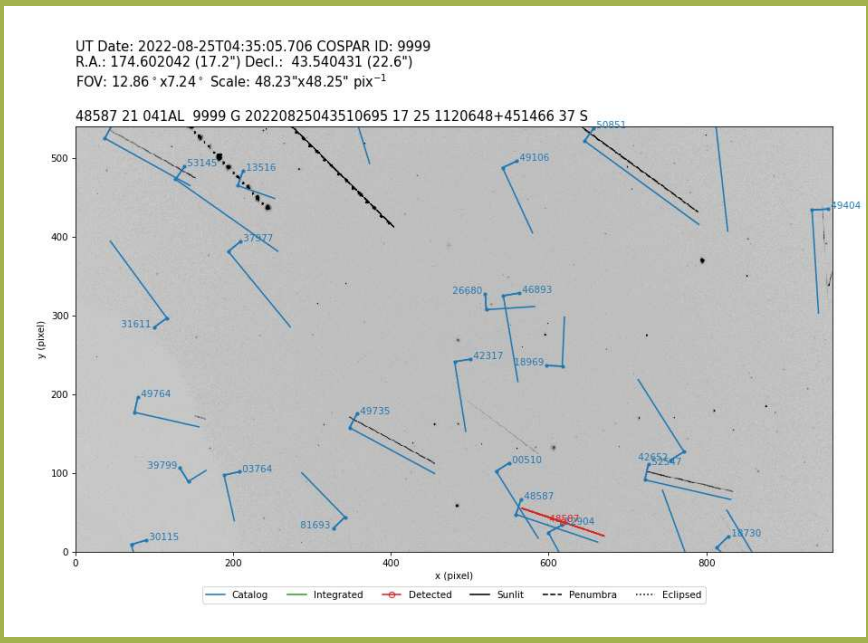
SatNOGS Optical

Unofficial

Guide



by

Jeff Moe

SatNOGS Optical Unofficial Guide

by Jeff Moe

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Introduction

SatNOGS Optical

Introduction

The SatNOGS Optical Unofficial Guide documents how to set up and run an optical ground station for the Libre Space Foundation (LSF)'s SatNOGS network. The LSF supports "free and accessible space for all, creating Open Source space technologies."[1]

Process Overview

SatNOGS Optical Process Overview.[2] See figure 1, page x.

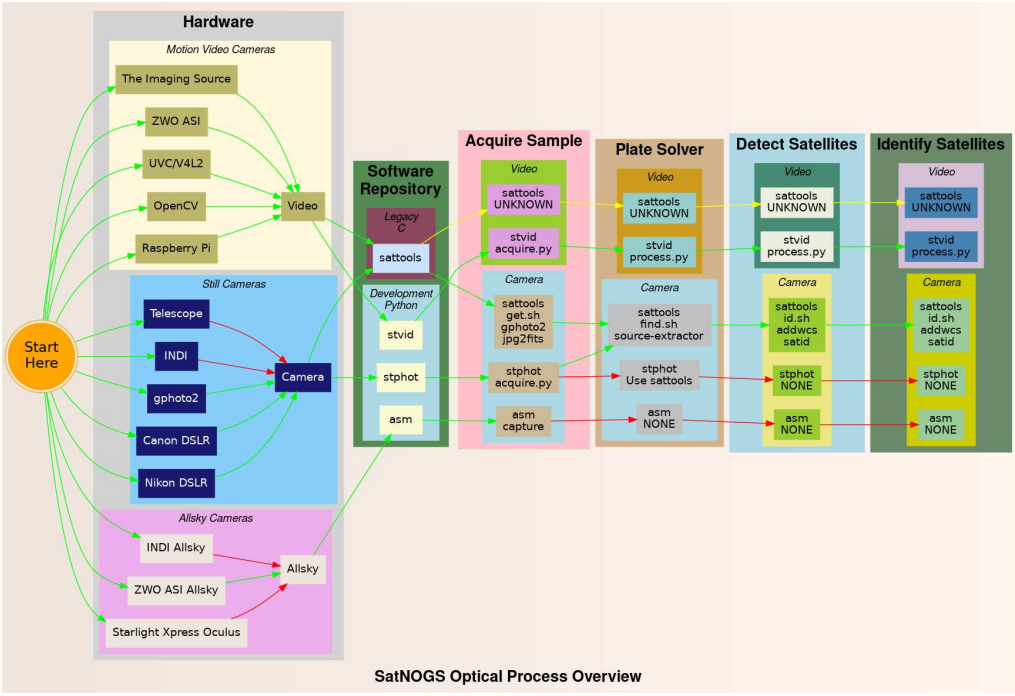

Figure 1: SatNOGS Optical Process Overview

[1] https://libre.space

[2] https://spacecruft.org/spacecruft/SNOPO

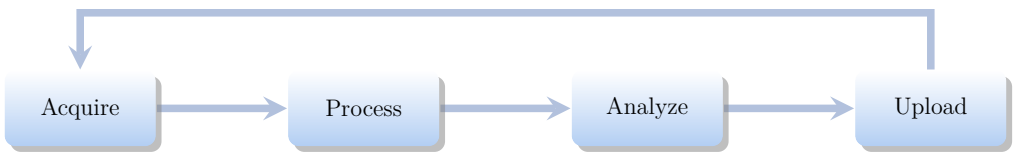

Figure 2: SatNOGS Optical Operation Process

Satellites

Artificial Satellites in Space

1.1 Overview of Satellites

Artificial satellites are rocks with modems.

Ground Stations

Ground Stations on Earth

2.1 Overview of Ground Stations

Ground stations.

2.1.1 SatNOGS Ground Stations

The LSF built the SatNOGS network using distributed, volunteer-run, radio frequency (RF) ground stations, such as in figure 2.1, page 16.[1] It shows a SatNOGS ground station with Very High Frequency (VHF) (right) and Ultra High Frequency (UHF) (left) antennas on a mast with Altazimuth mount (Alt/Az mount) rotator.

Figure 2.1: SatNOGS ground station with antennas.

2.1.2 SatNOGS Optical Ground Stations

The LSF is developing the SatNOGS Optical to add optical ground stations to the distributed network.

Prototype optical ground stations are being developed. An example setup, using a Skywatcher EQ6-R Pro telescope tripod and tracking mount, can be seen in Figure 2.2, page 17.

[1] https://spacecruft.org/assets/i/spacecruft-rotator.png

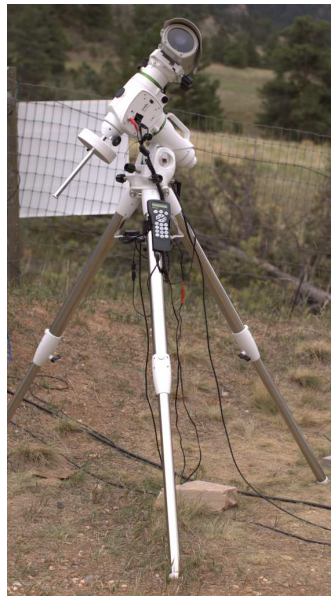

Figure 2.2: SatNOGS Optical ground station prototype.

Hardware

Design and Set Up Equipment

3.1 Overview of Hardware

Hardware considerations for a SatNOGS Optical ground station.

Main hardware components in an optical ground station:

Listing 3.1: Hardware List Overview

- Lens.
- Camera.
- Computer.

Other components:

Listing 3.2: Hardware Components

- Ethernet cable.
- USB cable.
- Enclosure.
- Power supply.
- Tripod.
- Manual or tracking mount.
- Power source, grid or alternative.
- Internet, wifi or ethernet.

3.2 Camera

Cameras being tested:

Listing 3.3: Cameras under test

- The Imaging Source IMX174 based.
- ZWO ASI IMX174 based monochrome.
- digital single-lens reflex (DSLR) camera.

NOTICE:
ZWO/ASI cameras require proprietary non-libre software on host computer.

3.3 Lenses

Lenses being tested:

Listing 3.4: Lenses under test

- Kowa 50mm f1.4 C-mount.
- Canon EF 50mm f1.2 USM.

3.4 Embedded Computer

Computers, such as Raspberry Pi, that can be used.

Listing 3.5: Embedded computer options

- Odroid N2 — Confirmed working.
- Odroid M1 — Testing.
- Raspberry Pi 3 — ?
- Raspberry Pi 4 — ?
- Intel NUC — ?

3.4.1 Comparison

Comparing embedded computers for SatNOGS Optical.

Make	Model	Architecture	Max RAM	eMMC
Odroid	N2	ARM64	4 GB	Yes
Odroid	M2	ARM64	8 GB	Yes

Table 3.1: Comparison of embedded computers

3.5 Example Tracking Ground Station

This is an example of a tracking ground station. It is a prototype, so there are lots of mis-matched, overbuilt/underbuilt parts. The full setup on tripod, can be seen in 2.2, page 17.

A close up of the setup can be seen at 3.1, page 22, showing the Skywatcher telescope tracking mount, a Bosch Power over Ethernet (PoE) camera enclosure, and through the

Figure 3.1: SatNOGS Optical ground station prototype.

glass the camera lens. In the background is a white antenna for Global Navigation Satellite System (GNSS) (Global Positioning System (GPS)) and a solar power setup.

The camera lens is protected by the enclosure glass, which is Ingress Protection code 67 (IP67) (XXX) rated. See a close up of the front of the enclosure and camera lens in figure 3.2, page 23.

As seen in figure 3.3, page 23, the left side of the enclosure has a hinge for opening. The bottom white component is part of the telescope mount.

Figure 3.4, page 24, shows the right side of the enclosure. Two mounting bolt access points can be seen on each end. These are unscrewed with a hex head tool (supplied) to open the enclosure.

The enclosure is opened from the right side, as shown in figure 3.4, page 24.

Inside the camera enclosure, as shown in Figure 3.6, page 25, is:

Listing 3.6: SatNOGS Optical Ground Station Components

- The Imaging Source DMX camera with Sony IMX174 CMOS.
- Kowa 50mm f1.4 C-mount lens.
- Odroid N2 running Debian.
- Odroid N2 plastic enclosure, large half, hole drilled for ad-hoc mounting.
- Blower fan on top, with power cable (came with Bosch enclosure).

Figure 3.2: Camera enclosure, front side, showing glass and lens.

Figure 3.3: Camera enclosure, left side, showing hinge.

- Fan, maybe not so useful, with power cable (came with Bosch enclosure).
- Camera mounting plate (came with Bosch enclosure).
- Camera mounting screws, M6x25 (?).
- Ethernet cable, internal, short white (came with Bosch enclosure).
- PoE ethernet cable, external, plugged into PoE switch for data and power.

Figure 3.4: Camera enclosure, right side.

Figure 3.5: Camera enclosure, right side, opened.

- USB 3 cable, internal, way too long, needs replacing, from Odroid to camera. XXX flat connector
- USB 3 cable, external, from Odroid to telescope mount. XXX large rectangle connector
- "Custom" 12V DC power cable from Bosch PoE to Odroid.
- Assorted nuts, bolts, and washers for an ad-hoc standoff height.

The top of the enclosure shows weather protection and a sun visor. See figure 3.7, page 25.

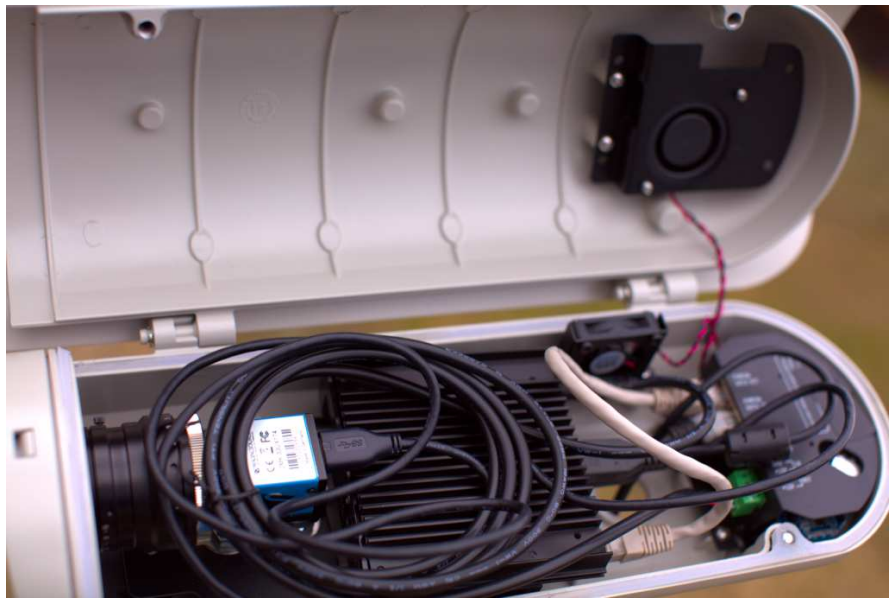

Figure 3.6: Camera enclosure, opened.

Figure 3.7: Camera enclosure, top.

Setup

Install and Configure Software

4.1 Setup Optical Ground Station Software

HOWTO set up and configure a SatNOGS Optical ground station.

Setup an embedded computer, such as an Odroid N2, with Debian stable (11/Bullseye) or testing (Bookworm).

See each repository for latest documentation.

Install dependencies from Debian repository:

```
sudo apt update
sudo apt install python3-virtualenv python3-pip python3-dev \
    source-extractor astrometry.net \
    libeigen3-dev giza-dev libx11-dev \
    astrometry-data-tycho2 astrometry-data-tycho2-07 \
    astrometry-data-tycho2-08 astrometry-data-tycho2-09 \
    astrometry-data-tycho2-10-19
```

Next, install the `hough3d-code` dependency.

```
git clone https://gitlab.com/pierros/hough3d-code
cd hough3d-code
make all
sudo cp -p hough3dlines /usr/local/bin/hough3dlines
```

Install `satpredict` from using either the cbassa or spacecruft repo.

```
cd ../
git clone https://spacecruft.org/spacecruft/satpredict
# Or
#git clone https://github.com/cbassa/satpredict
cd satpredict/
make
sudo make install
```

Now install `stvid`, the main acquisition and processing application. It is written in Python. Either use the spacecruft `git` repository or the cbassa one.

```
cd ../
git clone https://spacecruft.org/spacecruft/stvid
# Or use upstream:
#git clone https://github.com/cbassa/stvid
```

Optionally, set up a Python virtual environment:

```
cd stvid
virtualenv -p python3 env
source env/bin/activate
pip install --upgrade pip
```

Install dependencies. Numpy needs to be installed first, or the install fails.

```
pip install --upgrade numpy
pip install --upgrade -r requirements.txt
```

If the system `python3-numpy` conflicts, you could try installing numpy in the virtualenv thusly:

```
pip install --upgrade --ignore-installed numpy
```

Debian in bug `#941466` changed the name of the `sextractor` dependency to `source-extractor`, so a symlink is needed for now:

```
sudo ln -s /usr/bin/source-extractor /usr/local/bin/sextractor
```

4.2 Configure

Configure the embedded computer.

```
cd stvid/
cp -p configuration.ini-dist configuration.ini
# Edit
# Note for fields st-username and st-password, *don't* use quotes.
# Set:
vi configuration.ini
```

Edit various `configuration.ini` fields:

```
# For example:
observer_cospar = 9999        # COSPAR number of observer's site
observer_name = Jeff Moe      # Name of observer
observer_lat = 40.568912      # Latitude of location in decimal degrees
observer_lon = -105.225852    # Longitude of location in decimal degrees
observer_height = 1860         # Elevation of location in meters

observations_path = ./data/obs # Path for raw acquisitions
tle_path = ./data/tle          # Path where TLEs are stored (and updated)
results_path = ./data/results   # Path for results of processed obs

st-username = foo
st-password = bar

# Path to source-extractor
sex_config = /usr/share/source-extractor/default.sex
```

Store downloads here:

```
mkdir -p ./data/obs ./data/tle ./data/results
```

The `ST_DATADIR` variable is still used, from `sattools`. Maybe set all these in `~/.bashrc` (suit to fit directory setup):

```
export ST_DATADIR=$HOME/sattools
export ST_TLEDIR=$HOME/TLE
export ST_OBSDIR=$HOME/satobs
export ST_LOGIN="identity=foo@no:pass"
```

Set `astrometry.net` to run in parallel, assuming you have enough RAM: (This doesn't appear to work? Breaks?).

```
sudo vim /etc/astrometry.cfg
# Uncomment:
inparallel
```

Operation

HOWTO Run a Station

5.1 Overview of Operation

HOWTO run a SatNOGS Optical ground station, after it has been set up and congfigured.

5.2 Acquire Data with **stvid**

Acquire data with `acquire.py` from `stvid`. Enter `virtualenv`, if used:

```
cd stvid/
source env/bin/activate
```

Get the latest TLEs:

```
./update_tle.py
```

Acquire live data from camera.

```
cd stvid/
./acquire.py
```

Figure 5.1: Satellite images acquired by stvid.

5.3 Process Data

Process data with using stvid. Adjust dated directory to actual directory name.

```
cd stvid/
./process_new.py -c config_new.ini -d data/obs/20220825_1/020502/
```

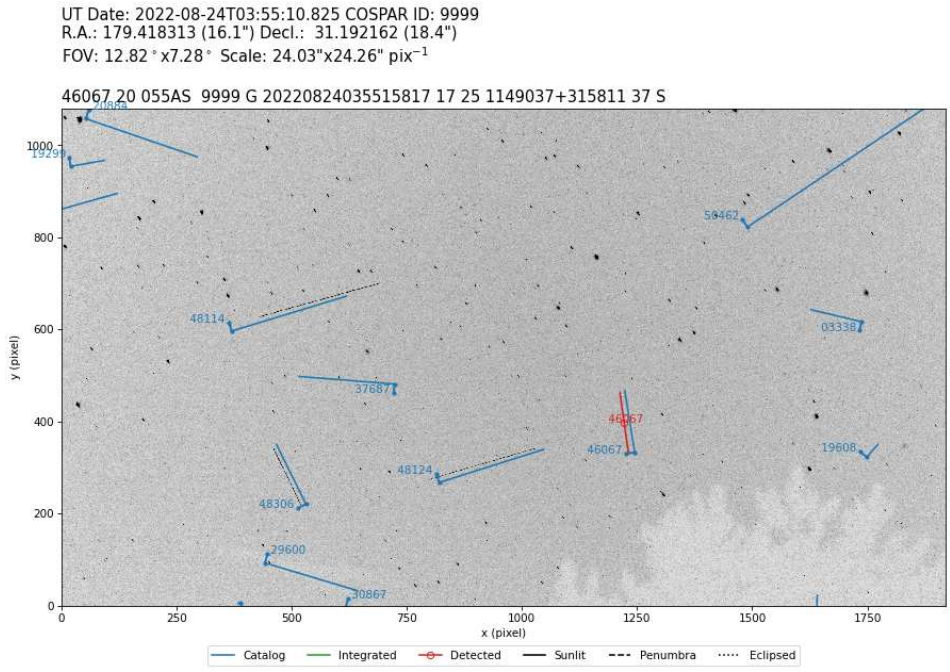

Figure 5.2: Satellite images processed by stvid.

5.4 Upload Data

Push. The SatNOGS network isn't ready for optical data yet.

Analysis

More Than Just Starlink and Old Rocket Bodies

6.1 Overview of Analysis

Analyze data with applications, such as AstroImageJ.

AstroImageJ can read FITS format files. See 6.1, page 36, for a screenshot displaying a FITS file generated by `stvid`.

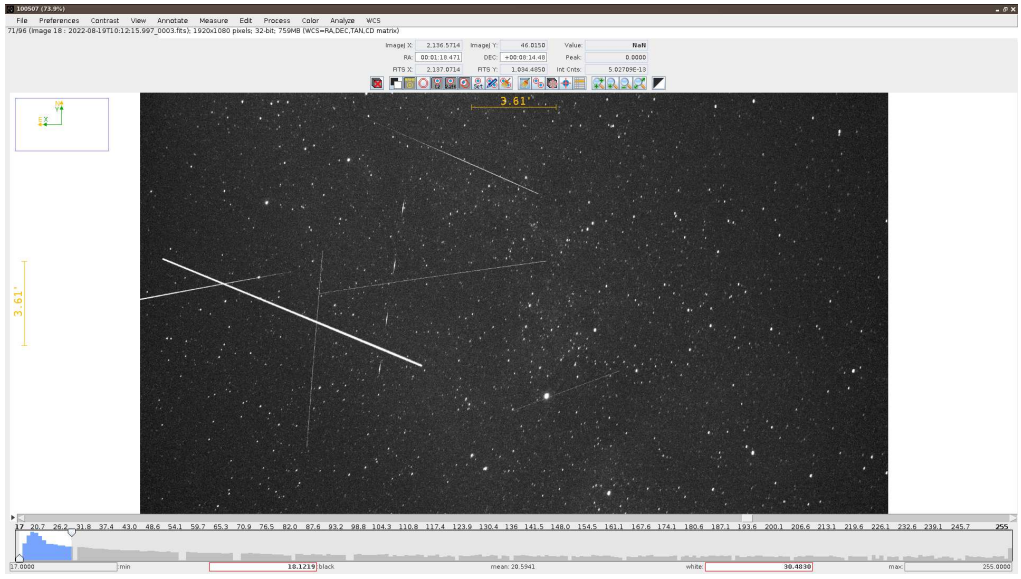

Figure 6.1: AstroImageJ screenshot viewing FITS file.

Support

Help!

7.1 Support

How to get help.

- `#satnogs-optical` channel in Matrix — `#satnogs-optical:matrix.org`
- LSF Community Forum — `https://community.libre.space`

Contact

Email, Chat, Forum

8.1 Contact

Jeff Moe

Username: `jebba`
Email: moe@spacecruft.org

Glossary

Alt/Az mount a simple two-axis mount for supporting and rotating an instrument about two perpendicular axes – one vertical and the other horizontal. Rotation about the vertical axis varies the azimuth (compass bearing) of the pointing direction of the instrument. Rotation about the horizontal axis varies the altitude angle (angle of elevation) of the pointing direction. These mounts are used, for example, with telescopes, cameras, and radio antennas[1].

antenna the interface between radio waves propagating through space and electric currents moving in metal conductors, used with a transmitter or receiver[2].

artificial satellite Satellite launched by teh hoomans.

AstroImageJ Application for astronomy and satellite image analysis.

Debian a GNU's Not Unix! (GNU)/Linux distribution composed of free and open-source software, developed by the community-supported Debian Project, which was established by Ian Murdock on August 16, 1993. Debian is the basis for many other distributions, notably Ubuntu. Debian is one of the oldest operating systems based on the Linux kernel.[3].

DSLR digital single-lens reflex.

FITS Flexible Image Transport System is an open standard defining a digital file format useful for storage, transmission and processing of data: formatted as multi-dimensional arrays (for example a 2D image), or tables. FITS is the most commonly used digital file format in astronomy. The FITS standard was designed specifically for astronomical data, and includes provisions such as describing photometric and spatial calibration information, together with image origin metadata[4].

GHz gigahertz.

GNSS Global Navigation Satellite System.

[1] https://en.wikipedia.org/w/index.php?title=Altazimuth_mount&oldid=1056074953
[2] https://en.wikipedia.org/w/index.php?title=Antenna_(radio)&oldid=1104603350
[3] https://en.wikipedia.org/w/index.php?title=Debian&oldid=1105900486
[4] https://en.wikipedia.org/w/index.php?title=FITS&oldid=1091431488

GNU is an extensive collection of free software, which can be used as an operating system or can be used in parts with other operating systems. The use of the completed GNU tools led to the family of operating systems popularly known as Linux. Most of GNU is licensed under the GNU Project's own GNU General Public License (GPL). GNU is also the project within which the free software concept originated.[5].

GPS Global Positioning System.

ground station a setup of equipment such as computers, cameras, Software-defined radios (SDRs), antennas, and receivers, located on Earth, observing space.

hough3d-code Software application for Iterative Hough Transform for Line Detection in 3D Point Clouds[6].

IP67 Ingress Protection code 67.

ITU The International Telecommunication Union is a specialized agency of the United Nations responsible for many matters related to information and communication technologies.[7].

kHz kilohertz.

Linux is a free and open-source, monolithic, modular, multitasking, Unix-like operating system kernel. It was originally authored in 1991 by Linus Torvalds for his i386-based PC, and it was soon adopted as the kernel for the GNU operating system, which was written to be a free (libre) replacement for Unix.[8].

LSF Libre Space Foundation is a non-profit foundation registered since 2015 in Greece and the creators of the SatNOGS project[9].

mast typically tall structures designed to support antennas for telecommunications and broadcasting[10].

Matrix an open standard and communication protocol for real-time communication [11].

MHz megahertz.

Open Source is source code that is made freely available for possible modification and redistribution. Products include permission to use the source code, design documents, or content of the product. The open-source model is a decentralized software development model that encourages open collaboration. A main principle of open-source software development is peer production, with products such as source code,

[5] https://en.wikipedia.org/w/index.php?title=GNU&oldid=1103488294
[6] https://gitlab.com/pierros/hough3d-code
[7] https://en.wikipedia.org/w/index.php?title=International_Telecommunication_Union&oldid=1105915792
[8] https://en.wikipedia.org/w/index.php?title=Linux_kernel&oldid=1105840074
[9] https://libre.space/about-us/
[10] https://en.wikipedia.org/w/index.php?title=Radio_masts_and_towers&oldid=1103964392
[11] https://en.wikipedia.org/w/index.php?title=Matrix_(protocol)&oldid=1106244486

blueprints, and documentation freely available to the public. The open-source movement in software began as a response to the limitations of proprietary code. The model is used for projects such as in open-source appropriate technology[12].

optical ground station a ground station using optical equipment (cameras) instead of antennas.

PoE Power over Ethernet.

RF Radio frequency is the oscillation rate of an alternating electric current or voltage or of a magnetic, electric or electromagnetic field or mechanical system in the frequency range from around 20 kilohertz (kHz) to around 300 gigahertz (GHz). This is roughly between the upper limit of audio frequencies and the lower limit of infrared frequencies; these are the frequencies at which energy from an oscillating current can radiate off a conductor into space as radio waves.[13].

rotator a device used to change the orientation, within the horizontal plane, of a directional antenna. Most antenna rotators have two parts, the rotator unit and the controller. The controller is normally placed near the equipment which the antenna is connected to, while the rotator is mounted on the antenna mast directly below the antenna. Rotators are commonly used in amateur radio[14].

SatNOGS Open Source global network of satellite ground-stations[15].

SatNOGS Optical Project by the LSF to expand the SatNOGS network to add optical ground stations.

satpredict Software application to compute satellite predictions[16].

SDR Software-defined radio is a radio communication system where components that have been traditionally implemented in analog hardware (e.g. mixers, filters, amplifiers, modulators/demodulators, detectors, etc.) are instead implemented by means of software on a personal computer or embedded system[17].

stvid Satellite tools video application for acquiring and processing sky images[18].

UHF Ultra High Frequency is the International Telecommunication Union (ITU) designation for radio frequencies in the range between 300 megahertz (MHz) and 3 GHz, also known as the decimetre band as the wavelengths range from one meter to one tenth of a meter (one decimeter). Lower frequency signals fall into the VHF or lower bands.[19].

[12] https://en.wikipedia.org/w/index.php?title=Open_source&oldid=1103126225
[13] https://en.wikipedia.org/w/index.php?title=Radio_frequency&oldid=1104615064
[14] https://en.wikipedia.org/w/index.php?title=Antenna_rotator&oldid=1064620974
[15] https://satnogs.org/
[16] https://github.com/cbassa/satpredict
[17] https://en.wikipedia.org/w/index.php?title=Software-defined_radio&oldid=1106659618
[18] https://github.com/cbassa/stvid
[19] https://en.wikipedia.org/w/index.php?title=Ultra_high_frequency&oldid=1096417717

VHF Very High Frequency is the ITU designation for the range of radio frequency electromagnetic waves (radio waves) from 30 to 300 MHz, with corresponding wavelengths of ten meters to one meter. Frequencies immediately below VHF are denoted high frequency (HF), and the next higher frequencies are known as UHF[20].

[20] https://en.wikipedia.org/w/index.php?title=Very_high_frequency&oldid=1105564543

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Colophon

Created with 100% Free Software
Debian GNU/Linux
LaTeX