SatNOGS Optical Unofficial Guide

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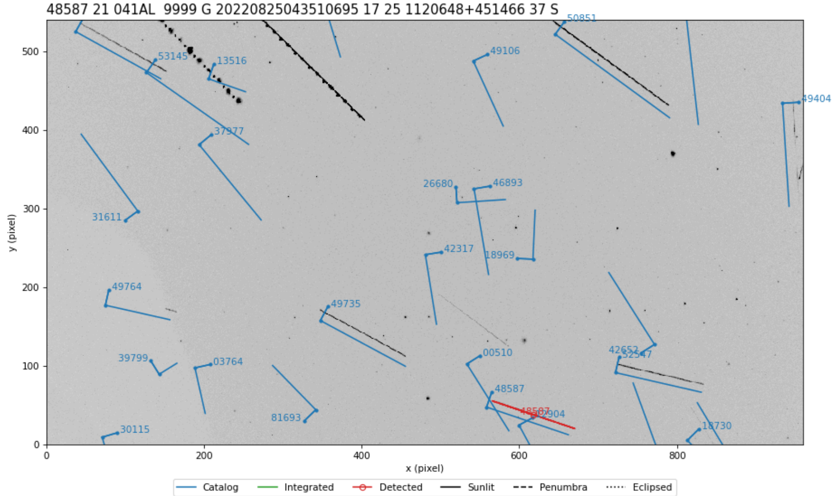

SatNOGS Optical *Unofficial* Guide

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SatNOGS Optical Unofficial Guide

by Jeff Moe

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Dedicated to free users

Space should be claimed
the libre way.

Libre Space Foundation

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Introduction

SatNOGS Optical

The SatNOGS Optical Unofficial Guide documents how to set up and run an optical ground station for the LSF (Libre Space Foundation)'s SatNOGS network.

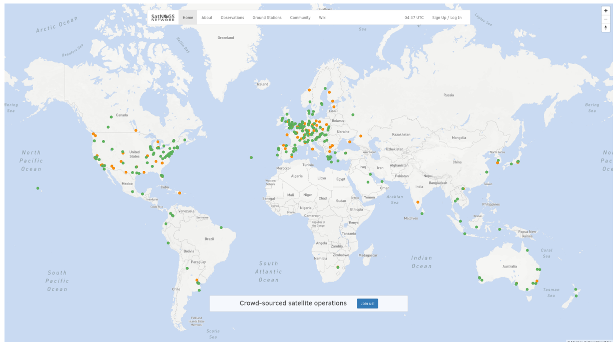

Figure 1: SatNOGS Network.

Unofficial Guide Overview

First, an overview of the this text, then the LSF and some of it's key projects, such as the SatNOGS network. A cursory review of satellites and existing RF (radio frequency) ground stations will be followed by a big picture view of acquiring and processing images of satellites. Hardware is reviewed, then software to run on it, with many options, including what is best. Finally, what to do with the data (idk!). The chapters that follow are listed below.

- Satellites — What are we looking at?
- Ground Stations — How Earth talks to satellites and back.
- Toolchain and Process — The big picture of what hardware and software is needed to set up an optical ground station for use on the distributed network.
- Hardware — Details on appropriate hardware configurations, and example setups.
- Software — A look at the myriad software related to satellites, and what works best at present for SatNOGS Optical.
- Acquire — Convert photons to bits. Pointing a camera at the sky works.
- Solve — Pictures of stars reveal the time and location of the photo. Plate solvers reviewed.
- Detect — The plate solver says where the photo is, now detect if are there moving tracks that aren't stars that could be satellites.

- Identify — With time, location, satellite detection, TLEs (two-line element sets) are overlaid and compared with detected satellites. Satellite identification by computers and humans.
- Upload — When ready, data will be pushed to the SatNOGS network.
- Support — Where development is occurring and questions answered!

Libre Space Foundation

The LSF supports “free and accessible space for all, creating Open Source space technologies.”[1]

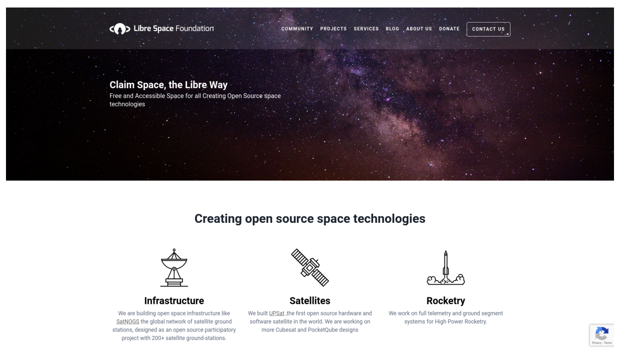

Figure 2: Libre Space Foundation Website.

Select LSF projects:

- SatNOGS — Global network of satellite ground stations
  `https://satnogs.org`
- UPSat — First OSH (open-source hardware) and OSS (open-source software) satellite in the world
  `https://upsat.gr/`

SatNOGS Network

SatNOGS is the LSF’s global network of satellite ground stations.

Network Status

The SatNOGS RF network has been running successfully for years. Adding an optical network is a new development. At present there are zero nodes on the network.

[1] `https://libre.space`

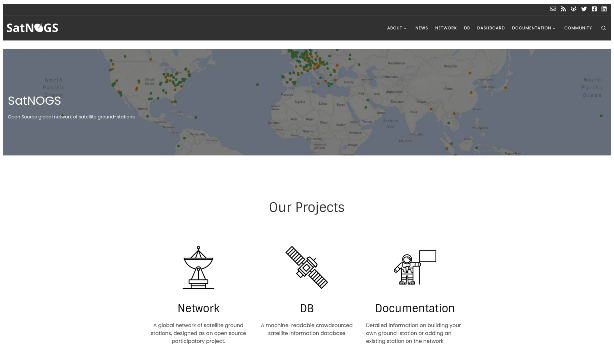

Figure 3: SatNOGS Website.

Some software already exists, some is being ported from C to Python, and other parts remain to be done. There is software available for acquiring optical data of satellites. There is no facility at present for pushing data back to the network.

Satellites

Artificial Satellites in Space

1.1 Overview of Satellites

Artificial satellites are rocks with modems.

1.2 SatNOGS DB

The SatNOGS DB is a database that lists satellites, many of which can be tracked by network operators.

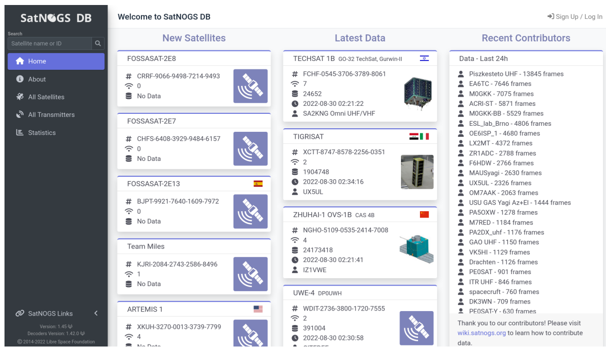

Figure 1.1: SatNOGS DB website.

Individual satellites can be viewed, such as the RamSat CubeSat.

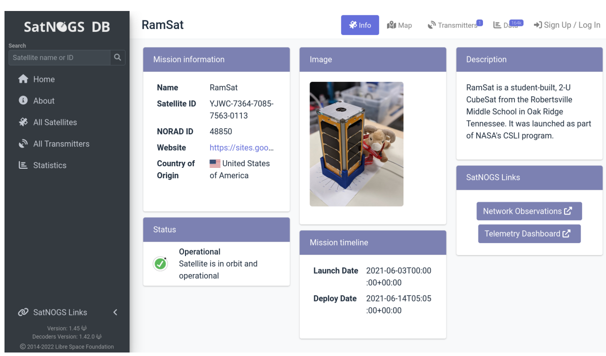

Figure 1.2: SatNOGS DB RamSat CubeSat web page.

For some satellites, telemetry is available in a Grafana dashboard. See the RamSat telemetry dashboard.

1.3 Libre Satellites

Satellites in orbit, decayed, or designs on Earth that generally support the libre way. Select libre satellites:

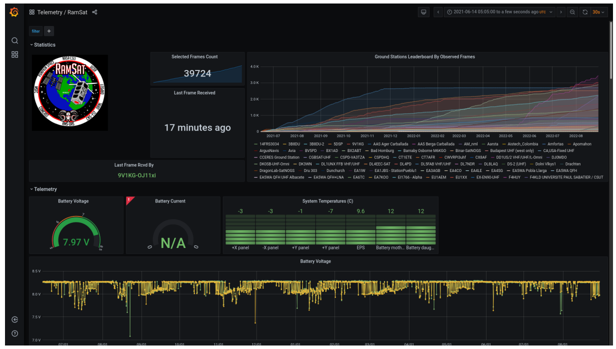

Figure 1.3: SatNOGS DB RamSat CubeSat telemetry web page.

- UPSat — First libre OSH and software satellite in the world. Created by the LSF. https://upsat.gr/

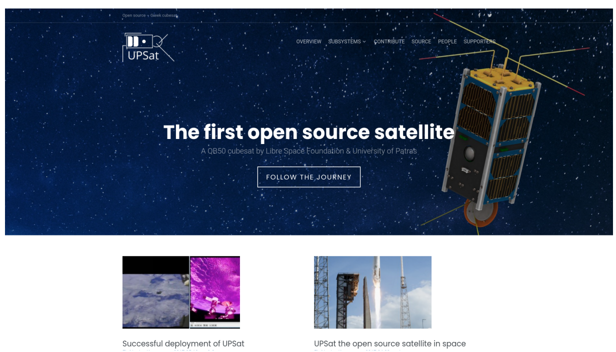

Figure 1.4: UPSat Website.

RF Observations can be scheduled on the SatNOGS network. See 1.5, page 18 for a example list of observations of the RamSat CubeSat.[1]

Individual RF observations are uploaded to the SatNOGS network, as can be seen in the example observation of the RamSat by SatNOGS ground station "2380 - Piszkesteto UHF" run by volunteer bcsak (username).

1.4 Satellite Orbits

Satellite orbits. See SGP (Simplified General Perturbations) and SDP (Simplified Deep Space Perturbations).

[1] https://network.satnogs.org/observations/?future=0&norad=48850&observer=&station=&start=&end=&transmitter_mode=&page=2

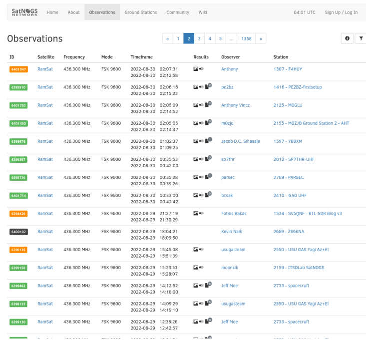

Figure 1.5: List of observations of the RamSat CubeSat, example.

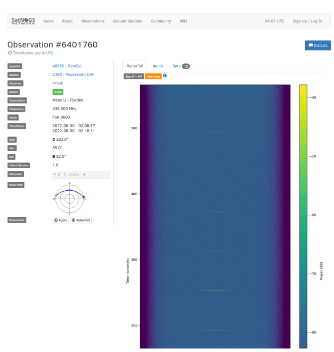

Figure 1.6: Sample observation of RamSat CubeSat on SatNOGS website.

Ground Stations

Looking up from Earth

2.1 Overview of Ground Stations

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

2.2 SatNOGS Ground Stations

The LSF built the SatNOGS network using distributed, volunteer-run, RF ground stations using SDRs, such as in figure 2.1, page 20.[1] It shows a SatNOGS ground station with VHF (Very High Frequency) (right) and UHF (Ultra High Frequency) (left) antennas on a mast with an Alt/Az mount (Altazimuth mount) rotator. SDRs can be used as RF receivers.[2]

Figure 2.1: SatNOGS ground station with antennas.

Ground stations can be viewed on the SatNOGS network website, such as as the example in figure 2.2, page 21.[3]

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

[2] Wikipedia contributors. Software-defined radio — Wikipedia, The Free Encyclopedia. https://en.wikipedia.org/w/index.php?title=Software-defined_radio&oldid=1107093398. [Online; accessed 28-August-2022]. 2022

[3] https://network.satnogs.org/stations/2733/

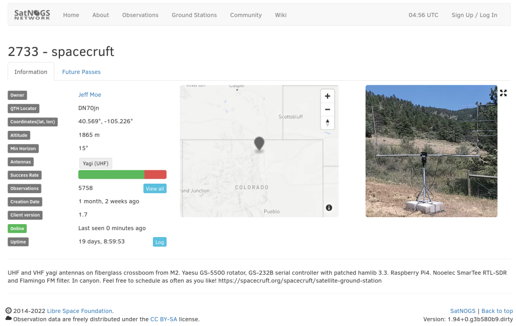

Figure 2.2: Ground station viewed on SatNOGS website, example.

2.3 SatNOGS Optical Ground Stations

The LSF is developing 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 2.3, page 22.

Figure 2.3: SatNOGS-Optical ground station prototype.

Toolchain and Pipeline Make Old Photons Useful Again

3.1 SatNOGS Optical HOWTO

SatNOGS Optical is the nascent distributed network of optical ground stations.

This chapter gives a top level review what is needed in terms of hardware and software to build an operating optical ground station.

3.2 Toolchain

SatNOGS Optical Process Overview.[1] See figure 3.1, page 25, described below.

1. Hardware — Hardware, such as cameras and computers, is to be selected and set up.
2. Software — The best currently available software is to be downloaded, installed, and configured.
3. Acquire — Data samples, typically in the form of FITS (Flexible Image Transport System) file photographs, need to be acquired by running a camera outside at night taking pictures of the sky.
4. Plate solver — Acquired data samples need to be processed by a plate solver. See 7.1, page 48.
5. Detect satellites — Using TLEs and the "solved" plates, detect satellites. See 8.1, page 52.
6. Identify satellites — With satellites detected in the previous step, identify what they are. See 9.1, page 54.

3.3 Hardware

Discussed in this section are some of the hardware options to be explored. More explicit instructions of a particular hardware installation can be see in 4.1, page 30. Below is discussed camera options, for details on computers and other parts, also see the Hardware chapter.

For the purposes here, are three main categories of hardware. Depending which category of equipment is selected, it impacts everything else, such as the software used. Main categories:

- Motion video cameras — Moving images.
- Still camera — Still photos.
- Allsky cameras — Views of all, or nearly all of the sky.

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

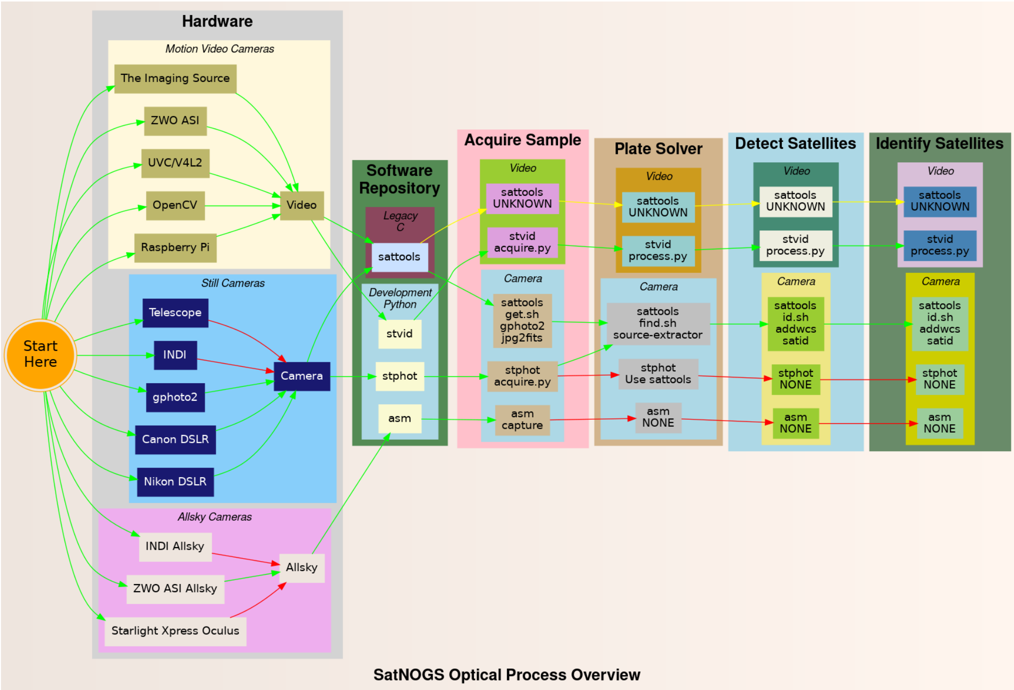

Figure 3.1: SatNOGS Optical Process Overview

Different types of equipment can be used in different categories. Some can be used in multiple setups, most just in one. If available, using motion video cameras will work best for detecting satellites with the developing SatNOGS toolchain. Examples of motion video camera sources that could be used:

- The Imaging Source Cameras based on IMX174 — Known to work. Recommended. High quality cameras, believed to be usable following DFSG (Debian Free Software Guidelines).
- ZWO ASI based on IMX174 — Known to work. Not DFSG compatible. Uses proprietary SDK. Currently in prototype development.
- UVC/Video4Linux2 — "Any" video camera that works with the Linux kernel. Typically, the device will appear similar to `/dev/video0`. A camera that works with the software isn't necessarily sensitive enough to detect satellites, however, as most are designed for bright environments.
- OpenCV — Devices that work with OpenCV can be used. To work well, they need to be sensitive.

- Raspberry Pi — The PiCamera can be used. A good lower cost option. Recommended. Many non-Raspberry Pi devices are also compatible with the Pi MIPI interface.

Still cameras can also be used productively. The current Python toolchain is in very early development and not completely usable yet.

See the list below for still camera options:

- Telescopes — Can definitely take images of satellites. Not the best tool at present, as it isn't well integrated into the toolchain. The FOV (Field of View) is generally too small. The mounts are optimized for different types of tracking than satellites. This is changing, and longer term could be well-supported. Using RASA (Rowe-Ackermann Schmidt Astrograph) style astrographs is likely the best option.
- INDI (Instrument Neutral Distributed Interface) — Typically used for control of telescopes and associated instrumentation, such as tracking mounts and cameras. Cannot be used directly with the current developing SatNOGS toolchain. It is not seen as the future path forward as it isn't well optimized for SatNOGS Optical usage. That said, it is very useful at present for running a tracking mount with KStars and Ekos, for example, in lieu of a better option. Camera software in the INDI platform typically produce image FITS files.
- gphoto — The Linux kernel recognizes many cameras that can be used with gphoto tools and drivers, available in Debian. This is the recommended option at present for still cameras. DSLR (digital single-lens reflex) cameras, such as from major manufacturers Canon and Nikon, are used with gphoto.

Considering the hardware options above, they need to be matched with corresponding software. Not all options work (at all), and some cannot be easily used to perform all steps needed.

There are also broader "paths" that need to be considered:

- sattools — Deprecated because it is in C, and the decision was made to move forward with applications primarily written in Python. Sattools is the most complete toolkit, however, so no matter what path is chosen, some parts of it will likely be used for now. It can be used with motion video cameras and still cameras. It includes many other software tools related to satellites.
- stvid — This is the best path if a motion video camera is available. It is in Python and is the tool the SatNOGS Optical project is using as the basis for future development. It still depends on some C tools from sattools.
- `stphot` — Written in Python this is what the SatNOGS Optical project will likely use in the future. It is in very early development, but can acquire data (take photos) with gphoto-compatible cameras.
- `asm` — All Sky Monitor for taking pictures of all, or nearly all of the sky, such as with a 150 or 180 degree view. The `asm` application is in pre-development, but is

in Python and could be the basis for future SatNOGS Optical development. The difficulty with all sky cameras is the plate solver isn't written to use images from the "fish-eye" view of an all sky camera.

- Other — There are many other satellite and telescope software packges freely available on the Internet. Many could be adapted for usage.

Hardware

Design and Set Up Equipment

4.1 Overview of Hardware

Hardware considerations for a SatNOGS Optical ground station.

Main hardware components in an optical ground station:

- Lens.
- Camera.
- Computer.

Other components:

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

4.2 Camera

Cameras being tested:

- The Imaging Source IMX174 based.
- ZWO ASI IMX174 based monochrome.
- DSLR camera.
- PiCamera.

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

4.3 Lenses

Lenses being tested:

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

4.4 Embedded Computer

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

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

4.4.1 Comparison

Comparing embedded computers for SatNOGS Optical.

Make	Model	Architecture	Max RAM	eMMC
Odroid	N2	ARM64	4 GB	Yes
Odroid	M1	ARM64	8 GB	Yes

Table 4.1: Comparison of embedded computers

4.5 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 2.3, page 22.

A close up of the setup can be seen at 4.1, page 32, showing the Skywatcher telescope tracking mount, a Bosch PoE (Power over Ethernet) camera enclosure, and through the glass the camera lens. In the background is a white antenna for GNSS (Global Navigation Satellite System) (GPS (Global Positioning System)) and a solar power setup.

The camera lens is protected by the enclosure glass, which is IP67 (Ingress Protection code 67) (XXX) rated. See a close up of the front of the enclosure and camera lens in figure 4.2, page 32.

As seen in figure 4.3, page 33, the left side of the enclosure has a hinge for opening. The bottom white component is part of the telescope mount.

Figure 4.4, page 33, 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 4.4, page 33.

Inside the camera enclosure, as shown in Figure 4.6, page 35, is:

- The Imaging Source DMX camera with Sony IMX174 CMOS (Complementary metal–oxide–semiconductor).

Figure 4.1: SatNOGS-Optical ground station prototype.

Figure 4.2: Camera enclosure, front side, showing glass and lens.

Figure 4.3: Camera enclosure, left side, showing hinge.

Figure 4.4: Camera enclosure, right side.

- Kowa 50mm f1.4 C-mount lens.
- Odroid N2 running Debian GNU (GNU's Not Unix!) Linux system.
- Odroid N2 plastic enclosure, large half, hole drilled for ad-hoc mounting.
- Blower fan on top, with power cable (came with Bosch enclosure).
- 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.
- USB 3 cable, internal, way too long, needs replacing, from Odroid to camera. XXX flat connector

Figure 4.5: Camera enclosure, right side, opened.

- 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 4.7, page 35.

4.6 Future Designs

There is some discussion of using much large “lenses”, such as RASA “telescope” (See: astrograph). The primary concern is the lack of satellite tracking mounts, because telescope mounts are generally too slow, and need to leap-frog the satellite. Rotators used for antennas aren’t stable enough for a camera.

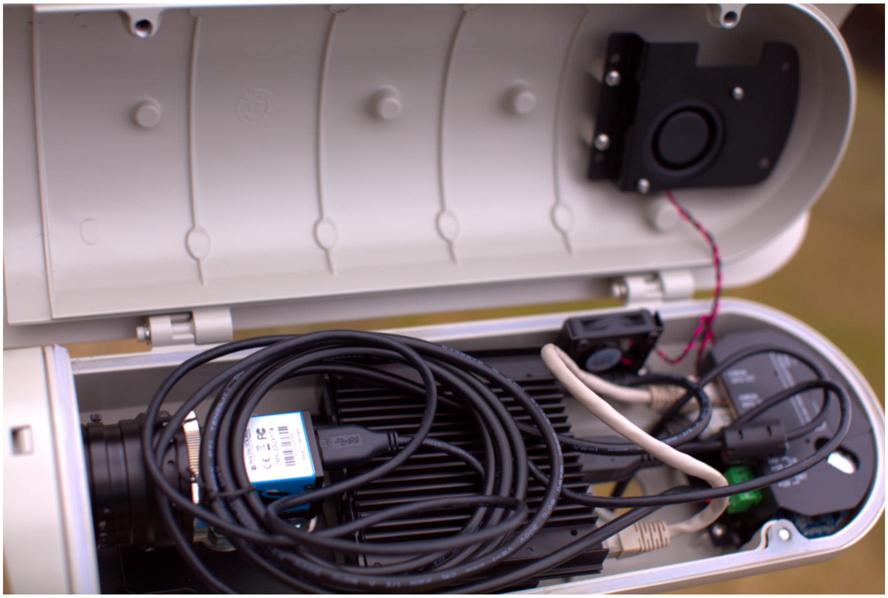

Figure 4.6: Camera enclosure, opened.

Figure 4.7: Camera enclosure, top.

Software

Satellite Applications on Earth

5.1 Software Overview

See 5.1, page 38 for a diagram with an overview of the software process.

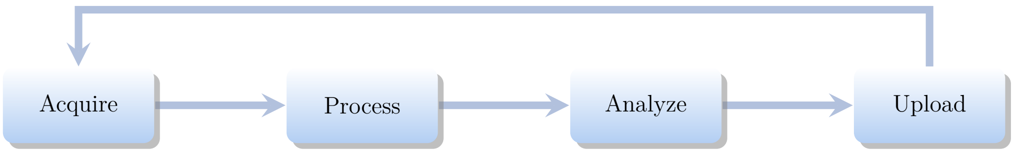

Figure 5.1: SatNOGS Optical Operation Pipeline

5.2 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
```

5.3 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
```

5.4 skymap

Use skymap for viewing satellite orbits tracks projected on a map of of the sky. Skymap is part of sattools. Skymap isn't a required part of the toolchain, but it is useful to see what satellites are visibile at a particular time and location.

Source:

* `https://github.com/cbassa/sattools`

My fork:

* `https://spacecruft.org/spacecruft/sattools`

NOTICE:
The main upstream sattools package requires non-libre pgplot on host computer.

Described below is how to build and install my fork of sattools to use skymap instead of upstream. Upstream requires non-libre software which also happens to be very difficult for most users to compile.

```
sudo apt install giza-dev git make dos2unix source-extractor wcslib-dev \
     libgsl-dev gfortran libpng-dev libx11-dev libjpeg-dev libexif-dev

git clone https://spacecruft.org/spacecruft/sattools

cd sattools/

make

sudo make install

# To clean
make clean
```

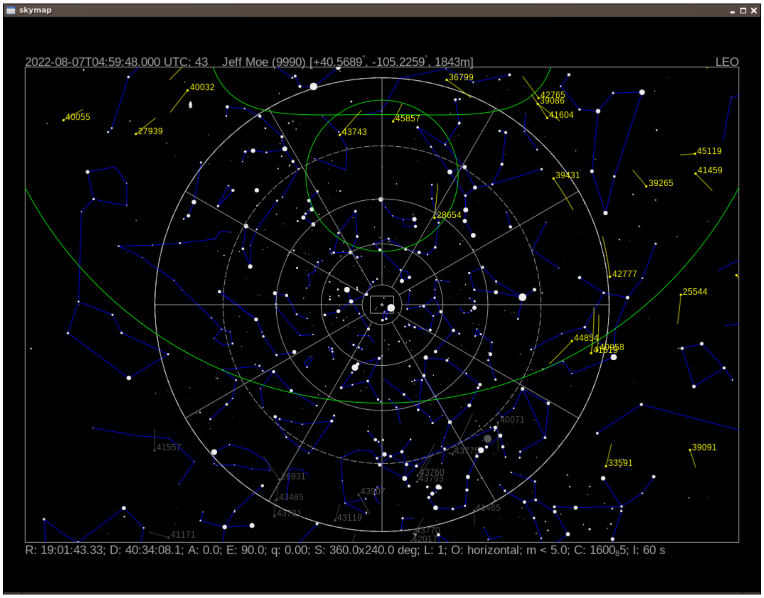

Figure 5.2: `skymap` example screenshot.

```
# To rebuild
make clean
make

# To uninstall
sudo make uninstall
```

See below for skymap usage:

```
cd bin/
./tleupdate

# set config in ~/.bashrc XXX

./skymap --help
Usage: skymap [OPTION]
Visualize satellites on a map of the sky.

-t, --time     Date/time (yyyy-mm-ddThh:mm:ss.sss) [default: now]
-c, --catalog    TLE catalog file [default: satnogs.tle]
-i, --id    Satellite ID (NORAD) [default: all]
-R, --ra    R.A. [hh:mm:ss.sss]
-D, --decl     Decl. [+dd:mm:ss.ss]
-A, --azimuth    Azimuth (deg)
-E, --elevation    Elevation (deg)
-w, --width    Screen width (default: 1024). Set height too.
-g, --height     Screen height (default: 768). Set width too.
-n, --nmax     nmax line resolution/speed (default 128)
-S, --all-night    All night
-Q, --no-stars    No stars
-a, --all-objects    Show all objects from catalog (default: LEO)
```

```
-h, --help    This help
-s, --site    Site (COSPAR)
-d, --iod    IOD observations
-l, --length    Trail length [default: 60s]
-P, --planar-id    planar search satellite ID
-r, --planar-alt    planar search altitude
-V, --visibility-alt    altitude for visibility contours
-p, --positions-file    File with xyz positions
-L, --longitude    manual site longitude (deg)
-B, --latitude    manual site latitude (deg)
-H, --elevation    manual site elevation (m)
```

Acquire

Twinkle, Twinkle, Little Starlink

6.1 Overview of Operation

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

6.2 Setup 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 6.1: Satellite images acquired by stvid.

6.3 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/
```

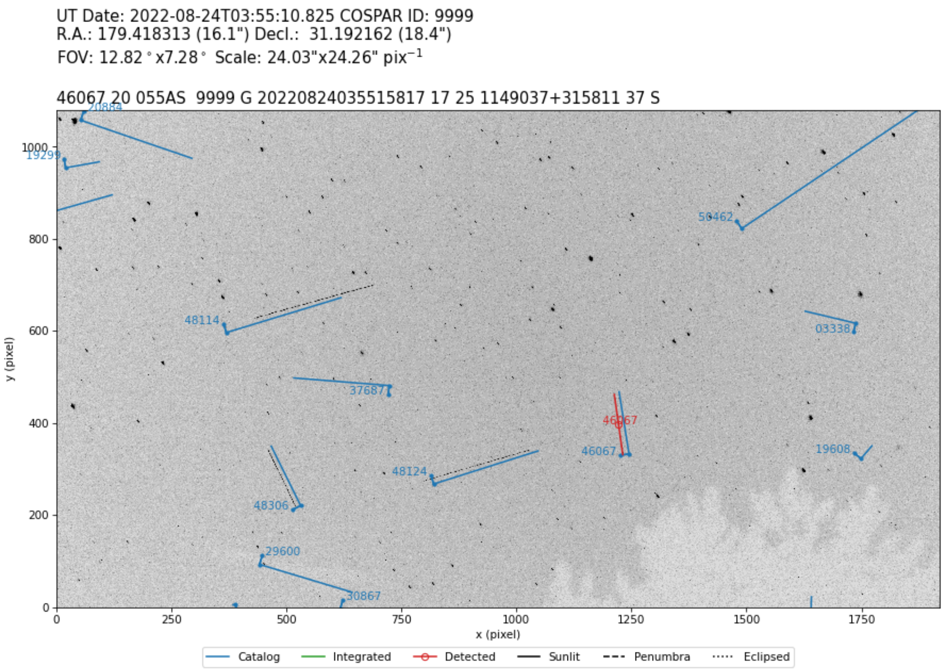

Figure 6.2: Satellite images processed by stvid.

Solve

Place from Pixels

7.1 Plate Solver

A “plate solver” will take an image of stars and detect the time and place of the picture. There are two main steps:

1. Extract stars from an image, such as a FITS file generated by `stvid`.
2. “Solve” the image of the stars in the image against vast databases of star images.

See below for a list of software tools that detect/extract stars from images (e.g. FITS).

- Source Extractor.
- XXX Kstars with ekos adds `Internal SEP`.
- XXX Kstars with ekos adds `Builtin method for solver`.

See below for a list of plate solvers that can be used.

- astrometry.net locally.
- astrometry.net Internet.
- astap.
- Watney.

7.2 Source Extractor

`Source Extractor`, formerly `SExtractor` and some other names, is an application to extract stars from images. The software has been widely used for many years.
`https://www.astromatic.net/software/sextractor`

7.3 astrometry.net

Astrometry.net is a website and software that can be run locally to solve a plate of stars that has been extracted from `Source Extractor`. XXX

> NOTICE:
> Using astrometry.net online requires an account with non-libre services. The astrometry.net software can be installed locally to avoid this.

7.4 Star Databases

To use a plate solver, you will need star databases. They can get large. The `stvid` application includes a basic star database. XXX The `4200` series is also recommended.

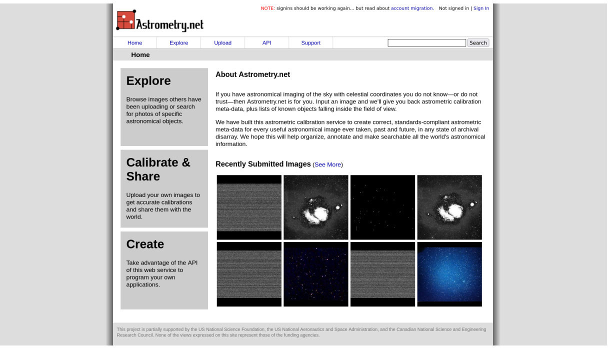

Figure 7.1: nova.astrometry.net website.

7.5 World Coordinate System

WCS (World Coordinate System) info. XXX

7.6 Plate Solving with `stvid`

Use the `process.py` scripts described at XXX to solve plates with `stvid`.

Detect

Find Satellites

8.1 Satellite Detection

Description of satellite detection processes.

8.2 stvid Detection with `process.py`

To detect satellite in a FITS file using the stvid toolchain, run `process.py` or, if it exists, the `process_new.py` Python script.

8.2.1 `process.py` Operation

This assumes you have installed `stvid` as shown in section 6.2. Adjust dated directory to actual directory name.

```
cd stvid/
# Maybe you need to update TLE
./update_tle.py
./process_new.py -c config_new.ini -d data/obs/20220825_1/020502/
```

Identify

More Than Just Old Rocket Bodies

9.1 Overview of Satellite Identification

The LSF is developing a project called SIDLOC (Spacecraft Identification and Localization), for satellite identification and localization. With the addition of many more satellites in orbit there is a growing need for SSA (Space Situational Awareness).

9.2 `stvid`'s `process.py` for Identification

The best tool for identifying satellites from FITS files is the `process.py` script from `stvid`, available here:

* `https://github.com/cbassa/stvid`
My fork is here:
* `https://spacecruft.org/spacecruft/stvid`

9.3 Identifying Satellites with `satid`

The deprecated C application, `satid` from the `sattools` package can help identify satellites. See figure 9.1, page 54 for output from my Giza port of `satid`.[1]

* `https://github.com/cbassa/sattools`
My fork is here:
* `https://spacecruft.org/spacecruft/sattools`

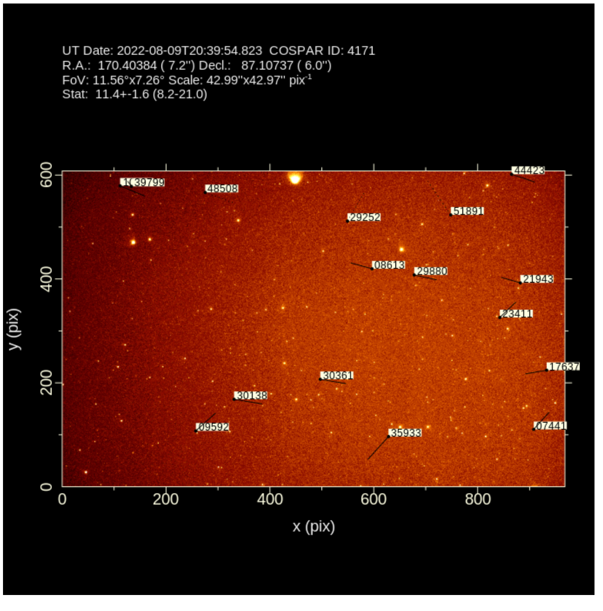

Figure 9.1: `satid` example.

[1] `https://spacecruft.org/spacecruft/sattools/media/branch/spacecruft/img/satid-giza-3.png`

9.4 AstroImageJ

Analyze data with applications, such as AstroImageJ.

FITS files are commonly used in astronomy.[2] AstroImageJ can read FITS format files. See 9.2, page 55, for a screenshot displaying a FITS file generated by `stvid`.

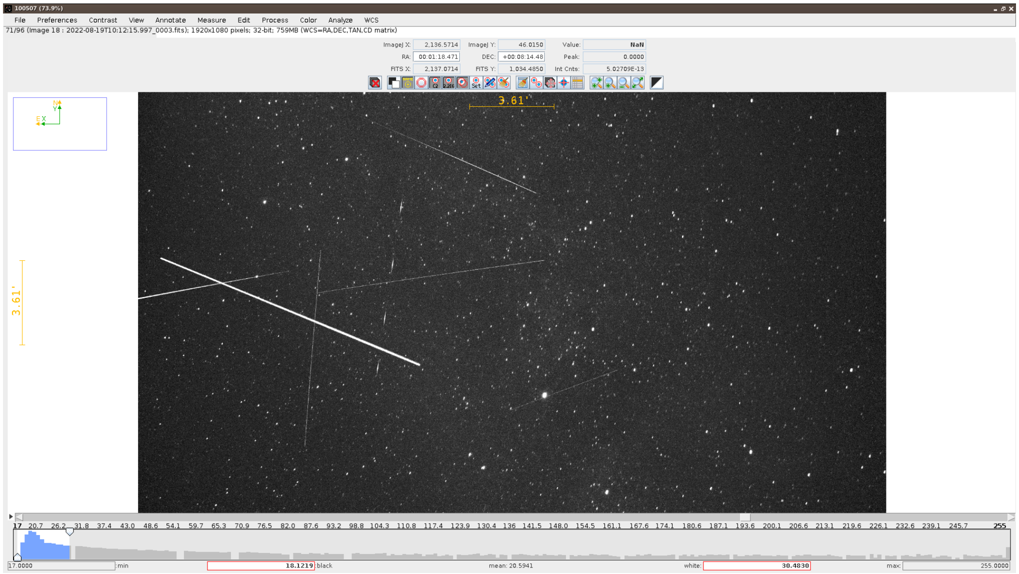

Figure 9.2: AstroImageJ screenshot viewing FITS file.

[2]Wikipedia contributors. FITS — Wikipedia, The Free Encyclopedia. `https://en.wikipedia.org/w/index.php?title=FITS&oldid=1091431488`. [Online; accessed 28-August-2022]. 2022

Upload

Send Data to the SatNOGS Network

10.1 Upload Data

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

Support

Help!

11.1 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

12.1 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 is a satellite put into orbit by humans, not "naturally" occurring.

astrograph is a telescope designed for the sole purpose of astrophotography. Astrographs are mostly used in wide-field astronomical surveys of the sky and for detection of objects such as asteroids, meteors, and comets.[3]

AstroImageJ Application for astronomy and satellite image analysis.[4]

C is a general-purpose computer programming language. It was created in the 1970s by Dennis Ritchie, and remains very widely used and influential. By design, C's features cleanly reflect the capabilities of the targeted CPUs. It has found lasting use in operating systems, device drivers, protocol stacks, though decreasingly for application software. C is commonly used on computer architectures that range from the largest supercomputers to the smallest microcontrollers and embedded systems. C is used in the sattools suite of applications.[5]

CMOS Complementary metal-oxide-semiconductor (pronounced "see-moss").

COTS Commodity off the shelf.

[1] Wikipedia contributors. Altazimuth mount — Wikipedia, The Free Encyclopedia. https://en.wikipedia.org/w/index.php?title=Altazimuth_mount&oldid=1056074953. [Online; accessed 28-August-2022]. 2021

[2] Wikipedia contributors. Antenna (radio) — Wikipedia, The Free Encyclopedia. https://en.wikipedia.org/w/index.php?title=Antenna_(radio)&oldid=1104603350. [Online; accessed 28-August-2022]. 2022

[3] Wikipedia contributors. Astrograph — Wikipedia, The Free Encyclopedia. https://en.wikipedia.org/w/index.php?title=Astrograph&oldid=1106095357. [Online; accessed 30-August-2022]. 2022

[4] https://www.astro.louisville.edu/software/astroimagej/

[5] Wikipedia contributors. C (programming language) — Wikipedia, The Free Encyclopedia. https://en.wikipedia.org/w/index.php?title=C_(programming_language)&oldid=1106686212. [Online; accessed 30-August-2022]. 2022

CubeSat is a class of miniaturized satellite based around a form factor consisting of 10 cm (3.9 in) cubes. CubeSats have a mass of no more than 2 kg (4.4 lb) per unit, and often use COTS (Commodity off the shelf) components for their electronics and structure. CubeSats are put into orbit by deployers on the International Space Station, or launched as secondary payloads on a launch vehicle. More than a thousand CubeSats have been launched.[6]

DCS distributed control system.

Debian a 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.[7]

DFSG Debian Free Software Guidelines is a set of guidelines that the Debian Project uses to determine whether a software license is a free software license, which in turn is used to determine whether a piece of software can be included in Debian. The DFSG is part of the Debian Social Contract.[8]

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.[9]

FLOSS Free/libre and open-source software. See also: FOSS (free and open-source software).

FOSH Free open-source hardware. See also: OSH.

FOSS free and open-source software is a term used to refer to groups of software consisting of both Free Software and OSS where anyone is freely licensed to use, copy, study, and change the software in any way, and the source code is openly shared so that people are encouraged to voluntarily improve the design of the software. This is in contrast to proprietary software, where the software is under restrictive copyright licensing and the source code is usually hidden from the users. FOSS maintains the software user's civil liberty rights. Other benefits of using FOSS can include decreased software costs, increased security and stability (especially in regard to malware), protecting privacy, education, and giving users more control

[6] Wikipedia contributors. CubeSat — Wikipedia, The Free Encyclopedia. `https://en.wikipedia.org/w/index.php?title=CubeSat&oldid=1106408835`. [Online; accessed 30-August-2022]. 2022

[7] Wikipedia contributors. Debian — Wikipedia, The Free Encyclopedia. `https://en.wikipedia.org/w/index.php?title=Debian&oldid=1105900486`. [Online; accessed 28-August-2022]. 2022

[8] Wikipedia contributors. Debian Free Software Guidelines — Wikipedia, The Free Encyclopedia. `https://en.wikipedia.org/w/index.php?title=Debian_Free_Software_Guidelines&oldid=1086423235`. [Online; accessed 31-August-2022]. 2022

[9] Wikipedia contributors, FITS — Wikipedia, The Free Encyclopedia

over their own hardware. Free and open-source operating systems such as Linux and descendants of BSD are widely utilized today, powering millions of servers, desktops, smartphones (e.g., Android), and other devices. Free-software licenses and open-source licenses are used by many software packages. The free software movement and the open-source software movement are online social movements behind widespread production and adoption of FOSS, with the former preferring to use the terms FLOSS (Free/libre and open-source software) or free/libre.[10]

FOV Field of view.

Free Software or libre software, is computer software distributed under terms that allow users to run the software for any purpose as well as to study, change, and distribute it and any adapted versions. Free software is a matter of liberty, not price; all users are legally free to do what they want with their copies of a free software (including profiting from them) regardless of how much is paid to obtain the program. Computer programs are deemed "free" if they give end-users (not just the developer) ultimate control over the software and, subsequently, over their devices.[11]

GHz gigahertz.

GNSS Global Navigation Satellite System.

GNU "GNU's Not Unix!" 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 GPL (GNU General Public License). GNU is also the project within which the Free Software concept originated.[12]

GPL GNU General Public License is a series of widely used Free Software licenses that guarantee end users the four freedoms to run, study, share, and modify the software. The license was the first copyleft for general use. Historically, the GPL license family has been one of the most popular software licenses in the FLOSS software domain.[13]

GPS Global Positioning System.

Grafana is a multi-platform Open Source analytics and interactive visualization web application. It provides charts, graphs, and alerts for the web when connected to supported data sources. Users can create complex monitoring dashboards using

[10] Wikipedia contributors. Free and open-source software — Wikipedia, The Free Encyclopedia. https://en.wikipedia.org/w/index.php?title=Free_and_open-source_software&oldid=1106343648. [Online; accessed 30-August-2022]. 2022

[11] Wikipedia contributors. Free software — Wikipedia, The Free Encyclopedia. https://en.wikipedia.org/w/index.php?title=Free_software&oldid=1106538260. [Online; accessed 28-August-2022]. 2022

[12] Wikipedia contributors. GNU — Wikipedia, The Free Encyclopedia. https://en.wikipedia.org/w/index.php?title=GNU&oldid=1103488294. [Online; accessed 28-August-2022]. 2022

[13] Wikipedia contributors. GNU General Public License — Wikipedia, The Free Encyclopedia. https://en.wikipedia.org/w/index.php?title=GNU_General_Public_License&oldid=1106596497. [Online; accessed 28-August-2022]. 2022

interactive query builders. It is used by the SatNOGS project to visualize satellite telemetry.[14]

ground station a setup of equipment such as computers, cameras, SDRs, antennas, and receivers, located on Earth, observing space.

hough3d-code is a software application for Iterative Hough Transform for Line Detection in 3D Point Clouds.[15]

INDI Instrument Neutral Distributed Interface is a DCS (distributed control system) protocol to enable control, data acquisition and exchange among hardware devices and software front ends, emphasizing astronomical instrumentation.[16]

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.[17]

kHz kilohertz.

libre The English adjective free is commonly used in one of two meanings: "at no monetary cost" (gratis) and "with little or no restriction" (libre). This ambiguity of free can cause issues where the distinction is important, as it often is in dealing with laws concerning the use of information, such as copyright and patents. The terms gratis and libre may be used to categorise computer programs, according to the licenses and legal restrictions that cover them, in the free software and open source communities, as well as the broader free culture movement. For example, they are used to distinguish freeware (software gratis) from Free Software (software libre). "Think free as in free speech, not free beer." – Richard Stallman.[18]

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.[19]

LSF Libre Space Foundation is a non-profit foundation registered since 2015 in Greece and the creators of the SatNOGS project.[20]

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[14] Wikipedia contributors. Grafana — Wikipedia, The Free Encyclopedia. `https://en.wikipedia.org/w/index.php?title=Grafana&oldid=1104046322`. [Online; accessed 30-August-2022]. 2022

[15] `https://gitlab.com/pierros/hough3d-code`

[16] Wikipedia contributors. Instrument Neutral Distributed Interface — Wikipedia, The Free Encyclopedia. `https://en.wikipedia.org/w/index.php?title=Instrument_Neutral_Distributed_Interface&oldid=1062506145`. [Online; accessed 31-August-2022]. 2021

[17] Wikipedia contributors. International Telecommunication Union — Wikipedia, The Free Encyclopedia. `https://en.wikipedia.org/w/index.php?title=International_Telecommunication_Union&oldid=1105915792`. [Online; accessed 28-August-2022]. 2022

[18] Wikipedia contributors. Gratis versus libre — Wikipedia, The Free Encyclopedia. `https://en.wikipedia.org/w/index.php?title=Gratis_versus_libre&oldid=1085552810`. [Online; accessed 30-August-2022]. 2022

[19] Wikipedia contributors. Linux kernel — Wikipedia, The Free Encyclopedia. `https://en.wikipedia.org/w/index.php?title=Linux_kernel&oldid=1105840074`. [Online; accessed 28-August-2022]. 2022

[20] `https://libre.space/about-us/`

mast typically tall structures designed to support antennas for telecommunications and broadcasting.[21]

Matrix an open standard and communication protocol for real-time communication.[22]

MHz megahertz.

NASA is an independent agency of the US federal government responsible for the civil space program, aeronautics research, and space research.[23]

NORAD North American Aerospace Defense Command is a combined organization of the United States and Canada that provides aerospace warning, air sovereignty, and protection for Canada and the continental United States.[24]

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, 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.[25]

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

orbit is the curved trajectory of an object such as the trajectory of a planet around a star, or of a natural satellite around a planet, or of an artificial satellite around an object or position in space such as a planet, moon, asteroid, or Lagrange point. Normally, orbit refers to a regularly repeating trajectory, although it may also refer to a non-repeating trajectory. To a close approximation, planets and satellites follow elliptic orbits, with the center of mass being orbited at a focal point of the ellipse, as described by Kepler's laws of planetary motion. For most situations, orbital motion is adequately approximated by Newtonian mechanics, which explains gravity as a force obeying an inverse-square law. However, Albert Einstein's general theory of relativity, which accounts for gravity as due to curvature of spacetime, with orbits following geodesics, provides a more accurate calculation and understanding of the exact mechanics of orbital motion.[26]

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[21] Wikipedia contributors. Radio masts and towers — Wikipedia, The Free Encyclopedia. https://en.wikipedia.org/w/index.php?title=Radio_masts_and_towers&oldid=1103964392. [Online; accessed 28-August-2022]. 2022

[22] Wikipedia contributors. Matrix (protocol) — Wikipedia, The Free Encyclopedia. https://en.wikipedia.org/w/index.php?title=Matrix_(protocol)&oldid=1106244486. [Online; accessed 28-August-2022]. 2022

[23] Wikipedia contributors. NASA — Wikipedia, The Free Encyclopedia. https://en.wikipedia.org/w/index.php?title=NASA&oldid=1107567899. [Online; accessed 30-August-2022]. 2022

[24] Wikipedia contributors. NORAD — Wikipedia, The Free Encyclopedia. https://en.wikipedia.org/w/index.php?title=NORAD&oldid=1105457081. [Online; accessed 30-August-2022]. 2022

[25] Wikipedia contributors. Open source — Wikipedia, The Free Encyclopedia. https://en.wikipedia.org/w/index.php?title=Open_source&oldid=1103126225. [Online; accessed 28-August-2022]. 2022

[26] Wikipedia contributors. Orbit — Wikipedia, The Free Encyclopedia. https://en.wikipedia.org/w/index.php?title=Orbit&oldid=1106406646. [Online; accessed 30-August-2022]. 2022

OSH open-source hardware consists of physical artifacts of technology designed and offered by the open-design movement. Both FOSS and open-source hardware are created by the open-source culture movement and apply a like concept to a variety of components. It is sometimes, thus, referred to as FOSH (Free open-source hardware). The term usually means that information about the hardware is easily discerned so that others can make it – coupling it closely to the maker movement. Hardware design (i.e. mechanical drawings, schematics, bills of material, PCB layout data, HDL source code and integrated circuit layout data), in addition to the software that drives the hardware, are all released under free/libre terms. The original sharer gains feedback and potentially improvements on the design from the FOSH community. There is now significant evidence that such sharing can drive a high return on investment for the scientific community. It is not enough to merely use an open-source license; an open source product or project will follow open source principles, such as modular design and community collaboration.[27]

OSS open-source software is computer software that is released under a license in which the copyright holder grants users the rights to use, study, change, and distribute the software and its source code to anyone and for any purpose. Open-source software may be developed in a collaborative public manner. Open-source software is a prominent example of open collaboration, meaning any capable user is able to participate online in development, making the number of possible contributors indefinite. The ability to examine the code facilitates public trust in the software. Open source code can be used for studying and allows capable end users to adapt software to their personal needs in a similar way user scripts and custom style sheets allow for web sites, and eventually publish the modification as a fork for users with similar preference.[28]

perturbation is the complex motion of a massive body subjected to forces other than the gravitational attraction of a single other massive body. The other forces can include a third (fourth, fifth, etc.) body, resistance, as from an atmosphere, and the off-center attraction of an oblate or otherwise misshapen body.[29]

plate solver is software implementing a technique used in astronomy and applied on celestial images. Solving an image is finding match between the imaged stars and a star catalogue. The solution is a math model describing the corresponding astronomical position of each image pixel. The position of reference catalogue stars has to be known to a high accuracy so an astrometric reference catalogue is used. The image solution contains a reference point, often the image centre, image scale, image orientation and in some cases an image distortion model. With the astrometric solution it is possible to: 1) Calculate the celestial coordinates of any object on the image. 2) Synchronize the telescope mount or satellite pointing position to the center of the image taken. Astrometric solving programs extract the star x,y positions from

[27] Wikipedia contributors. Open-source hardware — Wikipedia, The Free Encyclopedia. `https://en.wikipedia.org/w/index.php?title=Open-source_hardware&oldid=1105615869`. [Online; accessed 30-August-2022]. 2022

[28] Wikipedia contributors. Open-source software — Wikipedia, The Free Encyclopedia. `https://en.wikipedia.org/w/index.php?title=Open-source_software&oldid=1104440334`. [Online; accessed 30-August-2022]. 2022

[29] Wikipedia contributors. Perturbation (astronomy) — Wikipedia, The Free Encyclopedia. `https://en.wikipedia.org/w/index.php?title=Perturbation_(astronomy)&oldid=1105431363`. [Online; accessed 30-August-2022]. 2022

the celestial image, groups them in three-star triangles or four-star quads. Then it calculates for each group a geometric hash code based on the distance and/or angles between the stars in the group. It then compares the resulting hash codes with the hash codes created from catalogue stars to find a match. If it finds sufficient statistically reliable matches, it can calculate transformation factors. There are several conventions to model the transformation from image pixel location to the corresponding celestial coordinates. The simplest linear model is called the WCS. A more advanced convention is SIP (Simple Imaging Polynomial) describing the transformation in polynomials to cope with non-linear geometric distortion in the celestial image, mainly caused by the optics.[30]

PoE Power over Ethernet.

Python is a high-level, interpreted, general-purpose programming language. Its design philosophy emphasizes code readability. It is often described as a “batteries included” language due to its comprehensive standard library. Python consistently ranks as one of the most popular programming languages. It is one of the main languages of the SatNOGS project and stvid.[31]

RASA Rowe-Ackermann Schmidt Astrograph.

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 kHz (kilohertz) to around 300 GHz (gigahertz). 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.[32]

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.[33]

satellite is an object intentionally placed into orbit in outer space. Except for passive satellites, most satellites have an electricity generation system for equipment on board. Most satellites also have a method of communication to ground stations, called transponders. Many satellites use a standardized bus to save cost and work, the most popular of which is small CubeSats. Similar satellites can work together as a group, forming constellations.[34]

[30] Wikipedia contributors. Astrometric solving — Wikipedia, The Free Encyclopedia. https://en.wikipedia.org/w/index.php?title=Astrometric_solving&oldid=1099832612. [Online; accessed 30-August-2022]. 2022

[31] Wikipedia contributors. Python (programming language) — Wikipedia, The Free Encyclopedia. https://en.wikipedia.org/w/index.php?title=Python_(programming_language)&oldid=1107007073. [Online; accessed 30-August-2022]. 2022

[32] Wikipedia contributors. Radio frequency — Wikipedia, The Free Encyclopedia. https://en.wikipedia.org/w/index.php?title=Radio_frequency&oldid=1104615064. [Online; accessed 28-August-2022]. 2022

[33] Wikipedia contributors. Antenna rotator — Wikipedia, The Free Encyclopedia. https://en.wikipedia.org/w/index.php?title=Antenna_rotator&oldid=1064620974. [Online; accessed 28-August-2022]. 2022

[34] Wikipedia contributors. Satellite — Wikipedia, The Free Encyclopedia. https://en.wikipedia.org/w/index.php?title=Satellite&oldid=1106286374. [Online; accessed 30-August-2022]. 2022

satid is part of sattools.[35]

SatNOGS Open Source global network of satellite ground stations.[36]

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

SatNOGS DB is an effort to create an hollistic, unified, global database for all artificial objects in space (satellites and spacecrafts). Users can view and export the data, contribute to it, or connect applications using an API. It is part of the SatNOGS project.[37]

satpredict is a software application to compute satellite predictions. It is used by stvid.[38]

sattools Satellite Tracking Toolkit. The main `sattools` applications are being ported to stvid and other related Python applications.[39]

SDP Simplified Deep Space Perturbations models apply to objects with an orbital period greater than 225 minutes, which corresponds to an altitude of 5,877.5 km, assuming a circular orbit. See also: SGP.[40]

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.[41]

SGP Simplified General Perturbations models apply to near earth objects with an orbital period of less than 225 minutes. Simplified perturbations models are a set of five mathematical models (SGP, SGP4, SDP4, SGP8 and SDP8) used to calculate orbital state vectors of satellites and space debris relative to the Earth-centered inertial coordinate system. This set of models is often referred to collectively as SGP4 due to the frequency of use of that model particularly with TLE sets produced by NORAD (North American Aerospace Defense Command) and NASA (National Aeronautics and Space Administration). These models predict the effect of perturbations caused by the Earth's shape, drag, radiation, and gravitation effects from other bodies such as the sun and moon. See also: SDP.[42]

SIDLOC Spacecraft Identification and Localization.

SIP Simple Imaging Polynomial.

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[35] https://github.com/cbassa/sattools/blob/master/satid.c
[36] https://satnogs.org/
[37] https://db.satnogs.org/
[38] https://github.com/cbassa/satpredict
[39] https://github.com/cbassa/sattools
[40] Wikipedia contributors. Simplified perturbations models — Wikipedia, The Free Encyclopedia. https://en.wikipedia.org/w/index.php?title=Simplified_perturbations_models&oldid=983925578. [Online; accessed 30-August-2022]. 2020
[41] Wikipedia contributors, Software-defined radio — Wikipedia, The Free Encyclopedia
[42] Wikipedia contributors, Simplified perturbations models — Wikipedia, The Free Encyclopedia

skymap is part of sattools. Vizualize satellites on a map of the sky.[43]

SSA Space Situational Awareness.

stvid Satellite tools video application for acquiring and processing sky images.[44]

telemetry is the in situ collection of measurements or other data at remote points and their automatic transmission to receiving equipment (telecommunication) for monitoring. The word is derived from the Greek roots tele, "remote", and metron, "measure". Although the term commonly refers to wireless data transfer mechanisms (e.g., using radio, ultrasonic, or infrared systems), it also encompasses data transferred over other media such as a telephone or computer network, optical link or other wired communications like power line carriers.[45]

telescope is an optical instrument using lenses, curved mirrors, or a combination of both to observe distant objects, or various devices used to observe distant objects by their emission, absorption, or reflection of electromagnetic radiation. The word telescope now refers to a wide range of instruments capable of detecting different regions of the electromagnetic spectrum, and in some cases other types of detectors.[46]

TLE two-line element set is a data format encoding a list of orbital elements of an Earth-orbiting object for a given point in time, the epoch. Using a suitable prediction formula, the state (position and velocity) at any point in the past or future can be estimated to some accuracy. TLEs can describe the trajectories only of Earth-orbiting objects. TLEs are widely used as input for projecting the future orbital tracks of space debris for purposes of characterizing "future debris events to support risk analysis, close approach analysis, collision avoidance maneuvering" and forensic analysis. The format was originally intended for punched cards, encoding a set of elements on two standard 80-column cards.[47]

UHF Ultra High Frequency is the ITU (International Telecommunication Union) designation for radio frequencies in the range between 300 MHz (megahertz) 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.[48]

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.[49]

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WCS World Coordinate System.

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