piNOAA: an independent daily Earth Observation service using a Raspberry Pi data processing platform

Diogo Pires Silva[a,b]*, José Eduardo[a,b]

[a] *Departamento de Electrónica, Telecomunicações e Informática, Universidade de Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal*, (D.P.S.) diogo.pires.silva@av.it.pt, (J.E.) jecs@av.it.pt
[b] *Instituto de Telecomunicações, Universidade de Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal*
* Corresponding Author

Abstract

Access to timely meteorological data is of extremely importance nowadays. The NOAA satellites operate in various primary and secondary roles, providing additional full global data coverage for a broad range of weather and environmental applications, supporting both short-term weather forecasting and long-term climate and environmental data records. In order to gather these data, we developed and implemented piNOAA using open-source APIs and a low-cost software-defined radio (SDR) receiver system. This platform includes a custom-made VHF quadrifilar helical antenna, a SDR USB Dongle and a Raspberry Pi (RPI). This platform implemented an independent daily meteorological service using space data publishing in social networks the atmosphere status activity over Portugal and much of the Iberian Peninsula, North Africa and its Atlantic adjacent area. This device provides the digital data to the RPI where the data is processed and posted in a social network. Recently we have installed piNOAA in Mozambique to publish daily service about meteoritical conditions on the South West Indian Ocean, centered in the South of Mozambique and the North of South Africa.
Keywords: NOAA, Raspberry Pi, Python,

Acronyms/Abbreviations

amplitude modulation (AM), acquisition of signal (AOS), application programming interface (API), automatic picture transmission (APT), geostationary operational environmental satellite (GOES), high resolution picture transmission (HRPT), infrared (IR), loss of signal (LOS), National Aeronautics and Space Administration (NASA), National Oceanic and Atmospheric Administration (NOAA), quadrifilar helicoidal (QFH), server message block (SMB), two-line element (TLE)

1. Introduction

The NOAA weather satellites are the generation of weather satellites prior to the GOES satellites. The four NOAA satellites (NOAA-15, -18, -19 and -20) are in polar orbits and thus have daily passages over any geographic region. They transmit APT and HRPT images in VHF and L band frequencies, respectively, simultaneously and are therefore suitable (low cost and ease of setup) to implement a daily Earth Observation service and space education activity.

An APT system is an analog image transmission system developed in the 1960s to be used on weather satellites [1-4].

Installing an autonomous and independent ground station platform could prove itself useful as a second resource in case there is a failure on weather prediction services which other services could depend on or for use in remote areas where internet access is more difficult or absent.

In this article we will describe the materials and software used in the project, the antenna design choices as well as our results and its discussions.

1.1 APT history

APT systems were developed by NASA in the 1960s. This is a unique television system which enables weather satellites to take pictures to the surface of the Earth, allowing the analysis of the cloud formations over wide areas and transmit them to cheap ground stations anywhere on Earth.

A satellite (TIROS VIII) with an experimental version of an APT system was launched in 1963, then two Nimbus satellites were launched in 1964 and 1966 which successfully demonstrated the APT system by transmitting thousands of pictures to APT ground stations all over the world [1-11].

1.2 How is it transmitted?

The data satellite links have two spectral data channels carrying an image each. During daytime one channel carries an image in the visible spectrum and at nighttime it is replaced by an infrared (IR) image and the other channel is in IR.

The data is transmitted between 137.1-137.9125 MHz and it is frequency modulated with a subcarrier of 2400 Hz AM. [12]

2. Material and methods

In the following sub-sections, the used hardware and software will be detailed.

2.1 Image capture system (hardware)

The receiver is currently mounted on the roof of Instituto de Telecomunicações in Aveiro as seen below and since August 2022 a similar piNOAA toolkit was installed at Oswuela, an education ONG based in Maputo, Mozambique. As part of the outreach activities of the **D**evel**O**pment of **P**ALO**P** Know**LE**dge in **R**adioastronomy (DOPPLER[1]) project, this piNOAA kit enables the coverage of Southern African and the Indian Ocean centered in Maputo, Mozambique.

Fig. 1 NOAA satellites receiver setup

The system is made of a QFH antenna and a box with electronics needed for the reception. The usual types of antennas used for NOAA reception (APT) are the QFH, the v-dipole and the crossed dipole, the QFH was chosen because of its omnidirectional radiation pattern in a single hemisphere even without a ground plane [13].

Regarding the electronics, the received signal goes into a module by Nooelec (Fig. 3 - 3) that filters (bandpass) a region of 5 MHz centered at 137.5 MHz and amplifies a minimum of 30 dB [14]. Since we are not powering it through a bias tee, we use a DC block (Fig. 3 – 2) [15] to isolate it from the SDR. For the signal acquisition we used the RTL-SDR dongle (Fig. 3 - 1) since it's a low-cost device with a frequency range that includes the band of interest 137-138 MHz [16] and is supported by a broad set of open-source software. Finally, we use a Raspberry Pi 3 to execute the necessary software to decode and store the satellite images (Fig. 3 - 4).

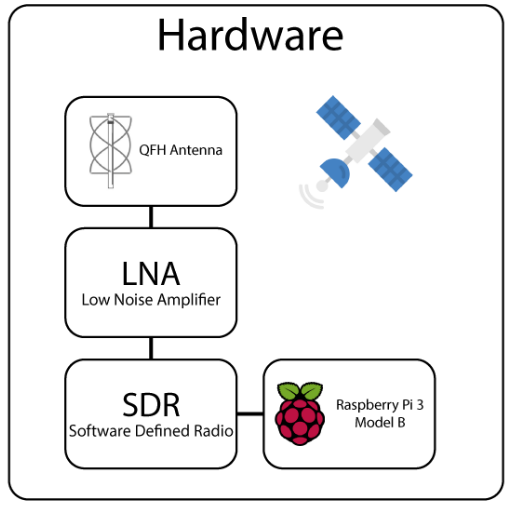

Fig. 2 Block diagram for the hardware setup

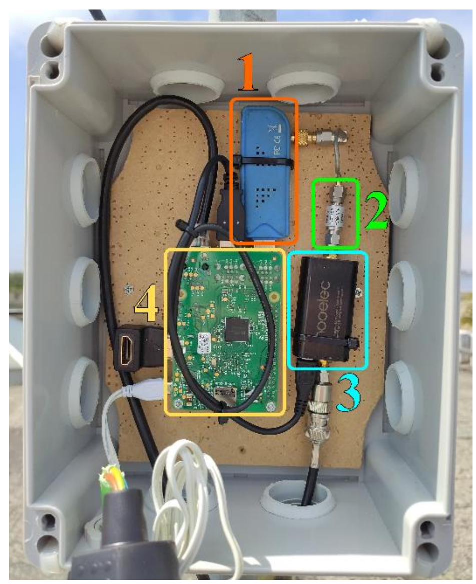

Fig. 3 Electronics setup

2.2 Software

[1] http://doppler.av.it.pt/

Finally, we set up a software pipeline combining the following code apps. A Python script was developed to automatize and check the acquisition of the images sent by the NOAA satellites (Fig. 4). The Predict [17] app, when requested, will output the propagation of the selected satellite orbit using data from a TLE file, which is updated daily. To improve the image quality reception, we developed testing app to enable reception only for satellites above 30º of elevation and avoid horizon interferences and shadow from tall buildings or trees. For this we created a secondary script to select the closest passage with a minimum elevation of 30º. After the selection process, the main script will wait for the AOS time to begin the signal capture until LOS using rtl_fm [18], resample the RAW file using SoX [19] to 11025Hz and save the output in MP3 format to enable decoding by the noaa-apt image decoder [20] twice: once with the map grid overlayed and the other without the map grid. The secondary script analyzes the orbit of the satellite to determine if the passage was from North to South or South to North. If it was found the latter case, the image will be rotated 180º. Finally, the acquired images are sent to a remote SMB server to be later analyzed. The image with the map grid overlay will be posted on Twitter using an API from Twitter and the reception cycle starts again by using Predict to determine the next passage.

This script is scheduled to run after the system boots and updates the satellite TLE file every day.

This algorithm was inspired by the "Automate recording of Low Earth orbit NOAA Weather Satellites", a work developed and made available in github [21].

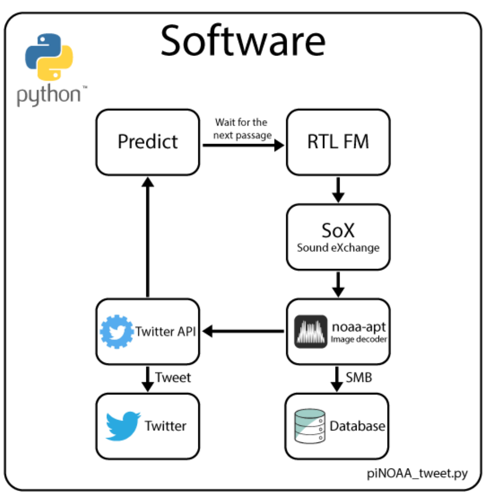

Fig. 4 Block diagram of the main script

3. Theory and calculation

To be able to capture the image data sent by the NOAA satellites an antenna needs to be designed in order to acquire it, with the most efficiency possible. Since the signal has a circular polarization a Quadrifilar Helicoidal antenna was chosen. An online calculator [22] that helps with the dimensions of the antenna was used having in consideration the characteristics of the satellites of interest (Table 1). The acquired signal should be then amplified using an LNA.

To automatize the system each of the passages must be predicted and the nearest one should be selected if it fills the minimum requirement of elevation of choice. The signal then must be recorded, demodulated and then decoded to produce an image.

Table 1. Characteristics of NOAA 15, 18 and 19 satellites. [23-25]

	NOAA15	NOAA18	NOAA19
APT (MHz)	137.6200	137.9125	137.1000
HRPT (MHz)	1702.5	1707.0	1698.0
Altitude (Km)	807	854	870
Period (minutes)	101.10	102.12	102.14
Precession Rate (min/month)	1.05	3.52	0.77

4. Results

All the following images and more can be found on the Twitter page of the project.

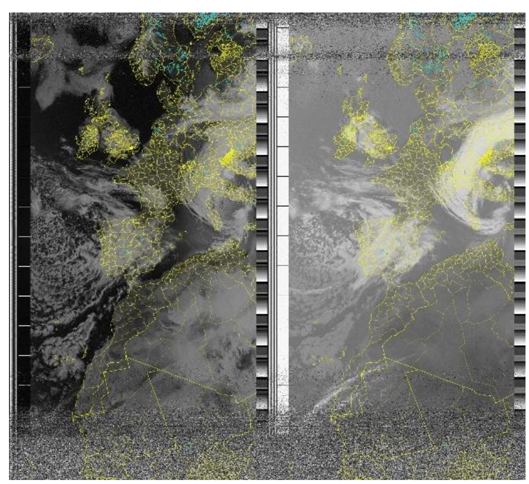

Fig. 5 Example of an acquired image during the day in Portugal.

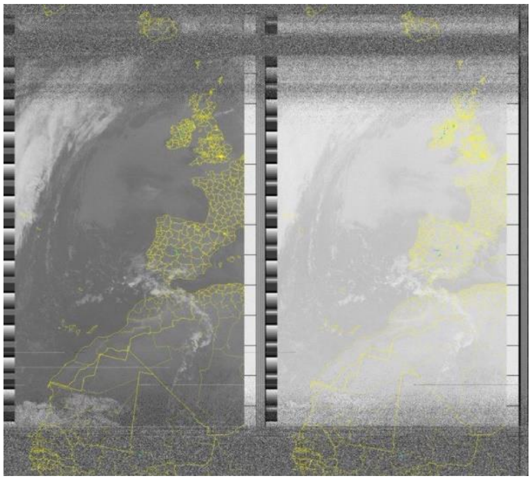

Fig. 6 Example of an acquired image during the night

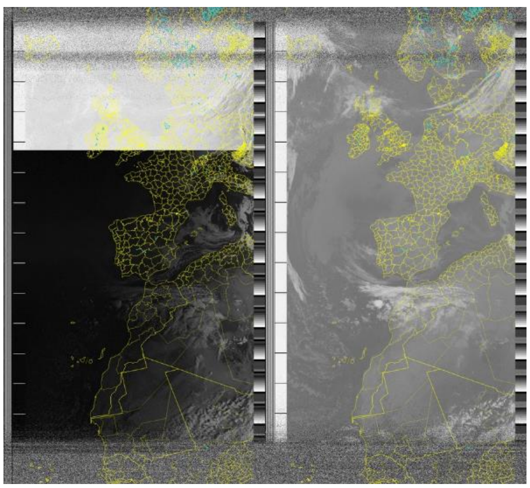

Fig. 7 Example of an acquired image of the transition from night to day mode

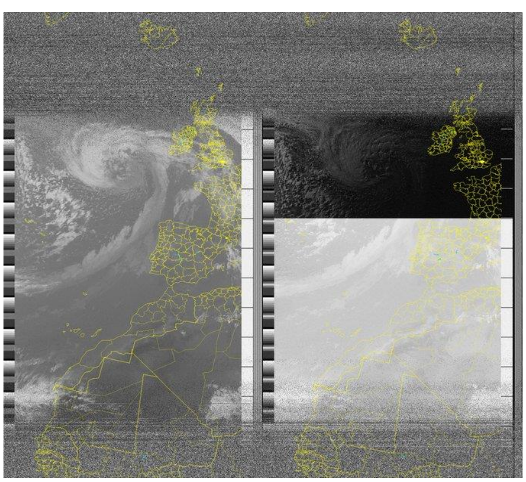

Fig. 8 Example of an acquired image of the transition from day to night mode

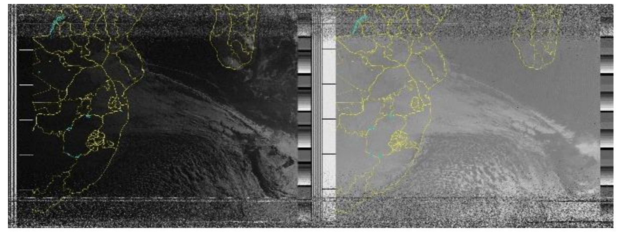

Fig. 9 Example of an acquired image from Maputo, Mozambique

5. Discussion

The work done here intends to update the TLE files of the satellite daily and post the received images on Twitter. It is possible to observe that the best images are taken during the day, when the visible channel is available, and that the passages with the highest degree of elevation also do have much less noise (avoid interferences closer to the horizon). Since the system is capturing all the satellite passages that meet the minimum elevation requirement (above 30º) it is possible to see the transition of the acquisition mode of the images, switching from night to day mode and vice versa.

6. Conclusions

The system is working as intended and now, more than 1000 images have been captured and posted on the Twitter project page. Since August 2022 it is proving a second service on atmospheric activity over Mozambique and the Indian Ocean African coastland.

In the future, this tool will be expanded to detect and receive image data from GOES satellites and using an automatic antenna positioning system in order to capture HRPT images from NOAA satellites.

piNOAA will also be used to assess meteorological data and assist operations at the Pampilhosa da Serra Space Observatory (PASO) and may be integrated into a visual assistance tool to aid operations of other observatory sensors.

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