy \
    -t 10 \
    h264_mp4_text.mp4
```

6. Install `picamera`

The `picamera` package is a pure Python interface to the Raspberry Pi camera module for Python language. If using the Raspbian distro, probably it has picamera installed by default. Run a test to check it is installed or not:

```
python -c "import picamera"
python3 -c "import picamera"
```

If no module found, install `picamera` from the system's package manager:

```
sudo apt-get install python-picamera python3-picamera
```

There are a lot of examples in the official guide. Here are some starting points:

Get maximum resolution of the camera

```
import picamera

with picamera.PiCamera() as cam:
    print(cam.MAX_RESOLUTION)
```

Take a snapshot

```
from time import sleep
from picamera import PiCamera

# setup a camera
camera = PiCamera()
camera.resolution = (1024, 768)

# camera warm-up time
sleep(2)

# capture an image
camera.capture('snapshot.jpg')
```

Now, for the testing purpose, let's record a 60-second video from the camera and measure the resource usage with `monitor`, then use `ffmpeg` to convert raw h264 to mp4:

6.1. Picamera H264 (.h264)

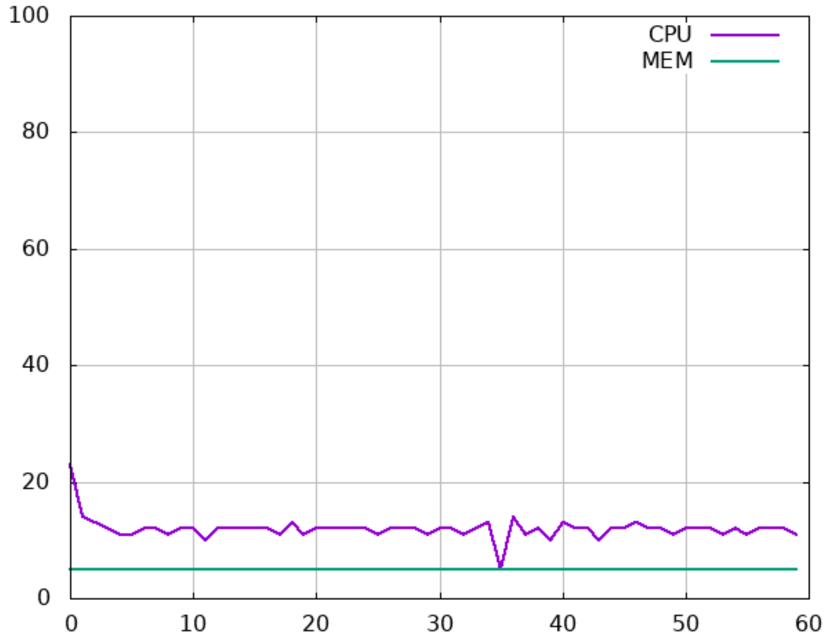
Recode a raw H264 video file

```
from picamera import PiCamera

# setup a camera
camera = PiCamera()
camera.resolution = (1024, 768)
camera.framerate = 30

# record a video
camera.start_recording('picamera.h264')
camera.wait_recording(60)
camera.stop_recording()
```

Convert to MP4 video file

```
ffmpeg -i picamera.h264 \
    -c:v copy picamera.mp4
```

- Performance:
  - Total time: 61 seconds
  - Average CPU: **11 (Good)**
  - Average MEM: **5 (Good)**
  - Input FPS: 30
  - Output FPS: **25**
- Quality:
  - Format: AVC (GPO: M=1, N=60)
  - Codec ID: avc1
  - Bit rate: *3 302 kb/s (Good)*



Picamera

6.2. Picamera H264 (.h264) with Text overlay

Now, try to detect how `picamera` can draw text on output video. Here is the test code:

```
from picamera import PiCamera
import datetime

TIMEFMT = '%Y-%m-%d %H:%M:%S.%f'

# setup a camera
camera = PiCamera()
```

```
camera.resolution = (1024, 768)
camera.annotate_text = datetime.datetime.now().strftime(TIMEFMT)

# record a video
camera.start_recording('picamera_text.h264')
start = datetime.datetime.now()

while (datetime.datetime.now() - start).seconds < 60:
  camera.annotate_text = datetime.datetime.now().strftime(TIMEFMT)
  camera.wait_recording(0.04) # 25fps

# stop it
camera.stop_recording()
```

Using `picamera` shows an impressive CPU and MEM usage, comparing to using FFmpeg. The result shows that the CPU uses twice as much as it does in non-overlay text, while the MEM keeps the same percentage.