Weather Satellite Tracking with RTL-SDR: NOAA 15 Image Reception and Signal Decoding

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***Abstract*—This study examines the growing number of satellites, this paper explores the importance of satellite tracking and highlights NOAA-15 for information transmission and weather monitoring. It offers a low-cost configuration for receiving circularly polarized signals, using a Software Defined Radio (SDR) at 137.62 MHz and a V-dipole antenna. The directional characteristics of the V-dipole maximize capture efficiency by improving signal reception during particular satellite orbits. The flexible SDR, in particular the RTL SDR USB dongle, is used to detail signal decoding for Automatic Picture Transmission (APT), allowing for effective processing and tracking. High-quality APT photos are produced by this hardware-software integration, highlighting NOAA's crucial role in international weather forecasting. The study also emphasizes how simple and inexpensive it is to use the V-dipole antenna to receive NOAA weather satellite signals.**

***Index Terms*—Software Define Radio, Information system, NOAA, APT, Cybersecurity.**

I. INTRODUCTION

An efficient tracking system is now required to control the rapidly growing number of satellites orbiting the Earth. The system is required to keep an eye on the motions of the numerous satellites in orbit above Earth due to their rapid increase in number [1]. The tracking of NOAA-15, a satellite used mostly for weather forecasting by the National Oceanic and Atmosphere Administration (NOAA), is the main topic of this research. NOAA uses three different types of satellites: polar orbiting satellites, geostationary satellites, and deep space satellites. Each type of satellite serves a specific and vital purpose [2]. A considerable number of 5,465 satellites are already in orbit, according to UCS 2022, and by 2031, 24,468 satellites will be in orbit, according to Euroconsult. The increasing number of satellites emphasizes the urgent need for effective satellite tracking. The primary goal of this project is to track NOAA-15 while also projecting its trajectory in real time onto the celestial sphere [3]. NOAA has expanded free access to satellite data and guaranteed universal accessibility by offering direct broadcasts throughout the United States and 100 additional nations globally. Automatic Picture Transmission (APT), which transmits photographs of the Earth's surface at a frequency of 137.62 MHz, is one of the data transmission techniques utilized by NOAA 15. In this experiment, the APT images at 137.62 MHZ were received using a V-dipole antenna [4].

The 137.62 MHz signal is detected by a V-dipole antenna [5]. A hardware RTL SDR processes the signal, and software does additional conversions to create the tracking images. Software Defined Radio (SDR) is a new extension of digital signal processing (DSP) [6]. SDR radios provide software-configurable features and a very wide frequency spectrum, in contrast to FM radios [7].

"Software radio" refers generally to a radio that uses a static hardware base and derives its flexibility from software. For our study, we have been using a USB dongle known as RTL SDR to receive signals [8]. Effective tracking systems are essential in today's space environment, mainly to handle the growing difficulties brought on by the growing number of satellites in Earth's orbit. Avoiding collisions is the biggest problem because of the congested orbital environment, which increases the likelihood of satellite collisions and the subsequent creation of dangerous space debris. These systems give operators accurate, real-time data on satellite positions, allowing them to anticipate any collisions and take prompt action to avert them.

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Frequency coordination presents another significant challenge, as the cohabitation of multiple satellites requires flawless communication. Effective tracking guarantees the best possible frequency assignment, reducing interference and improving dependable data transfer. Furthermore, resource optimization is essential because fuel-efficient orbital maneuvers require precise tracking, which extends the operational lifetime of satellites with limited resources. Furthermore, effective tracking systems support a sustainable orbital environment by keeping an eye on and anticipating possible collisions with junk, which helps to reduce space debris. Global satellite network management is further required by the cooperative use of space by different nations and organizations, and tracking systems are essential for promoting coordination and cross-national collaboration. All things considered, these systems deal with the complex issues surrounding space operations, guaranteeing the sustainability, longevity, and safety of satellites as well as the environment in orbit.

Five sections make up this paper in order to give a thorough knowledge of the work. Introduction is covered in Section 1, Objective is covered in Section 2, and Implementation is covered in Section 3, which also includes the RTL SDR USB dongle and the V-dipole antenna into the software section where decoding methods for the received APT signal are explained. The software's process for transforming the unprocessed signal data into useful tracking pictures of NOAA-15's trajectory across the horizon is described in this section. Section 4 covers the comprehensive overview of hardware and software integration whereas the section 5 includes the consideration of cybersecurity of satellite tracking. The tracking process and decoding method is present in section 6 of the paper. Section 7 demonstrate the Decoded Signal. Section 8, which wraps up the report, summarizes the results and can touch on the project's wider ramifications. It probably contains notes from the tracking, possible difficulties encountered, and adjustments that could be made for better outcomes. It may discuss the importance of satellite monitoring in general, the work's applicability given the growing number of satellites, and possible uses for the tracking information gleaned by NOAA-15.

II. OBJECTIVE

A. Climate Monitoring and Research

A critical component of climate study and monitoring are the satellites run by NOAA and other organizations. Regarding sea surface temperatures, ice coverage, quantities of greenhouse gases, and other environmental aspects, they offer priceless information. To assist scientists better understand and handle climate change, accurate tracking makes sure that these satellites are in the best places to collect data.

B. Scientific Research and Education

Images obtained by NOAA-15's APT transmission are among the satellite data that can be utilized for scientific and instructional purposes. While educators can use the real-time satellite images to improve learning experiences in classrooms, researchers can use it to investigate the Earth's surface, weather patterns, and other occurrences.

III. IMPLEMENTATION

Software and hardware used in the NOAA-15 satellite tracking implementation include an RTL-SDR USB dongle, which serves as the hardware component of the software-defined radio system, a V-Dipole antenna for receiving the 137.62 MHz APT signal transmitted by NOAA-15, and Cubic SDR software for interacting with the RTL-SDR and enabling signal reception. NOAA-15's trajectory and time are predicted by the use of GPredict software, which is based on orbital characteristics. WXtoImg software is then used to decode and process the received APT signal, producing real-time photos of the Earth's surface taken during NOAA-15's passes. This application helps with weather forecasting and environmental monitoring by enabling real-time tracking and visualization of NOAA-15's journey across the horizon. The configuration also enables data analysis and storage of the taken pictures, assisting with scientific and instructional endeavors.

The research was able to reduce the effect of weak signals on the received APT images by utilizing these Python libraries and image processing techniques, leading to more understandable and practical visualizations of NOAA-15's route across the surface of the Earth. The method of picture augmentation greatly increased the satellite's ability to see weather patterns and other pertinent aspects, which enhanced the tracking value of the satellite overall and helped to improve weather forecasting.

A. V-Dipole Antenna

Fig. 1. V-Dipole Antenna

Fig.1 represents A radio antenna with two conducting elements arranged in a V shape is called a V-dipole antenna. It is frequently employed in broadcasting and radio communication applications. An folded antenna is another name for the V-dipole antenna. This V-Dipole antenna will be used in this research to follow the NOAA 15 weather satellite. Satellite

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communication uses circular polarization as shown in Fig.2 because it is less sensitive to the receiving antenna's orientation than linear polarization [9].

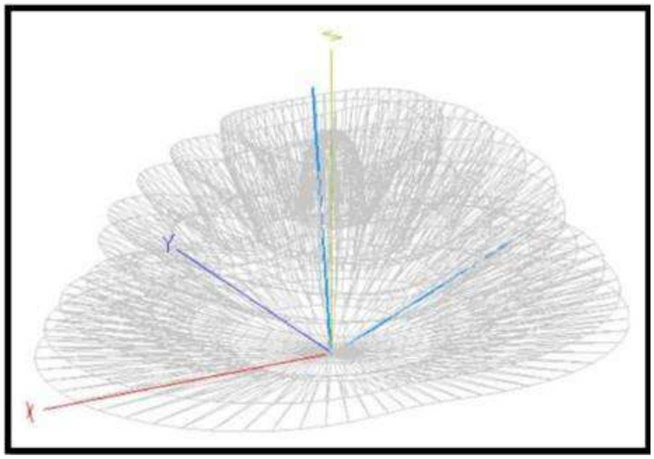

Fig. 2. 3D radiation pattern of V-dipole Antenna

To receive a circularly polarized signal, the receiving antenna must to be circularly polarized with the same sense of rotation. A relatively simple and inexpensive type of antenna, a V-dipole antenna can be used to receive the signals delivered by NOAA weather satellites. Depending on whether the NOAA satellite orbits from north to south or vice versa, the antenna is appropriately oriented toward either the north or the south. When the V dipole antenna is horizontal, the radiation pattern will be zeros (0) pointing toward the sky. The front, side, and top directions of the antenna are where satellite signals are most likely to be picked up by this arrangement [10].

B. Software Defined Radio (SDR)

Fig. 3. RTL-SDR Dongle

Several hardware components are used in a standard radio system to accomplish various tasks such signal filtering, modulation, demodulation, and decoding. These tasks are carried out by software in an RTL SDR system shown in Fig. 3, which runs on a dedicated hardware platform or a general-purpose computer [11,12]. SDR technology processes and manipulates radio frequency (RF) signals in the digital realm by using digital signal processing techniques. An analog- to-digital converter (ADC) samples the RF signal that is received, and software techniques are then used to extract, filter, demodulate, and decode the needed information [13].

RF front end: This part employs a mixer to combine the incoming signal with a signal generated by a local oscillator to form an Intermediate Frequency (IF), a low frequency signal. It also amplifies weak signals picked up by the antenna and eliminates background noise.

ADC: The ADC transforms an analog RF signal into a digital signal. The SDR's performance was predetermined by the ADC. An ADC's performance metrics include the following:

- Signal to Noise Ratio (SNR): the ratio of signal power to noise power in the output.
- Resolution: number of bits per sample.
- Linearity: its ability to accurately represent the input signal over a wide range of amplitudes.

Digital Front End: A digital downconverter (DDC) is used to further downconvert the digital signal to an IF or baseband signal after it has been transmitted to the digital front end. A digital representation of the received signal is the signal that comes after the DFE.

Signal processing: After the digital base band signal is sent to a signal processing block, software performs a variety of processes to decode the received signal shown in Fig. 4.

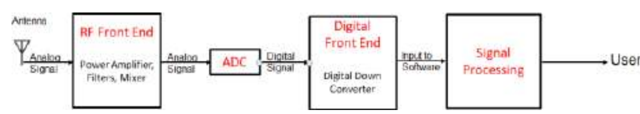

Fig. 4. SDR from a receiver's point of view

C. G-Predict

An open-source program called Gpredict is used to track satellites and predict their orbits. Professionals engaged in satellite communication, amateur radio operators, and satellite enthusiasts are the main users of it [14]. It enables users to follow satellite movement and position in real time. It offers graphical depictions of satellite trajectories that display the ground track and footprint coverage on a global map.

D. Cubic SDR

With suitable SDR gear, users can receive and decode radio signals using Cubic SDR, a software-defined radio (SDR) application. Although Cubic SDR cannot directly track satellites or decode data from NOAA weather satellites, it can be utilized in conjunction with other components to receive and analyze signals from NOAA satellites [15]. For this reason, we must install a different program called WXtoImg, which is made specifically for tracking and decoding NOAA weather satellites. Set up the software such that Cubic SDR acts as the receiver [16].

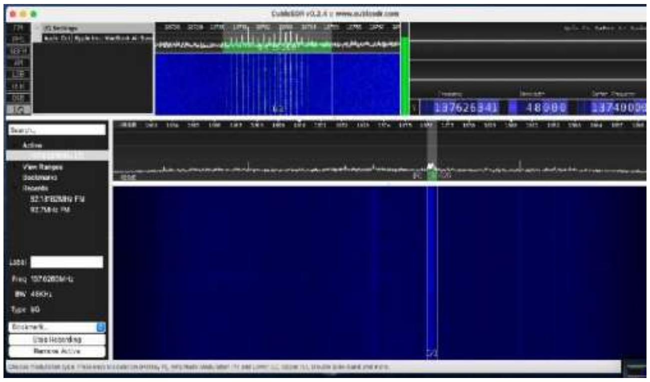

Fig. 5. Receiving Signal From NOAA

IV. Comprehensive Overview of Hardware and Software Integration

Two essential parts make up the hardware configuration of the NOAA-15 satellite tracking system. The main radio receiver is an RTL-SDR USB dongle that connects to the V-Dipole antenna in an easy-to-use manner. With its V-shaped form, this antenna best positions itself to receive the 137.62 MHz APT signal that NOAA-15 transmits. These hardware components work in tandem to provide accurate signal reception during the satellite's passes, laying the groundwork for efficient satellite tracking.

The software solution uses specialized tools to coordinate the tracking and decoding of satellites during the entire operation. The NOAA-15's trajectory may be precisely aligned with the satellite's orbit for the best possible signal reception according to the GPredict software. By serving as the RTL-SDR USB dongle's interface, Cubic SDR simplifies the signal reception procedure. In the meantime, WXtoImg software assumes a central role in deciphering the received APT signal, producing images of the Earth's surface in real time while NOAA-15 passes over. This software setup produces high-quality graphics that aid in environmental monitoring and weather forecasting by ensuring a smooth transition from signal reception to decoding.

V. Cybersecurity Considerations in Weather Satellite Tracking

In order to guarantee the integrity, confidentiality, and dependability of the data transmission and decoding process, cybersecurity issues must be addressed as RTL-SDR technology for weather satellite tracking advances. Because weather satellite systems have the ability to affect environmental monitoring, public safety, and national security, cybersecurity considerations are especially important. This section lists the main cybersecurity components and safeguards put in place to strengthen the system as a whole:

- **Secure Signal Transmission** Encryption techniques must be used during signal transmission in order to guard against data manipulation or illegal access when the data is being transmitted from the satellite to the receiving system. Using cryptographic methods and secure communication routes helps prevent data modification and interception.
- **Software Security Measures** Software tools used in signal decoding, including WXTOIMG, CUBIC SDR, and G-PREDICT, need to be updated with the most recent security fixes on a regular basis. Furthermore, using secure coding techniques and carrying out frequent security audits will lessen the possibility that bad actors will find vulnerabilities and exploit them.
- **Access Control and Authentication** Important cybersecurity precautions include limiting user authentication methods and limiting access to the satellite tracking system. This stops unauthorized people from taking over the tracking program and tampering with the decoding procedure.
- **Data Integrity Checks** It is guaranteed that the data used for weather analysis is accurate and has not been tampered with during transmission or decoding by incorporating methods to confirm the integrity of received data. Checksums and hash functions can be used to validate the integrity of data.
- **Network Security** It is essential to secure the network infrastructure that is used to send and receive satellite signals. Network security tools such as intrusion detection systems and firewalls can aid in thwarting attempts by outside attackers to take advantage of holes in the channels of communication.

VI. DECODING TECHNIQUE FOR THE RECEIVED SIGNAL

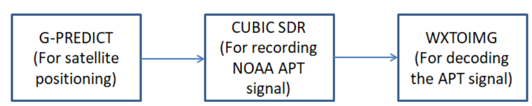

Fig. 6. Decoding Process

After a successful alignment, CUBIC SDR starts recording at the same frequency as the satellite shown in Fig.5. It is specifically designed to activate and record when the satellite passes directly overhead, reducing interference and enhancing signal clarity. When the pass is over, WXTOIMG comes into play. This program, which is intricately connected to local coordinates, decodes the recorded audio signal. Its main job is to convert the auditory data into a visual representation, which efficiently captures and renders the information extracted from NOAA 15's broadcast. The careful synchronization of hardware and software elements, encompassing accurate tracking, recording, and decoding, guarantees the effective extraction

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and conversion of satellite data into comprehensible visual depictions for thorough examination and interpretation.

A. Findings of the Research

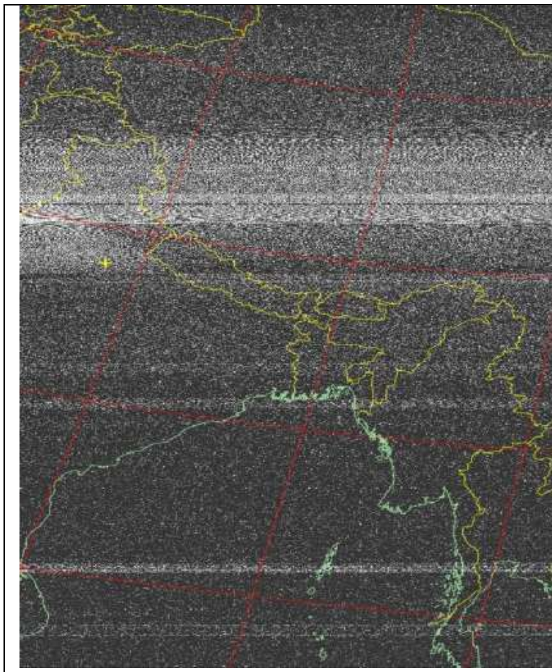
The research work concludes with significant findings that underscore the effectiveness of the integrated hardware-software system in satellite tracking. The study showcases the robustness of the software tools, including G-PREDICT, CUBIC SDR, and WXTOIMG, alongside the hardware components like the V-dipole antenna and RTL SDR, in efficiently tracking NOAA 15. This is evident in the system's precision in predicting, aligning, and recording signals during the satellite's overhead pass, establishing its reliability in satellite tracking operations. Furthermore, the research highlights the critical importance of optimizing signal capture by recording signals at precise times and frequencies. By strategically recording only during NOAA 15's direct overhead pass, the system ensures the highest quality signal reception, contributing to clearer and more accurate data capture. The study's emphasis on this meticulous approach reflects the commitment to maximizing the efficiency of data acquisition in satellite tracking.

A key discovery lies in the decoding and image transformation process facilitated by WXTOIMG, revealing the system's ability to convert raw audio signals into coherent visual representations. This transformative capability positions the research at the forefront of utilizing satellite transmissions for actionable data, particularly in the context of weather analysis. Lastly, the research underscores the broader applicability of its findings by emphasizing the significance of publicly available satellite data, such as NOAA 15, in enhancing global weather forecasting. The high-quality images produced through the integrated hardware-software solution hold the potential to improve weather prediction models and contribute to forecasting accuracy on a global scale.

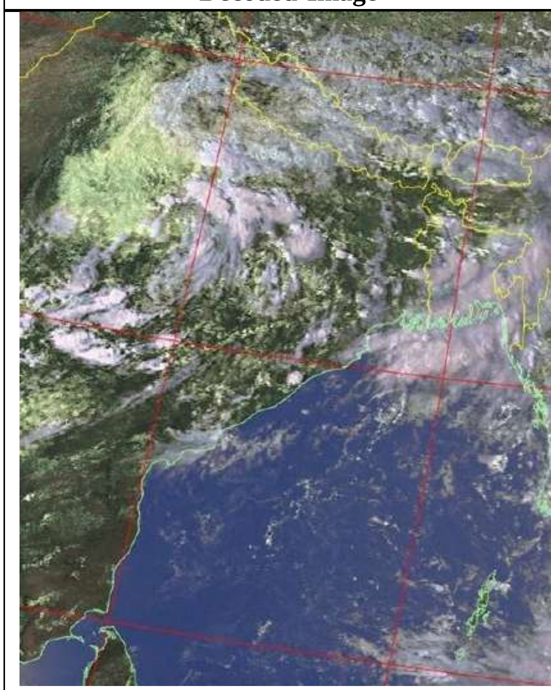
VII. Output of the Decoded Signal

The decoded signal from the NOAA satellite shown in Fig. 7 includes an image of the Earth's surface taken during one of NOAA-15's orbital missions. High-resolution photos showing weather patterns, cloud cover, topographical features, and natural events are included in this. Various elements can be analyzed and interpreted thanks to the decoded data, which reveals minute characteristics of the Earth's surface:

1) Weather Patterns and Storm Movements: Extensive data obtained from the photos on cloud formations, atmospheric conditions, and storm systems facilitate the tracking and monitoring of weather patterns over certain regions as well as their movement.
2) Environmental Shifts: Because ice cover, vegetation, and other environmental features can be observed, it is possible to monitor these changes and the possible effects they may have on ecosystems.
3) Impact of Human Activity: By observing changes in land use and features, the imagery can assist in the analysis of the consequences of human activity on the environment, such as pollution, urbanization, and deforestation.



Decoded Image



Improved Image

Fig. 7. Comparison of Decoded Image and Improved Image

4) Validation of Climate and Weather Models: By comparing these decoded images with information from other satellites or ground-based observations, current weather and climate models can be improved and validated, leading to increased precision and dependability.

These decoded graphics are great teaching aids in classroom settings. They can be used into lesson plans and PowerPoints to get students interested in studying about environmental studies, meteorology, satellite technology, and climate science. The photos' visual quality promotes investigation and comprehension of difficult scientific ideas pertaining to weather monitoring and Earth observation.

VIII. Result

Significant results were obtained from the decoding of the NOAA satellite signal, including high-resolution photos that showed the Earth's surface while NOAA-15 was in orbit. Intricate weather patterns, cloud formations, geographical information, and environmental phenomena were all recorded in these photos, which provide insightful information for meteorological analysis, weather monitoring, and environmental observation. They made it easier to watch storm motions, analyze atmospheric dynamics, keep an eye on vegetation and ice cover changes, and support the validation of current weather and climate models. These photos also functioned as powerful teaching tools, drawing students' attention to climate science, satellite technology, meteorology, and environmental studies while promoting a deeper comprehension of weather-related ideas and Earth observation.

IX. Conclusion

In conclusion, a multitude of important data that are essential for a variety of applications has been made available by the effective tracking and decoding of NOAA satellite signals, especially those from NOAA-15. With their precise depictions of weather patterns, cloud cover, topographical features, and climatic changes, the decoded photos provided a novel viewpoint on the surface of the Earth. These results are extremely important for scientific study, environmental analysis, and weather monitoring. Satellite technology is essential to the advancement of meteorology and climate science since it allows for the tracking of storm motions, the observation of changes in environmental features, the validation of weather models, and the capacity to educate students through visually engaging content. In addition to improving our knowledge of Earth's dynamics, the decoded imagery is a useful teaching tool that piques students' interest in satellite technology, meteorology, and environmental studies. This study demonstrates how important satellite data is to expanding our understanding of Earth's systems and how it may help advance scientific research and teaching.

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