

Development and Implementation of an Unmanned Aerial System for a 5G Vertical Use Case

A thesis presentation in partial fulfillment of the requirements for the degree of
Integrated Masters in Electrical and Computer Engineering

Christos Chasis – up1020710@g.upatras.gr
Network Architectures and Management group
Electrical and Computer Engineering department
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Brief Introduction

Use Case Scenario

Ground station unit provides the user with the ability to control a vehicle in real time, through the cellular network with line-of-sight not required

Vehicle should be able to transmit live video feeds to provide the user with appropriate feedback of its course

Application in search and rescue operations, remote takeover of autonomous vehicles or supervision of areas of interest

- Legacy systems utilize alternative radio frequency bands to transmit said video feeds which are prone to interference, low quality and medium to high latency
- By leveraging V2X connectivity, the user stands to benefit from the emerging 5G NR network, as increased coverage, low latency and quality of service are some of its main attributes. Commercial joysticks demonstrated jitter
- Various accessories that can augment the overall experience such as first person view (FPV) goggles and 360o cameras shall be supported in future iterations.

Requirements

- Open source
- Supports x64 platforms
- Easy modifications to conform to each use case
- Lightweight
- Battery autonomy

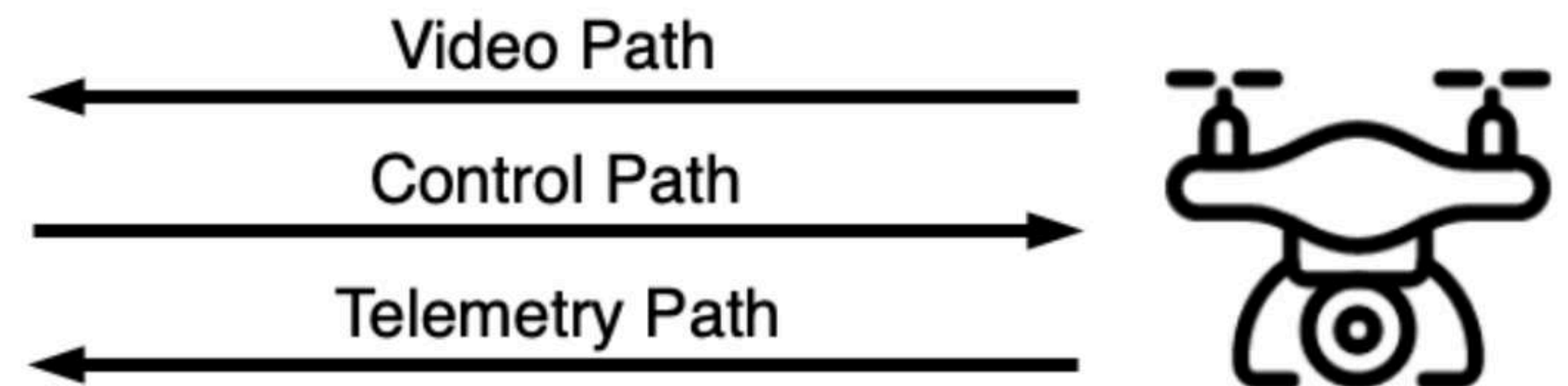
Architecture Overview

Network Slicing

The customizable network capabilities include data throughput, quality, latency, reliability and security.

From a mobile operator's point of view, a network slice is an independent end-to-end logical network that runs on a shared physical infrastructure, capable of providing a negotiated service quality and can be created on demand.

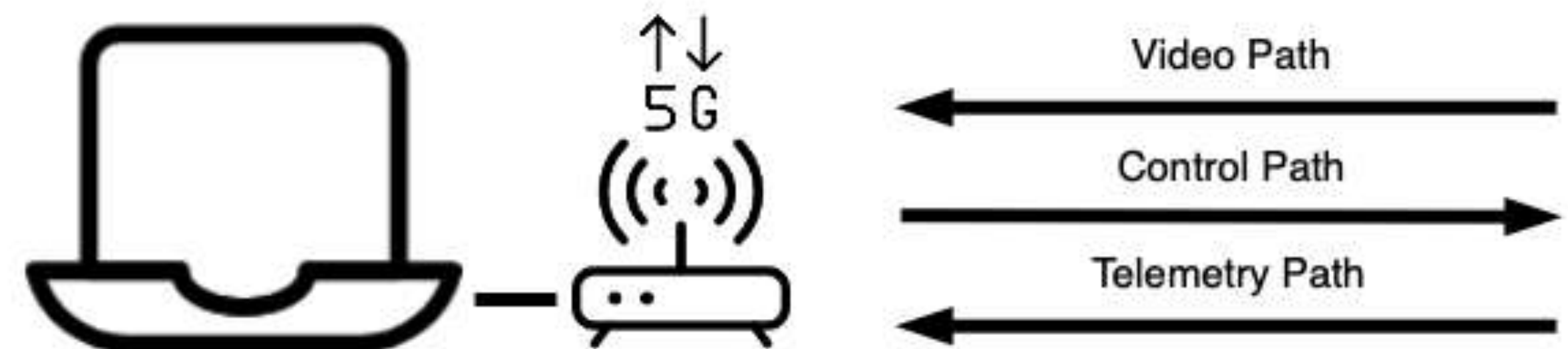
- Video streaming requires a significant amount of data
- Remote-control requires low latency and high reliability for delivery of commands
- To satisfy these requirements, capabilities provided by eMBB and URLLC slices are critical.



User Side

A wireless adapter will be used to relay a traditional two-stick radio controller's commands to the ground station software running on the laptop

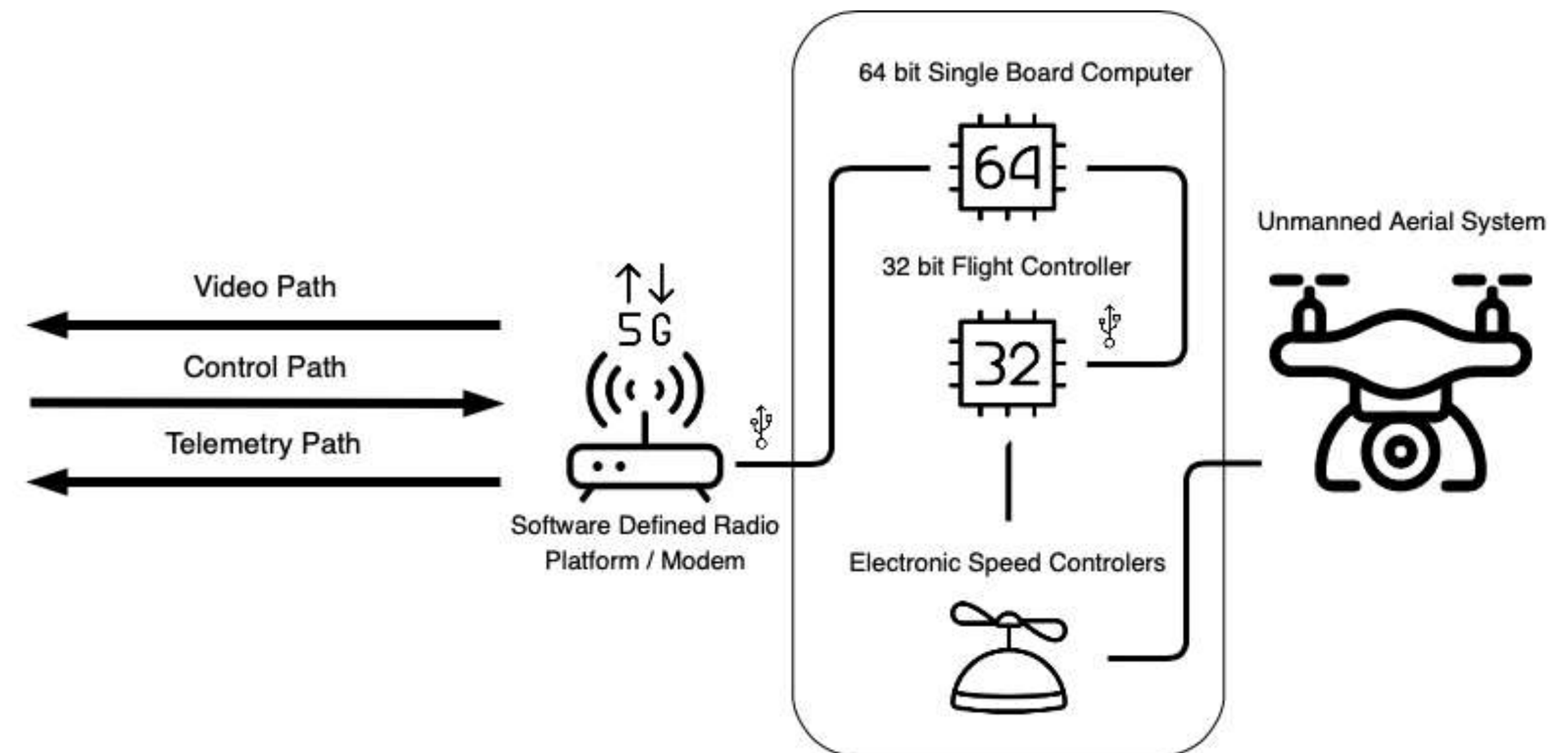
- Laptop keyboard input must be avoided
- Use wireless adapter for included radio remote
- Commercial joysticks demonstrated jitter
- FPV goggles can be added later



Vehicle Side

Workload-intensive tasks such as video encoding and streaming while maintaining timely reaction to received commands are vital to its operation.

Commercial off-the-shelf solutions prove to be severely incapable of conforming to our platform needs



Hardware Architecture

Intel Aero Ready To Fly

Headroom for future expansions, as additional cameras or sensors can easily be mounted

Nominal 20 minutes flight time well

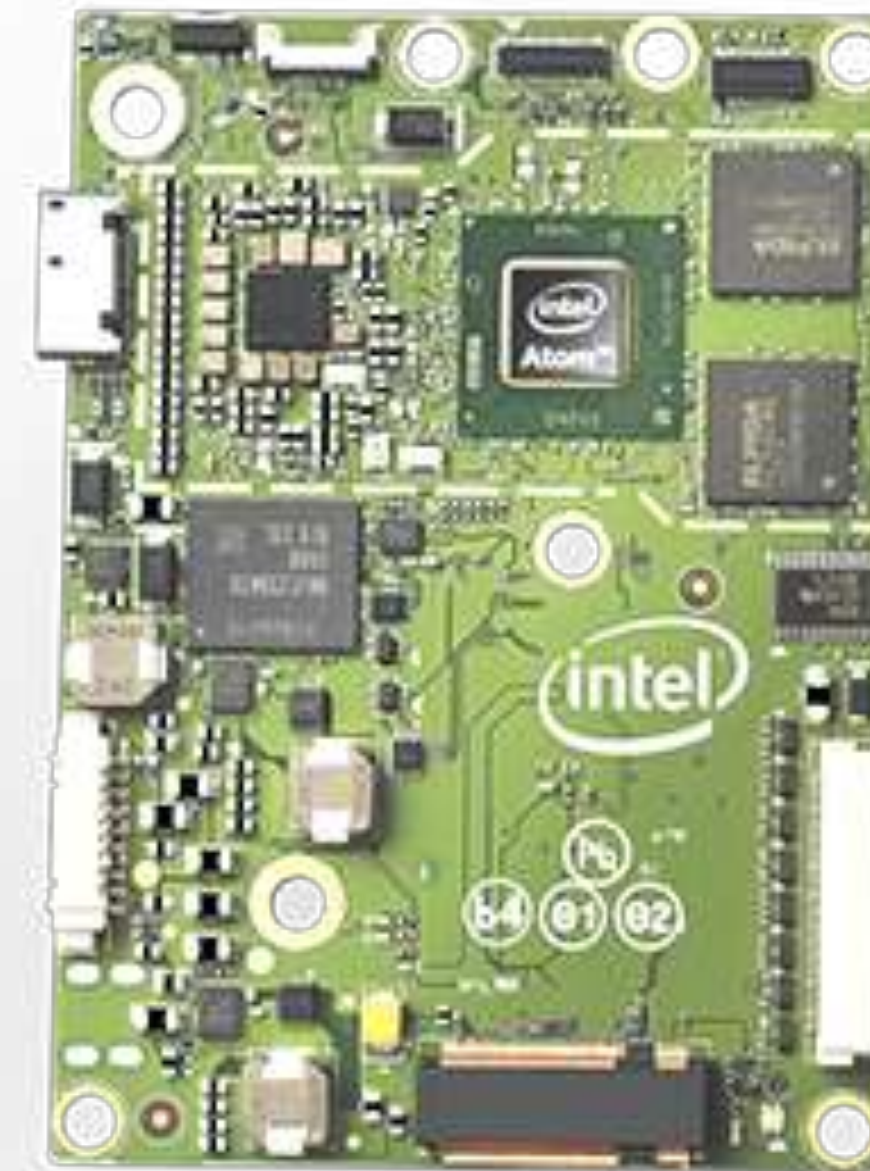
Combined takeoff weight of 1.9kgs.



Intel Aero Compute Board

Comes bundled with Intel's own flight controller, that connects over a serial port to the companion computer

All signals from the Aero Flight Controller are routed through the MAX10 FPGA to the IO Expansion connector.



Intel Realsense R200

Intel® RealSense R200 module implements a long range, stereovision 3D imaging system that implements a variety of capabilities to be used accordingly.

It consists of an infrared laser projection system, two infrared and a full HD color imaging sensors.

Color data is provided by the full HD color imaging sensor.





Cellular Modem

The Intel Aero Compute Board enables LTE modem devices to be installed into the M.2 interface

Future M.2 form-factor modems can be swapped out, thus allowing easier connectivity upgrades and testing



0682
PN:G12Z024.06
MO:5200138549
MODEL:LN930
FCC ID:R17LN930
IC:5131A-LN930
Made in China

teit LN930
IMEI:356406060866893



Aux



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may not be,
eased, untl

AUX

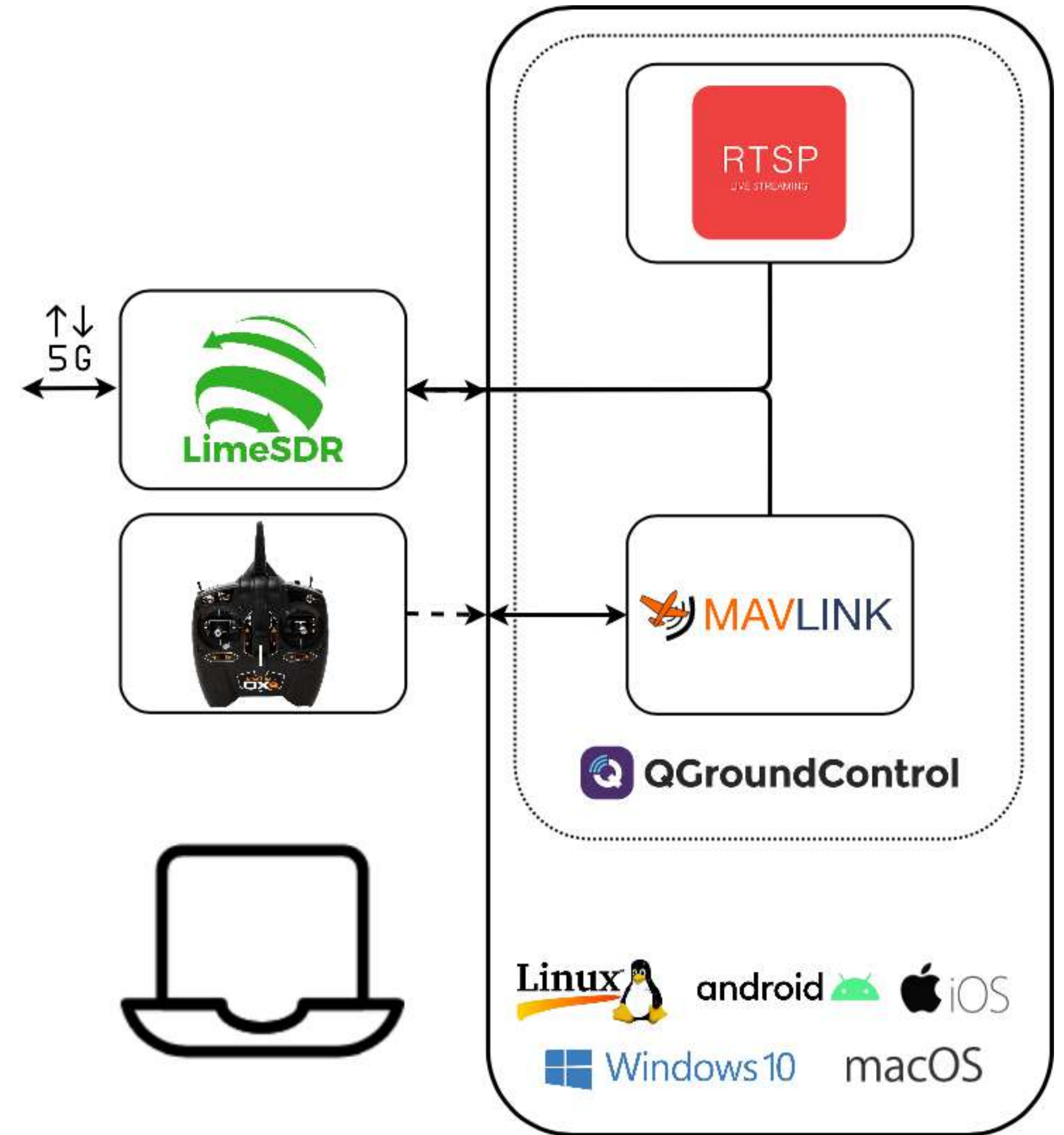


Software Architecture – User

User Side

Base station software that runs on all modern operating systems

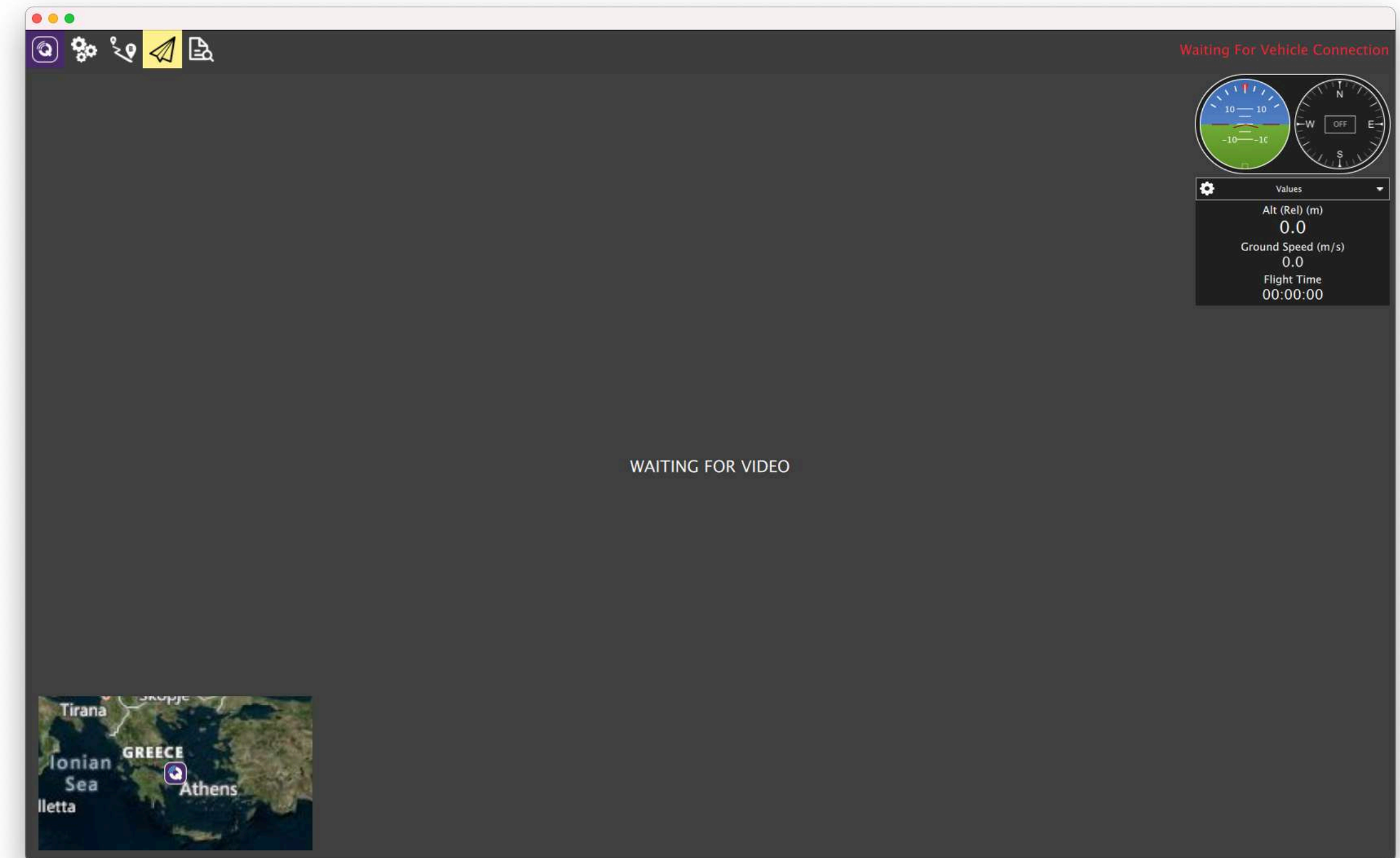
Concentrates all vital aspects of the operation in one platform



QGroundControl

QGroundControl provides full flight control and vehicle setup for PX4 or ArduPilot powered vehicles

The MAVLink "microservices" define higher-level protocols that MAVLink systems can adopt in order to better inter-operate and are used to exchange data





Waiting For Vehicle Connection



⚙	Values ▾
	Alt (Rel) (m)
	0.0
	Ground Speed (m/s)
	0.0
	Flight Time
	00:00:00

WAITING FOR VIDEO

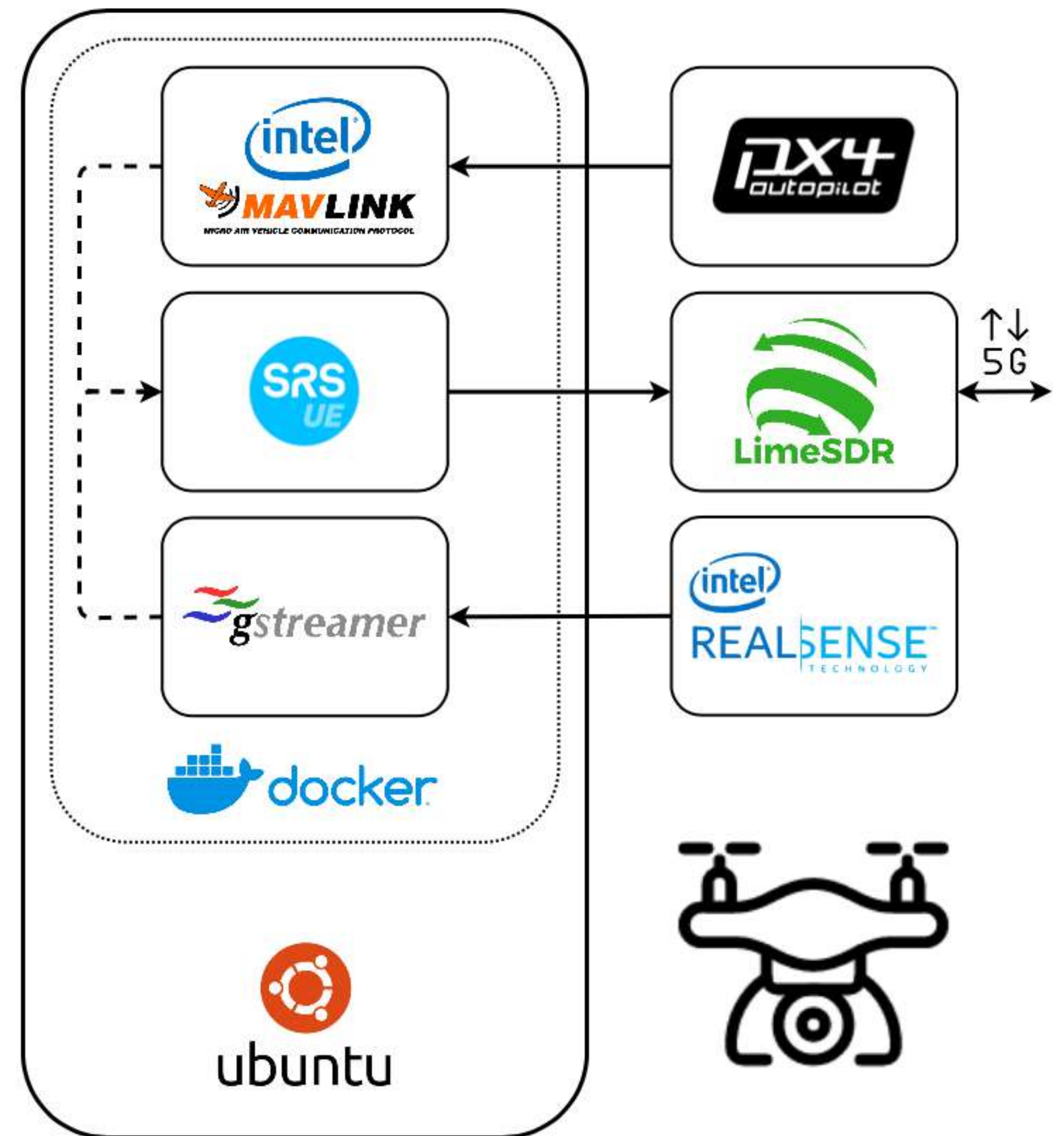


Software Architecture – Vehicle

Vehicle Side

Standalone operation on
desktop Ubuntu 16.04.3

Ability to use Docker to
further optimize resources
and availability



Operating System

By default, Intel Aero board and Intel Aero Ready To Fly kit are delivered with a Yocto Project build already flashed

In parallel to this Intel supported Yocto image, full native Ubuntu with Intel drivers is available as user installation



```
cchassis — aero@upatras-aero: ~ — ssh aero@192.168.2.9 — 80x24
aero@upatras-aero:~$ sudo apt-get update
Get:1 http://security.ubuntu.com/ubuntu xenial-security InRelease [109 kB]
Get:2 https://download.01.org/aero/deb xenial InRelease [2711 B]
Get:3 https://download.01.org/aero/deb xenial/main amd64 Packages [4834 B]
Hit:4 http://gr.archive.ubuntu.com/ubuntu xenial InRelease
Get:5 http://gr.archive.ubuntu.com/ubuntu xenial-updates InRelease [109 kB]
Fetched 226 kB in 5s (37,9 kB/s)
Reading package lists... Done
N: Skipping acquire of configured file 'main/binary-i386/Packages' as repository
'https://download.01.org/aero/deb xenial InRelease' doesn't support architecture
'i386'
aero@upatras-aero:~$ sudo apt-get -y install aero-system
Reading package lists... Done
Building dependency tree
Reading state information... Done
The following additional packages will be installed:
  aero-ardupilot aero-bios aero-camera-streaming-daemon aero-fpga aero-init
  aero-mavlink-router aero-optical-flow aero-px4 aero-spi-xfer aero-systemd
  aero-utils firmware-atomisp i2c-tools linux-headers-4.4.76-aero-1.2
  linux-image-4.4.76-aero-1.2
Suggested packages:
  libi2c-dev python-wxgtk2.8
The following NEW packages will be installed:
  aero-system
```

```
cchassis — aero@upatras-aero: ~ — ssh aero@192.168.2.9 — 80x24
GNU nano 2.5.3      File: /etc/default/grub
# If you change this file, run 'update-grub' afterwards to update
# /boot/grub/grub.cfg.
# For full documentation of the options in this file, see:
#   info -f grub -n 'Simple configuration'

GRUB_DEFAULT="Advanced options for Ubuntu>Ubuntu, with Linux 4.4.76-aero-1.2"
#GRUB_HIDDEN_TIMEOUT=0
GRUB_HIDDEN_TIMEOUT_QUIET=true
GRUB_TIMEOUT=10
GRUB_DISTRIBUTOR=`lsb_release -i -s 2> /dev/null || echo Debian`
GRUB_CMDLINE_LINUX_DEFAULT="quiet splash"
GRUB_CMDLINE_LINUX=""

# Uncomment to enable BadRAM filtering, modify to suit your needs
# This works with Linux (no patch required) and with any kernel that obtains
# the memory map information from GRUB (GNU Mach, kernel of FreeBSD ...)
#GRUB_BADRAM="0x01234567,0xfefefefe,0x89abcdef,0xefefefef"

# Uncomment to disable graphical terminal (grub-pc only)
#GRUB_DISABLE_GRAPHICAL_TERMINAL=true

^G Get Help  ^O Write F
^X Exit      ^R Read F
```

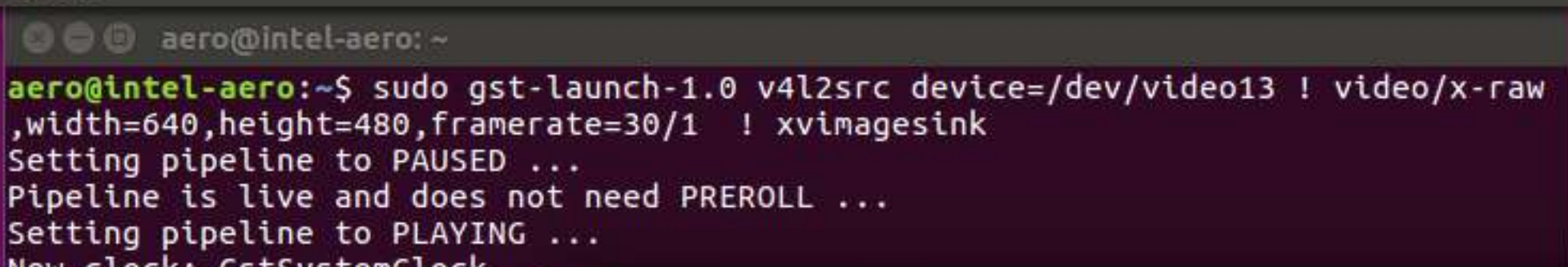
```
cchassis — aero@upatras-aero: ~ — ssh aero@192.168.2.9 — 80x24
aero@upatras-aero:~$ uname -a
Linux upatras-aero 4.10.0-28-generic #32~16.04.2-Ubuntu SMP Thu Jul 20 10:19:48
UTC 2017 x86_64 x86_64 x86_64 GNU/Linux
aero@upatras-aero:~$ dpkg --get-selections | grep linux-image
ii  linux-image-4.10.0-28-generic      4.10.0-28.32~16.04.2
    amd64                            Linux kernel image for version 4.10.0 on 64 bit x86 SM
P
ii  linux-image-4.4.76-aero-1.2       4.4.76-aero-1.2-1
    amd64                            Linux kernel, version 4.4.76-aero-1.2
ii  linux-image-extra-4.10.0-28-generic 4.10.0-28.32~16.04.2
    amd64                            Linux kernel extra modules for version 4.10.0 on 64 bi
t x86 SMP
ii  linux-image-generic-hwe-16.04     4.10.0.28.31
    amd64                            Generic Linux kernel image
aero@upatras-aero:~$
```


librealsense

Intel developed library
specifically for interfacing
with RealSense cameras

```
cchassis — aero@upatras-aero: ~ — ssh aero@192.168.2.9 — 80x24
aero@upatras-aero:~$ git clone -b legacy --single-branch https://github.com/IntelRealSense/librealsense.git
Cloning into 'librealsense'...
remote: Enumerating objects: 14, done.
remote: Counting objects: 100% (14/14), done.
remote: Compressing objects: 100% (13/13), done.
remote: Total 16947 (delta 3), reused 11 (delta 1), pack-reused 16933
Receiving objects: 100% (16947/16947), 6.06 MiB | 219.00 KiB/s, done.
Resolving deltas: 100% (11958/11958), done.
Checking connectivity... done.
aero@upatras-aero:~$
```

```
cchassis — aero@upatras-aero: ~/librealsense/build — ssh aero@192.168...
-- Configuring done
-- Generating done
-- Build files have been written to: /home/aero/librealsense/build
aero@upatras-aero:~/librealsense/build$ make
Scanning dependencies of target realsense
[ 1%] Building CXX object CMakeFiles/realsense.dir/src/archive.cpp.o
[ 2%] Building CXX object CMakeFiles/realsense.dir/src/context.cpp.o
[ 3%] Building CXX object CMakeFiles/realsense.dir/src/device.cpp.o
[ 4%] Building CXX object CMakeFiles/realsense.dir/src/ds-device.cpp.o
[ 5%] Building CXX object CMakeFiles/realsense.dir/src/ds-private.cpp.o
[ 6%] Building CXX object CMakeFiles/realsense.dir/src/f200.cpp.o
[ 7%] Building CXX object CMakeFiles/realsense.dir/src/hw-monitor.cpp.o
[ 9%] Building CXX object CMakeFiles/realsense.dir/src/image.cpp.o
[10%] Building CXX object CMakeFiles/realsense.dir/src/ivcam-private.cpp.o
[11%] Building CXX object CMakeFiles/realsense.dir/src/ivcam-device.cpp.o
[12%] Building CXX object CMakeFiles/realsense.dir/src/log.cpp.o
[13%] Building CXX object CMakeFiles/realsense.dir/src/motion-module.cpp.o
[14%] Building CXX object CMakeFiles/realsense.dir/src/r200.cpp.o
[15%] Building CXX object CMakeFiles/realsense.dir/src/rs.cpp.o
[17%] Building CXX object CMakeFiles/realsense.dir/src/sr300.cpp.o
[18%] Building CXX object CMakeFiles/realsense.dir/src/stream.cpp.o
[19%] Building CXX object CMakeFiles/realsense.dir/src/sync.cpp.o
[20%] Building CXX object CMakeFiles/realsense.dir/src/timestamps.cpp.o
```

csh & gstreamer

Runs as a daemon
proposing network streams
of the cameras

Open-source multimedia framework, is able to provide the granularity that's required in our use-case

```

cchassis — aero@upatras-aero: ~ — ssh aero@192.168.2.9 — 80x24
aero@upatras-aero:~$ echo 'deb https://download.01.org/aero/deb xenial main' | s
udo tee /etc/apt/sources.list.d/intel-aero.list
deb https://download.01.org/aero/deb xenial main
aero@upatras-aero:~$ wget -qO - https://download.01.org/aero/deb/intel-aero-deb.
key | sudo apt-key add -
OK
aero@upatras-aero:~$ sudo apt-get -y install gstreamer-1.0 libgstreamer-plugins-
base1.0-dev libgststrtspserver-1.0-dev gstreamer1.0-vaapi gstreamer1.0-plugins-bas
e gstreamer1.0-plugins-good gstreamer1.0-plugins-bad gstreamer1.0-libav ffmpeg v
4l-utils python-pip
Reading package lists... Done
Building dependency tree
Reading state information... Done
Note, selecting 'libqtgstreamer-1.0-0' for regex 'gstreamer-1.0'
Note, selecting 'gir1.2-gstreamer-1.0' for regex 'gstreamer-1.0'
Note, selecting 'libqt5gstreamer-1.0-0' for regex 'gstreamer-1.0'
gir1.2-gstreamer-1.0 is already the newest version (1.8.3-1~ubuntu0.1).
gstreamer1.0-plugins-good is already the newest version (1.8.3-1ubuntu0.4).
The following additional packages will be installed:
  autotools-dev debhelper dh-strip-nondeterminism freepats
  gir1.2-gst-plugins-base-1.0 gir1.2-gst-rtsp-server-1.0
  gstreamer1.0-plugins-bad-faad gstreamer1.0-plugins-bad-videoparsers
  1965-va-driver icu-devtools libaacs0 libass5 libavcodec-ffmpeg56
  libavdevice-ffmpeg56 libavfilter-ffmpeg5 libavformat-ffmpeg56

```

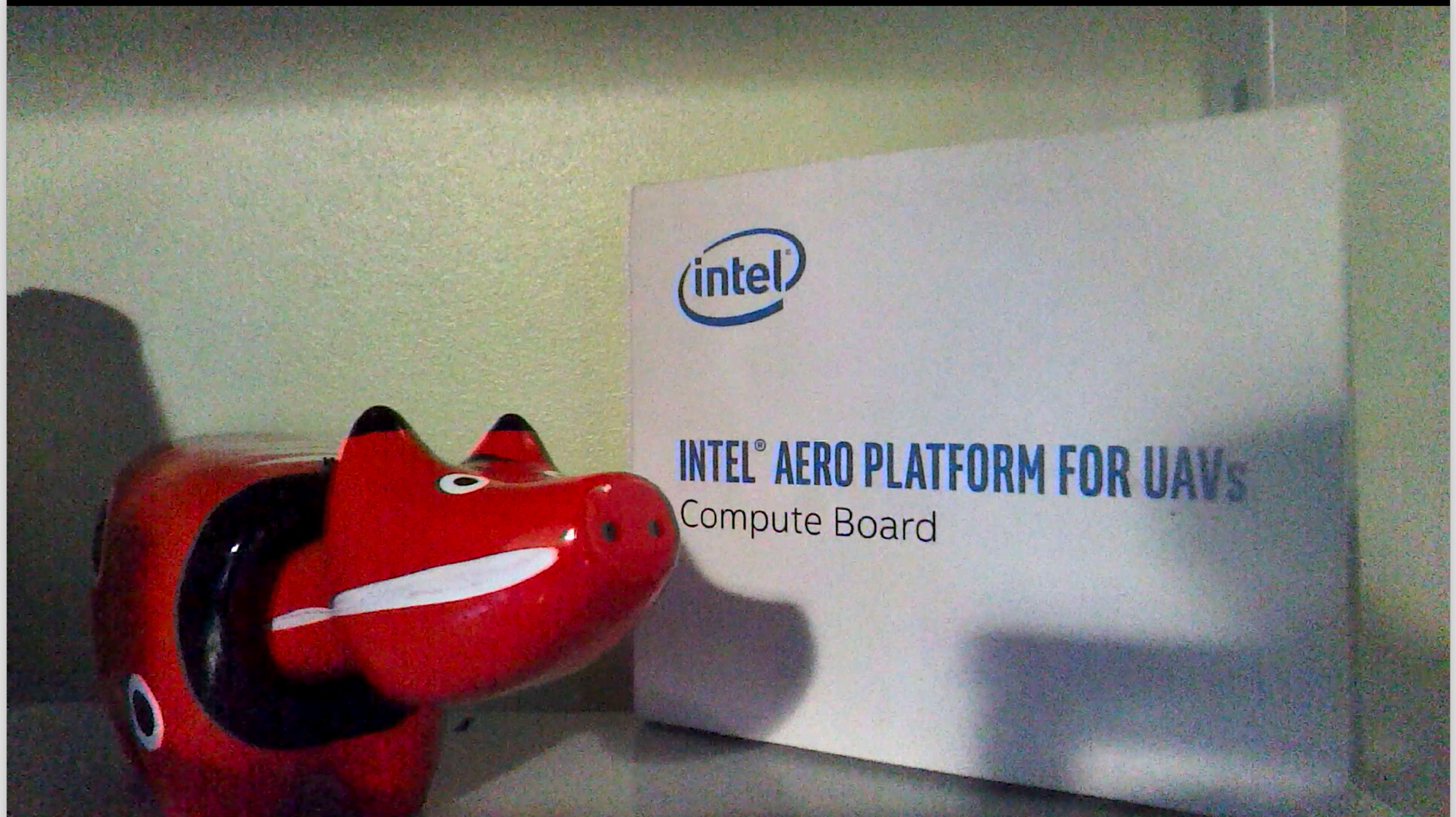
```

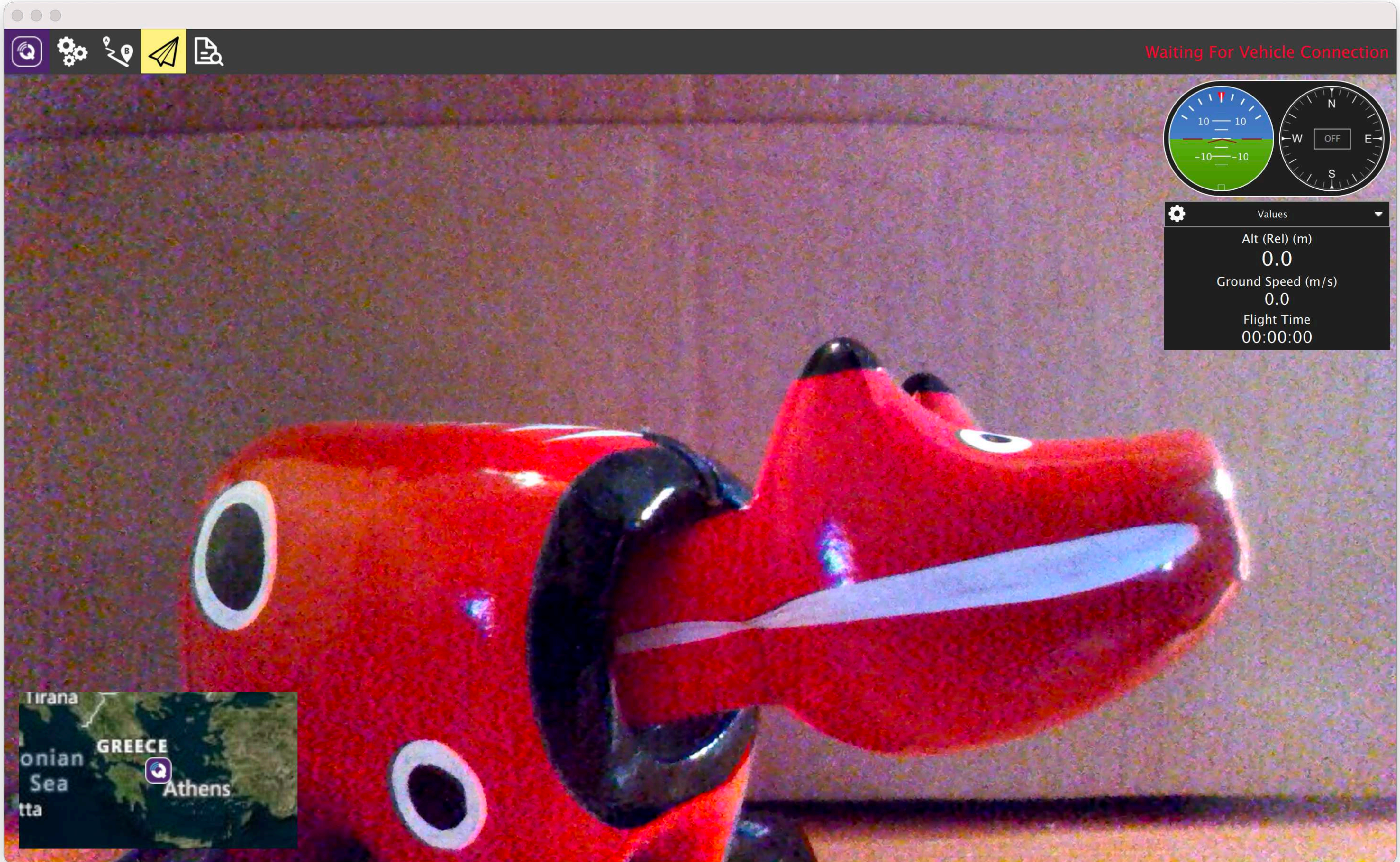
cchassis — aero@upatras-aero: ~/librealsense/build — ssh aero@192.168...

-- Installing: /usr/local/bin/c-tutorial-1-depth
-- Set runtime path of "/usr/local/bin/c-tutorial-1-depth" to ""
-- Installing: /usr/local/bin/cpp-tutorial-1-depth
-- Set runtime path of "/usr/local/bin/cpp-tutorial-1-depth" to ""
-- Installing: /usr/local/bin/cpp-callback
-- Set runtime path of "/usr/local/bin/cpp-callback" to ""
-- Installing: /usr/local/bin/cpp-enumerate-devices
-- Set runtime path of "/usr/local/bin/cpp-enumerate-devices" to ""
-- Installing: /usr/local/bin/cpp-headless
-- Set runtime path of "/usr/local/bin/cpp-headless" to ""
-- Installing: /usr/local/bin/cpp-motion-module
-- Set runtime path of "/usr/local/bin/cpp-motion-module" to ""
aero@upatras-aero:~/librealsense/build$ systemctl status csd
● csd.service — Camera Streaming Daemon
   Loaded: loaded (/lib/systemd/system/csd.service; enabled; vendor preset: enab
   Active: active (running) since Mon 2021-02-12 22:55:07 EET; 18min ago
   Main PID: 2076 (csd)
   CGroup: /system.slice/csd.service
           └─2076 /usr/bin/csd

Feb 12 22:55:07 upatras-aero systemd[1]: Started Camera Streaming Daemon.
Feb 12 22:55:08 upatras-aero csd[2076]: AVAHI START
Feb 12 22:56:34 upatras-aero csd[2076]: Failed to create avahi client: Daemon co
lines 1-10/10 (END)

```



Waiting For Vehicle Connection



Values
Alt (Rel) (m)
0.0
Ground Speed (m/s)
0.0
Flight Time
00:00:00

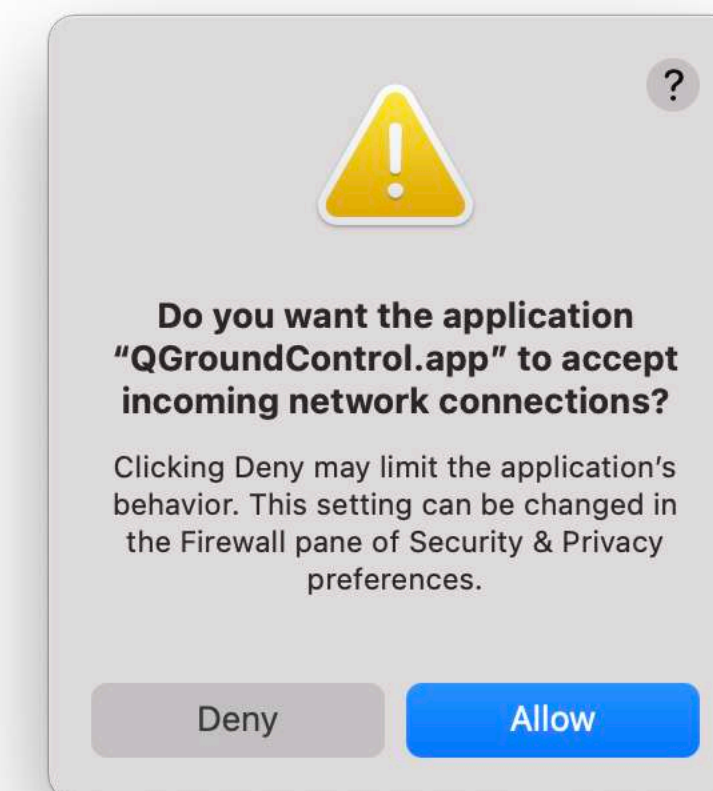


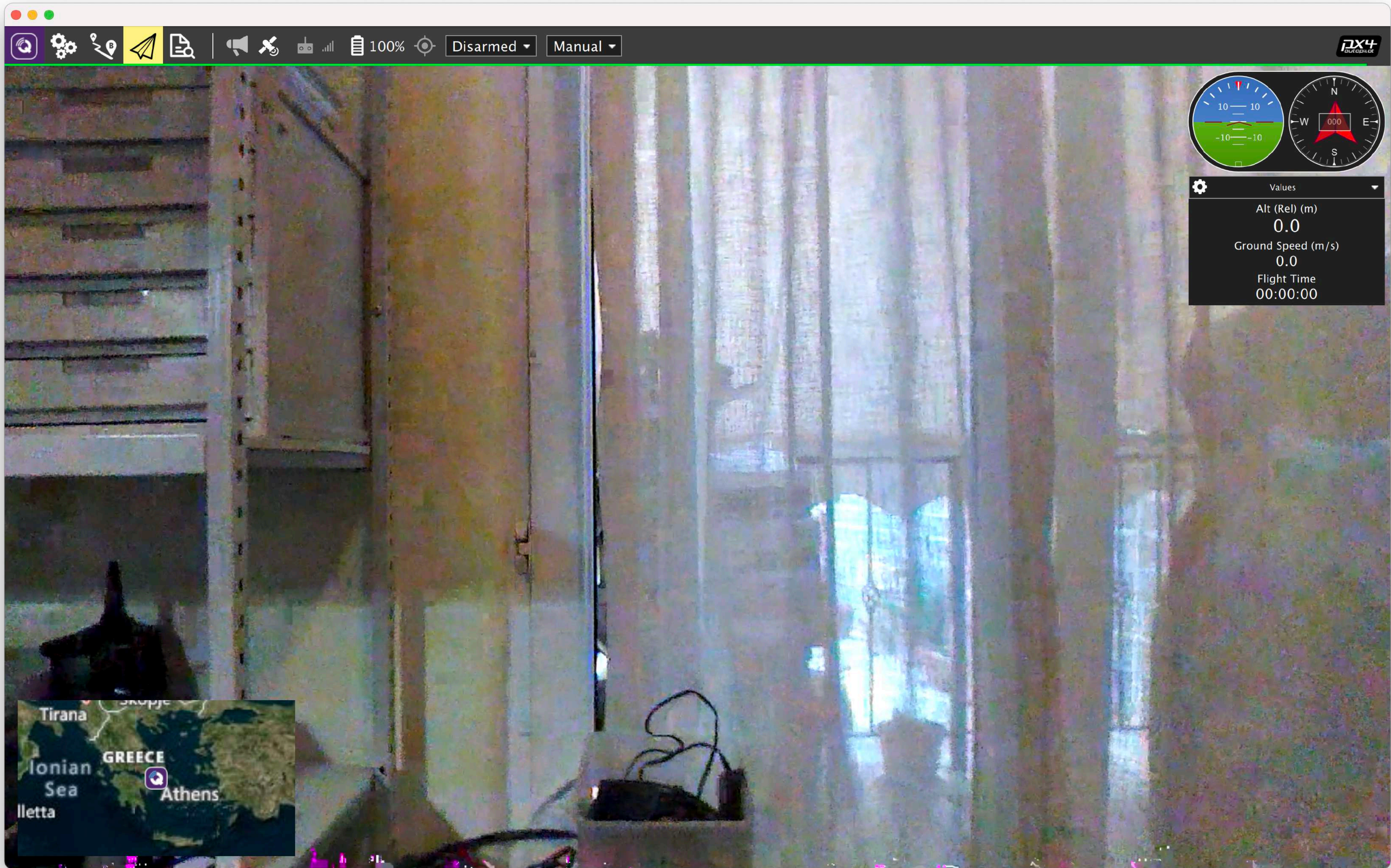
MAVLink-router

Encapsulation method for
MAVLink packets to traverse
the IP network

Versatility in terms of
addressing as it can route
streams to and from multiple
devices independently at the
same time

```
cchassis — aero@upatras-aero: ~ — ssh aero@192.168.2.9 — 80x24
aero@upatras-aero:~$ sudo pip install pymavlink
The directory '/home/aero/.cache/pip/http' or its parent directory is not owned
by the current user and the cache has been disabled. Please check the permission
s and owner of that directory. If executing pip with sudo, you may want sudo's -
H flag.
The directory '/home/aero/.cache/pip' or its parent directory is not owned by th
e current user and caching wheels has been disabled. check the permissions and o
wner of that directory. If executing pip with sudo, you may want sudo's -H flag.
Collecting pymavlink
  Downloading https://files.pythonhosted.org/packages/1b/59/34e07d7049e0cded0e7f
fbae3e44c36d4a182c85c2655dea5ca4cf1d9d9a/pymavlink-2.4.14.tar.gz (4.1MB)
    100% |████████████████████████████████████████| 4.1MB 101kB/s
Collecting future (from pymavlink)
  Downloading https://files.pythonhosted.org/packages/45/0b/38b06fd9b92dc2b68d58
b75f900e97884c45bedd2ff83203d933cf5851c9/future-0.18.2.tar.gz (829kB)
    100% |████████████████████████████████████████| 829kB 72kB/s
Collecting lxml (from pymavlink)
  Downloading https://files.pythonhosted.org/packages/15/55/ddcb9b3428c94aa2794f
248897418178ee812288688f9cc8ec5147a4be47/lxml-4.6.2-cp27-cp27mu-manylinux1_x86_6
4.whl (5.5MB)
    100% |████████████████████████████████████████| 5.5MB 91kB/s
Installing collected packages: future, lxml, pymavlink
Running setup.py install for future ... done
Running setup.py install for pymavlink ... done
```





Docker Containers

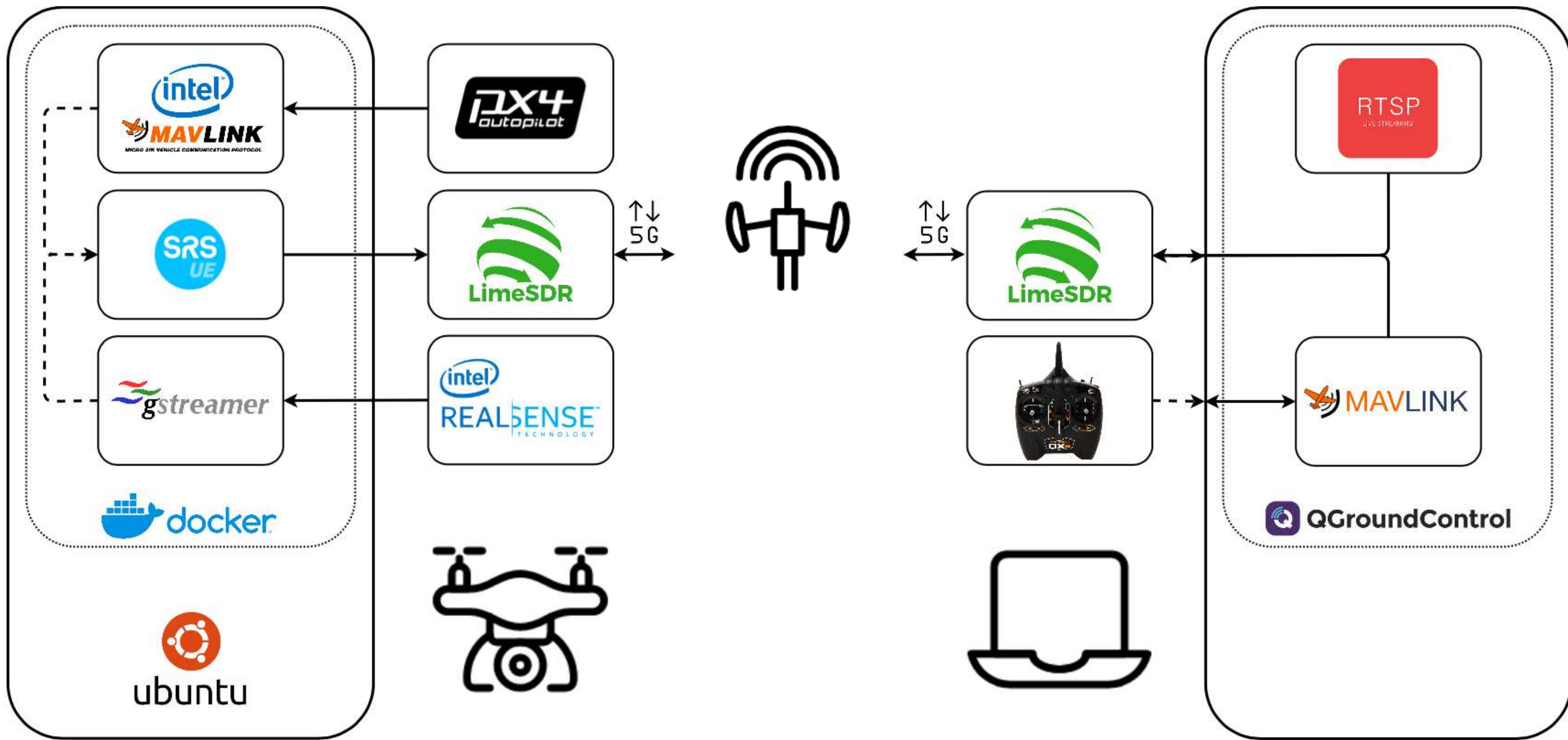
Each process can be installed, updated and run independently

Evolution to interact with the next-generation capabilities of 5G Core

Load balancing and fault tolerance



```
cchassis — ssh root@192.168.1.52 — 80x24
sha256:e9ee0ac439cc993e4dcfddb1a8df085d555dff7402c05f009bb898203c5fab7b
root@intel-aero:~# docker images
REPOSITORY          TAG                 IMAGE ID            CREATED
SIZE
<none>              <none>             e9ee0ac439cc        3 seconds ago
591 MB
cchassis/upatras-aero gstreamer          dd012eba0703        44 minutes ago
444 MB
cchassis/upatras-aero mavlink-router     1e3ed54fca8b        48 minutes ago
588 MB
ubuntu              16.04              096efd74bb89        2 weeks ago
127 MB
root@intel-aero:~# docker tag e9ee0ac439cc cchassis/upatras-aero:mavlink-router
root@intel-aero:~# docker push cchassis/upatras-aero:mavlink-router
The push refers to a repository [docker.io/cchassis/upatras-aero]
c41ecf06dd6a: Pushed
997b5ac3158a: Layer already exists
e27729ee6e59: Layer already exists
c4d7b15878d0: Layer already exists
06859de2f3e3: Layer already exists
f577d0e0bf70: Layer already exists
mavlink-router: digest: sha256:dfc1a8efce9e7ddf3b621be76006f3e90126831315525b9ee31cc10918950c42 size: 1574
root@intel-aero:~#
```

Conclusions

A fully operational platform was proposed and implemented, fully operational on a wireless IP network

Evolution possible on many aspects

- Flexible
- IP forwarding
- Ease of modification
- Streaming latency
- Compliance with other network protocols
- Automation & Provisioning

Thank you