MATLAB MODELS FOR WEATHER SATELLITE IMAGES TRANSMITTION AND RECEIVING SIMULATION

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Abstract. Studying and developing complex radio-electronic systems is almost impossible without creating their mathematical models. This article discusses three MATLAB models, which includes the formation, transmission and reception the images of the Earth and the atmosphere, obtained by low-orbit meteorological NOAA and METEOR-M satellites in various transmission formats (APT, HRPT, LRPT). The use of this models, allows us to simplify the studying of the methods and algorithms of analog and digital transmission and reception of satellite images without the use of hardware and software for direct reception satellite signals.

Introduction. Artificial Earth satellites (AES) provide us with a unique opportunity to look at the Earth from space. Meteorological satellites give us information about the formation and movement of clouds, ocean currents, temperature of the Earth’s surface, weather conditions, atmosphere and other factors affecting our lives. The most popular of this kind of services today are the Automatic Picture Transmission (APT) and High-Resolution Picture Transmission (HRPT) of the U.S. National Oceanic and Region Administration (NOAA) system [1], and Low-Rate Picture Transmission (LRPT) of the European METOP and METEOR-M systems [2].

A growing interest in such data and the means of obtaining them has been observed recently in the educational community. Especially useful is the work with these systems in the study of modern methods of encoding, transmission and reception of data in digital and analog ways. At the same time, work with real satellite signals does not allow to fully understand the meaning and technical content of those operations that were performed on them in the process of transmission and reception. Much more visual is the work with their mathematical and software models. The development and research of the software model that implements the transmission and reception of satellite images in APT, HRPT and LRPT formats is the subject of this work.

The transmission of meteorological images in the analog APT format has many attractive features - available frequency band for transmission (137-138 MHz), simple devices and programs for receiving and processing APT data, understandable data format. In addition, there are currently a lot of simple and cheap Software Defined Radio (SDR) receivers, which allow, using a personal
computer with simple and open software, to receive satellite signals and build images of the Earth's surface in real time. All this makes it very popular to work with APT data, in particular in the educational process. At the same time, analog APT has serious drawbacks - low spatial resolution of the received images (4x4 km/pixel), low noise immunity of analog transmission using frequency and amplitude modulation, especially at the beginning and at the end of the reception session (at low angles of satellites to horizon). All this does not allow obtaining detailed and high-quality images.

Images of the Earth's surface of significantly higher quality and higher spatial resolution (approximately 1x1 km/pixel) can be obtained using the digital HRPT image transmission method. The disadvantages of this method include the fact that the transmission is carried out at a much higher frequency (1.670–1.710 GHz), and in much wider frequency band (up to 4.5 MHz) [3]. In addition, a high gain antenna, low-noise UHF receiver, and an automatic satellite tracking system to control a highly directional antenna are required for HRPT reception. All this complicates the technical implementation of receiving data in the HRPT format and makes it much less accessible.

Finally, as an alternative to HRPT, a more modern method – LRPT was proposed for digitally transmitting images from low-orbit weather satellites with a frequency band not exceeding 150 kHz [3]. The working frequency range for transmission in the LRPT format is 137-138 MHz, that is, the same as for APT. As a result, the equipment for receiving LRPT (omnidirectional antenna, antenna amplifier, receiver) practically does not differ from those for APT. However, algorithms and software for receiving and processing digital data in this format are much more complex than for APT, since they include modern methods of data compression and error-correction encoding/decoding. In particular, the implementation of the LRPT format and its model includes: Earth's surface image compression/decompression based on the JPEG algorithm. Accordingly, the developed LRPT MATLAB simulation model can be conducive to study and better understanding the processes, taking place in modern satellite images transmission systems.

**APT system and MATLAB model structure.** The NOAA POES APT system have been developed for direct readout of satellite images using simple and low-cost receiving stations. On POES satellites, images in the APT format are produced using a scanning device (the Advanced Very High-Resolution Radiometer - AVHRR) by lowering the spatial resolution of the original data from 1x1 km/pixel to 4x4 km/pixel, and converting them into analog form. The transmission of images is carried out at VHF frequencies of 137-138 MHz in in analog format using amplitude modulation of the subcarrier and frequency modulation of the carrier at a speed of two scan lines per second. In one pass of the satellite above the receiving station, an image of the Earth's surface is formed with the size of 5800x3000 km.

The block diagram of the onboard and ground parts of the NOAA APT system is shown (fig.1). The block diagram of the MATLAB-model of the APT as a whole follows the structure of the NOAA APT system. As a source of transmitted data, the model uses any Earth's surface color image of high quality and the required size (fig.2).
The image is decomposed into color layers, interpolated to obtain the required size and spatial resolution and read line by line to form an analog image signal. To each half of line are added the synchronizing signals of half-frames A and B, as well as calibration (telemetry) signals. The resulting signal carries out the amplitude modulation of subcarrier 2400 Hz, and then the frequency modulation of the carrier. The signal is then transmitted through the channel with normal white noise.

In the receiving part of the MATLAB-model, frequency demodulation of the received signal is performed (using various frequency detection algorithms), amplitude demodulation (also by various algorithms to assess their quality). Next, the detection and extraction of synchronization signals (also by various methods to assess their noise immunity) and image decoding are performed. The final procedure is to calibrate the received image using telemetry signals to ensure the correct
transmission of the brightness of the image in each half-frame. Fig. 3 shows the image fragment of the Earth’s surface in visible and infrared ranges taken in the APT format.

Fig. 3. Received NOAA APT Earth’s surface image (SNR=15)

The developed APT MATLAB-model allows investigating the influence on the quality of image transmission: an amplitude and frequency modulation parameters; an amplitude and frequency demodulation algorithms; methods and parameters of detection and extraction of synchronization signals, as well as the noise level in a communication channel.

**HRTP system and MATLAB model structure.** As in the APT system, when transmitting images in the HRPT format, data are obtained from the AVHRR radiometer, but in digital form and with a significantly better spatial resolution (1.1x1.1 km). The structure of the HRPT transmission system and the corresponding MATLAB-model is shown (fig.4).

![HRPT system structure](image)
The AVHRR information for HRPT transmission has a fairly simple structure, and in general consists of frames. Each frame contains: sync bytes; satellite data; exact time label for each line of the image; calibration values; the information about the brightness of the image pixels. After the formation of the main frame, the system generates a real signal of the physical layer for its transmission over the communication channel. This process includes: Manchester coding of bit sequences; QPSK modulation. In the MATLAB-model, the data is formed from the image of the Earth's surface, similar to (fig.2). As well as in APT model, the image is decomposed into set of color layers, resampled to obtain the required for HRPT format size and spatial resolution and read line by line. Further, in accordance with the data structure, the HRPT frame of a fixed size is formed, the sequence of frames is subjected to Manchester coding, and the QPSK modulation. The modulated signal is then transmitted through the channel with noises.

Fig. 5 shows fragments of the received image at different levels of noise in the communication channel. Here, as in the case of receiving in the APT format, at a low SNR, a synchronization disturbance is observed (the loss of image lines - fig. 5 b).

LRPT system and MATLAB model structure. The most interesting and useful for studying modern methods of transmitting and receiving data is a new system for transmitting images in the LRPT format. Therefore, this part of the program model, which was partially published by us earlier in, was developed in the most detailed way.

The structure of the system for transmitting and receiving satellite images in the LRPT format is based on recommendations LRPT/AHRPT Global Specification of the Direct Broadcast Services [5], that describe this multi-level system from a telecommunications point of view and in terms of it. For the LRPT system, this detailed multi-level model, describing its functions and interaction of levels, and the basis of which its program MATLAB-model was built, is called the “CCSDS Service
Application Processing Layer (on fig. 6 – image forming and image compression). The image is subjected to compression using a modified JPEG-algorithm, providing a variable compression ratio in accordance with the nature of the compressed image [6,7]. The formation of the original picture element (MCU), that is an 8x8 matrix, applying a discrete cosine transform (DCT) to it, adaptive quantization of DCT coefficients, zigzag scanning of an 8x8 matrix, RLE and Huffman encoding.

Packetization Layer (on fig. 6 – data packetization). The transmitted data are formatted into basic units, called Source Packets. Each packet includes data from one image scan consisting of eight full lines of MSU-MR image, thus each scan consists of 196 MCUs. In the process of packetization, each scan is divided into 14 segments by 14 MCUs. The size of each partial packet of a compressed image is individual and depends on the degree of its compression.

Data Link Layer (on fig. 6 – Reed-Solomon encoding, scrambling and marker adding). This model level includes the following procedures: the formation of data packets of a given size (from partial packets of different sizes) and their block coding.
using (255,233) Reed-Solomon code. The resulting coding 8160-bit packets are subjected to scrambling, i.e., multiplied by a pseudorandom sequence, that ensures the pseudo-random nature of the entire transmitted data sequence. To determine the boundaries of each packet, a 32-bit synchronization marker is added to its beginning. The obtained communication packets are transmitted with a fixed speed of 72 kbit/s.

**LRPT Physical Layer (on fig. 6 - convolutional encoding and QPSK-modulation).** At this level, the CCSDS model, and, accordingly, the MATLAB model, performs the operations necessary for data transmission over a communication channel with interference – bit stream convolutional encoding with interleaving, inserting symbol synchronization markers and QPSK modulation.

On the receiving side of the communication channel, the data are processed in the reverse order. The received QPSK signal is demodulated using the recovered carrier, the detection of symbol synchronization and decoding using the Viterbi algorithm are performed. Next, data are derandomized, the frame synchronization impulses are detected to determine the boundaries of Reed-Solomon code blocks. The data blocks are decoded with the correction of errors, and are packaged for JPEG decoding. The implementation of the model in MATLAB is greatly simplified by using standard functions that perform the complicated procedures of Reed-Solomon and Hoffmann encoding/decoding, convolutional error correction encoding and Viterbi decoding.

The LRPT MATLAB model allows to study and investigate the effects that occur when compression the transmitted image using JPEG. In particular, in order to support a constant data transfer rate (bit/s), it is required to automatically change the parameters of the DCT quantization matrix (quality factor Q). Figures (fig. 7) and (fig. 8) shows the effect of Q change. When used the hard quantization (Q=21), the fragmentizing the image on the "squares" is observed. At the optimal level of quantization parameter (Q = 71), the quality of the restored image is significantly higher (fig. 8). The program allows you to obtain estimates of the image compression and the quality of the received image from the c quality factor Q. Using the model, you can study the effect of noise in the communication channel on the number of errors that occur during transmission, as well as the effect of the RS block correcting coding and on the resulting quality of the received image (fig. 9).

![Fig. 7. Restored image with the quality factor Q=21](image-url)
Conclusion. The reception and processing of weather satellite images in the VHF band became very popular nowadays, because it assumes using low-cost equipment (simple antennas, RTL-SDR-receivers, PC's) and open software. However, the use of free available software for receiving and decoding satellite images does not allow to fully understand the content of main transformations performed during the transmission and reception of images, data transfer formats and protocols, algorithms for processing received signals. Therefore, it is very useful to use software models for simulating the processes of transmitting and receiving images of the Earth and the atmosphere. In this paper, as in our previous work [8], we present the MATLAB-models for studying the space images transmission/receiving in different formats – APT, HRPT, LRPT. Working with the simulation model allows to study the content of each stage of transforming data in the process of its transmission and reception and to investigate their impact on the quality of restored image, the occurrence and correction of errors during transmission and reception etc.

The goal of the model development is to raise the interest of students on signal and image processing and to offer a laboratory platform for students who can experiment with different digital signal and image processing algorithms (the study of image compression using JPEG, correction encoding with a Reed-Solomon code, interleaving, convolutional coding/decoding, synchronization, Manchester coding/decoding, etc.). The developed model allows to trace the evolution of
satellite image transmission methods - from analog transmission in the APT format to the LRPT format, which includes all the attributes of a modern digital data transmission system - efficient compression, error-correction coding/decoding, digital modulation and reception. Using the developed MATLAB-model helps to make more accessible and effective the studying of methods and algorithms for analog and digital transmission and reception of satellite images, without ore in addition to applying equipment for direct reception of signals from satellites.

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REENGINEERING BASED ON 3D-SCANNING IN THE PROCESS OF PROPELLER ANALYTICAL STANDARD CONSTRUCTING FOR AN ULTRA-LIGHT TWIN-SEAT AIRCRAFT

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