ONLINE REAL-TIME VISUALIZATION OF RADIOSOLARIZ SPECTRUM AND SPECTROGRAM

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Keywords: *radioSolariz, solar radio-telescope, solar radio emissions data visualization.*

Abstract: *The radioSolariz project was conceived in 2019 by a team at Space Research and Technology Institute and Institute of Astronomy and National Astronomical Observatory – both institutions are members of Bulgarian Academy of Sciences.*

Thenceforth our team developed a novel solar radio-telescope having distributed structure and implementing a specialized wide-band antennas for circular polarization. The telescope was named radioSolariz (www.radioSolariz.space)

The current article discloses the visualization techniques used to present the radio emissions data to the end user, both in real-time and for off-line examination of stored information on the data server. The benefits of the utilized approach are discussed and the technology behind the realization is identified with the stress on performance, compatibility and platform independence.

ОНЛАЙН ВИЗУАЛИЗАЦИЯ В РЕАЛНО ВРЕМЕ НА СПЕКТЪРА И СПЕКТРОГРАМАТА НА RADIOSOLARIZ

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Ключови думи: *radioSolariz, слънчев радио-телескоп, визуализация на данни от слънчеви радио излъчвания.*

Резюме: *Проектът radioSolariz беше започнат през лятото на 2019 година от екип към Институт за космически изследвания и технологии и Институт по астрономия с Национална астрономическа обсерватория – и двете институции са част от Българска академия на науките.*

През последните дванадесет месеца нашият екип разработи иновативен слънчев радио-телескоп базиран на разпределена структура и използващ специализирани широколентови антени за кръгова поляризация. Телескопът беше наречен radioSolariz (www.radioSolariz.space)

Настоящата статия разкрива техниките за визуализация използвани при представяне на крайния потребител данните от радио емисиите. Данните се визуализират, както при наблюдението им в реално време така и при преглеждане на съществуващи записи съхранени на сървъра за данни. Дискутирани са предимствата на използвания подход, а също така технологията зад реализацията на визуализацията е коментирана в посока на производителност, съвместимост и платформена независимост.

Introduction

The radioSolariz solar radio-telescope is a project started in 2019 by a team currently represented by two Bulgarian Academy of Sciences institutes: Space Research and Technology Institute and Institute of Astronomy and National Astronomical Observatory.

The instrument is a novel distributed radio-telescope aiming at observations of radio emissions from the Sun in the upper high-frequency (HF) and the very high frequency (VHF) bands (frequencies between 25 MHz and 200 MHz).

After we carried out an in-depth research and observations of the current state of the art among distributed solar radio-telescopes in the world [1, 2], either existing or in design stage, we concluded that there are certain advantages of developing a novel solar radio-telescope having specialized antenna for circular polarizations in both directions – right-hand side circular polarization (RHCP) and left-hand side circular polarization (LHCP) (see Fig. 1). Further, a distributed structure of the instrument was conceived. Our investigation showed no competitive project was in existence and we decided to design and further develop the idea to prototype stage.

Members of our team already had extensive experience in radio-communications innovations for scientific purposes [3-5] and we felt capable of conceiving the project.

The design required six months. The development process of one antenna for right-hand side circular polarization, the digital receiver hardware, and the software took another six months to complete eventually leading to a working prototype in September 2020. The latter is used currently for testing purposes and further development.

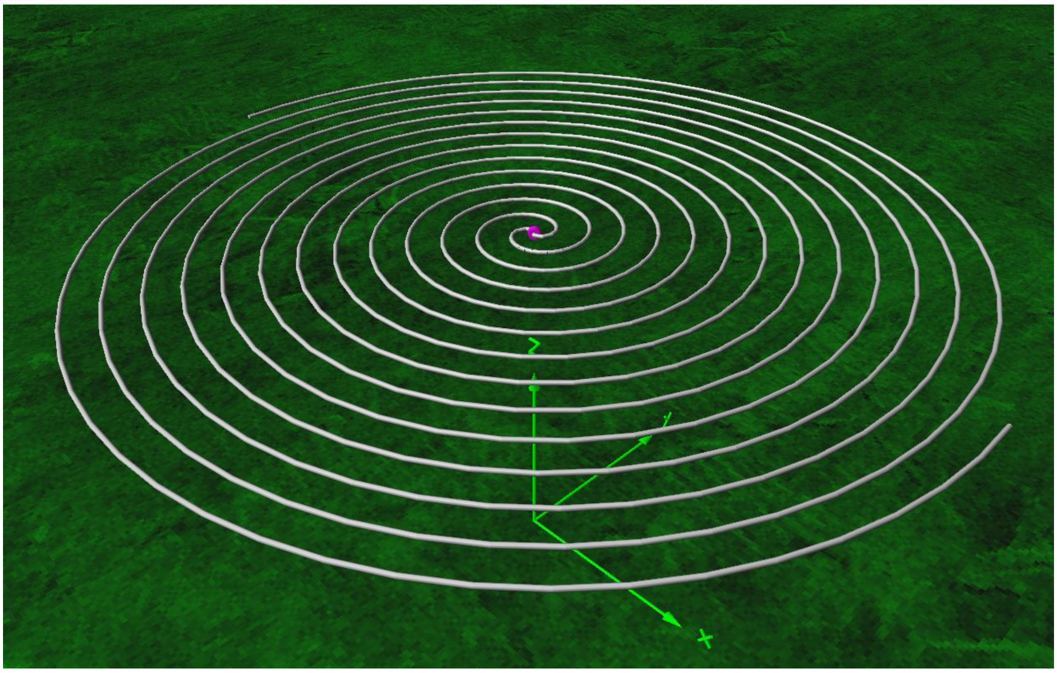

Fig. 1. Specialized RHCP circularly polarized antenna design implemented in the first radioSolariz prototype

The current article scrutinizes the software part of the project responsible for visual representation of the radio emissions data to the end user, both real-time and for examining already stored data on the data server. The focus in this report is on the real-time data presentation.

The telescope

The radioSolariz telescope is based on two important ideas that were successfully implemented:

1. A distributed radio-telescope paradigm.
2. Specialized wideband circularly polarized antenna adapted to the purpose of the aimed observations.

The distributed paradigm envisions the system having separate stations, connected to the main server using Internet. This idea has two benefits. Firstly, it gives the opportunity to collect data received at locations around the Earth, thus observing the solar radio emission full-time 24 hours a day. Secondly, the distributed approach, when comparing data from stations simultaneously observing the Sun, helps reduce or completely remove man-made and other types of interference. The unwanted noise is impacting each station, but having stations being physically apart from each other brakes the correlation between each station received noise sources. The low entropy of most man-made interferences also benefits their successful elimination.

The other major feature of the novel instrument is the antenna. It was needed to work on circular polarization for the purpose of data analysis and also it was required to have the following features:

- A wideband antenna, as required by the nature of the observations.
- Should have close to flat gain along the working band.
- It must be robust in construction and require insignificant maintenance.
- Should have small gain and consequent wide beam thus not requiring mechanical steering.
- Must not have side lobes throughout the receiving band.
- Needs to be isolated from receiving signals from the back thus being effectively shielded from nearby structures and hardware

We discovered that the spiral antenna (Fig. 1) is the best solution satisfying the above requirements. The spiral antenna is extremely wideband, has planar structure and thus is resistant to weather and animal influence, it offers almost flat gain in the working frequency band. The spiral antenna has wide beam and no side lobes throughout the receiving band which extends from starting frequency f to three times f which feature is beyond our requirements. This antenna is also implemented using a back plane effectively shielding it from backward signals. The spiral antenna has one more benefit – it is a balanced antenna and as such is highly unsusceptible to local electrostatic interference – it is suitable for installation in areas with near field electrostatic interference signals.

While the distributed paradigm and antenna design were the major advantage of the instrument, the development process was also aimed at designing the hardware using available off-the-shelf and inexpensive, but high quality modern receiver electronics. This way we wanted to obtain affordable manufacturing cost of the radioSolariz station and make the project feasible. Parts from a number of electronics vendors were tested and a few prototype receiver units were built during the past 6 months. The current prototype relies on integrated circuits from Analog Devices (www.analog.com).

The software that was developed is considerably complex, because the receiver is digital. This means that the data representing the received radio signal is digitized and then transferred to a computer. All control electronics and auxiliary modules, such as the GPS receiver, thermometers, etc., also communicate with the computer controlling the station through digital communication link. The telescope resorts to digital signal processing and the only analogue module that required analogue design, except the tuner is the antenna filter.

Graphical visualization software sub-system

Getting to the core of this study, the graphical visualization solution, a few major points of the design requirements shall be enumerated:

- The visualization interface must be accessed using the Internet.
- The visualization interface has to be platform independent. Must be runnable on any operating system and any device capable of browsing the Internet.
- The interface should not require installing any software applications or apps on the user's machine. Any such installations would cause the user experience to become cumbersome. Also, stressful events during software installation are to be avoided.
- The interface must be interactive, easy to understand and use, and be animated presenting the real-time data in a live moving (scrolling) spectrogram and dynamic spectrum.
- Appropriate colours should be chosen so that proper visual perception of signal magnitude be easily appreciated by the viewer but at the same time viewer's experience should stay natural and non-problematic for the eyes of the observer.
- The software must execute completely or almost completely on the user's device in order not to overload the radioSolariz web server.

Our initial graphics visualization software development started in the autumn of 2019 when we acquired data access to the LOFAR solar observations (see Fig. 2). We then advised the experimental development of an interactive online and web based (browser based) interface for accessing off-line LOFAR data using a static spectrogram that was user scrollable horizontally (see http://ialms.net/LOFAR/). This early experiment proved successful and a number of interactive options were implemented such as colour gradient selection, contrast and brightness adjustment, etc.

The visitor is allowed to load different sets of data and observe the data in a two dimensional spectrogram representing the recorded electromagnetic field intensity with usable data in the 25 MHz to 78 MHz frequency band. The time axis is showing timestamps in the UTC time format.

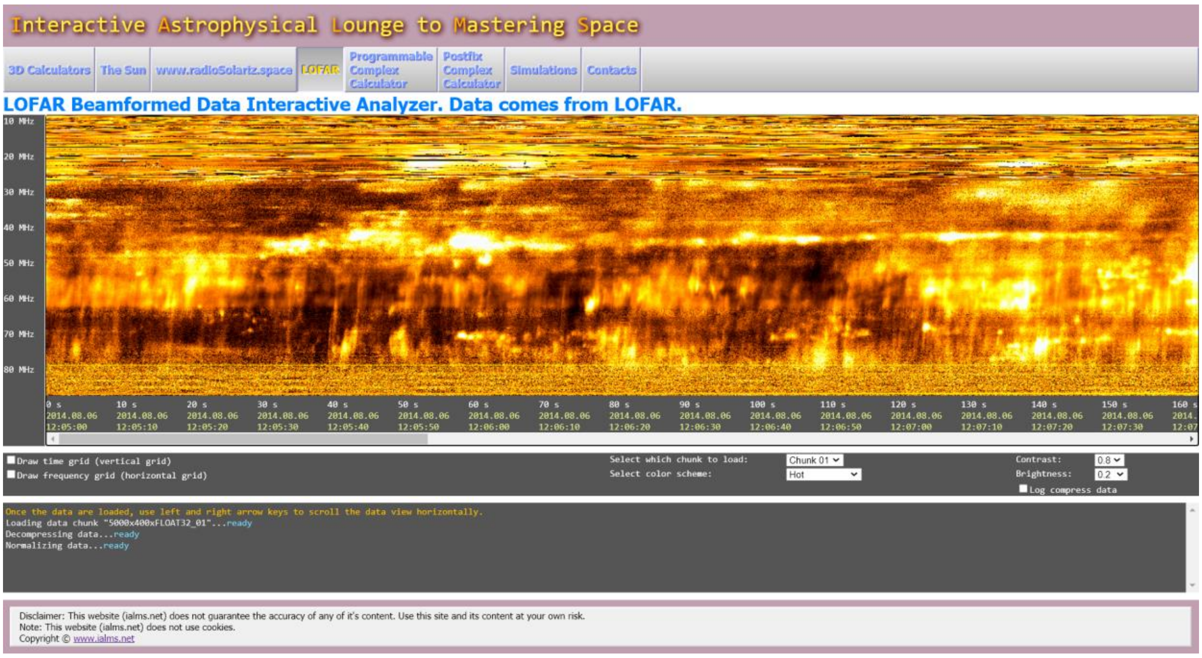

Fig. 2. Web-based online interactive visualization of LOFAR data developed by the team during the autumn of 2019 as part of radioSolariz preliminary research and design process (data provided by LOFAR). Internet address: www.ialms.net/LOFAR/

The LOFAR experiment aimed at proving the following initial requirements were realizable:

Table 1. Initial graphical visualisation requirements test and results

Requirement	**Fulfilment**
The visualization interface must be accessed using the Internet.	Realised.
The visualization interface has to be platform independent. Must be runnable on any operating system and any device capable of browsing the Internet	Executable on any hardware and operating system, supporting a web browser.
The interface should not require installing any software applications or apps on the user's machine.	Having the interface execute inside a web browser no additional software installation is required.
The interface must be interactive, easy to understand and use, and be animated presenting the real-time data in a live moving (scrolling) spectrogram and dynamic spectrum.	The modern web browsers offer rich graphical capabilities and user interaction handling. The chosen approach is adequate.
Appropriate colours should be chosen so that proper visual perception of signal magnitude be easily appreciated by the viewer but at the same time viewer's experience should stay natural and non-stressful for the eyes and visual perception.	Colour graphics is fully supported by modern web browsers.
The software must execute completely or almost completely on the user's device in order not to overload the radioSolariz web server.	The only action taking place at the radioSolariz web server is providing the requested data. All processing, user interaction and visualisation are performed on the user's device inside the web browser.

Another experiment was to compress the data that was to be communicated between the web server and the user interface. This task was successfully accomplished using the DEFLATE data compression algorithm supported by modern web browsers.

All these successful steps in our initial graphical user interface experiment led us to implement the acquired techniques into radioSolariz data visual representation and further to realize a real-time visualisation in an animated form, in contrast to LOFAR data that was off-line.

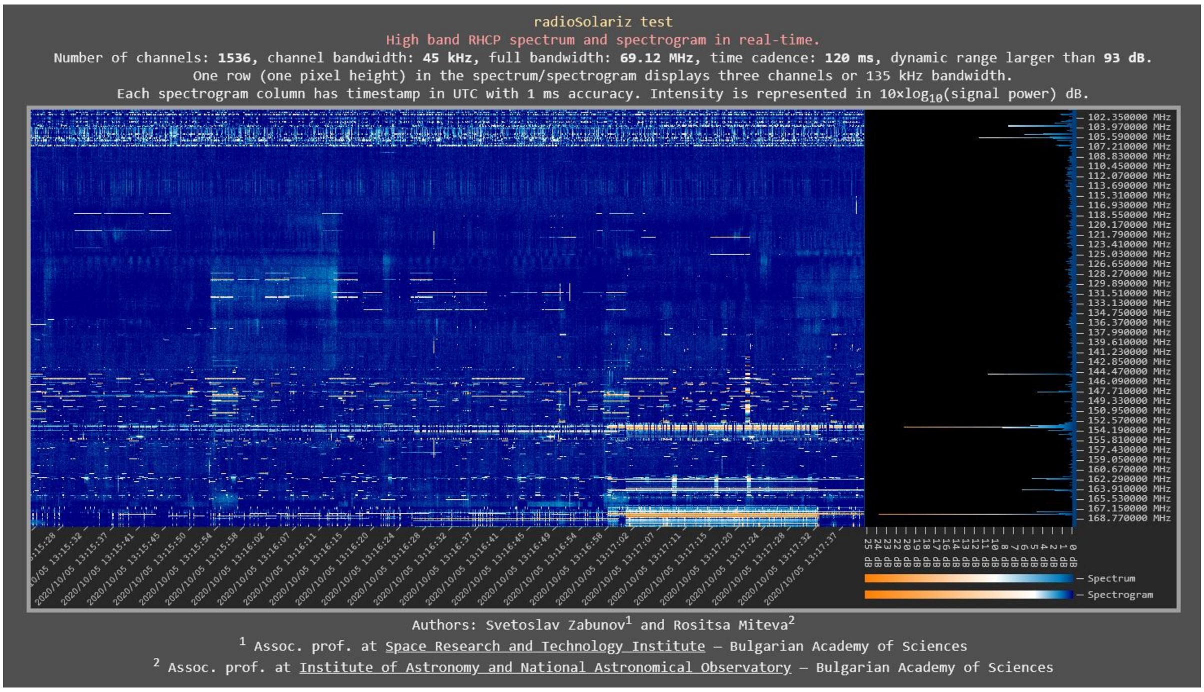

Fig. 3. RadioSolariz real-time spectrum and spectrogram graphical visualization test

Our approach relied on the already established in the scientific community layout of an astrophysical radio-spectrogram having the time dimension placed on the horizontal axis and the frequency dimension – on the vertical axis. Furthermore, the time should increase to the right thus showing the newest data to the right-most end of the spectrogram. If the data were real-time then new data would appear to the right most place of the spectrogram and old data move (scroll) to the left. The frequency of the visualized radio-waves intensity is increasing from top to bottom of the spectrogram. Such an approach visualizes all solar events starting from the inner solar atmosphere and expanding outwards to have their frequencies changing for high to low and thus simulates the events from the bottom to the top of the spectrogram pretending the viewer is “sitting” on the solar surface.

Our instrument exhibited high enough time resolution (cadence of 120 ms) as per its current prototype. This time cadence establishes near fluent movement (scrolling) of the spectrogram from right to left as time passes while receiving real-time data in the web browser. The time lag due to web-server to data server communication is in the order of few tens of seconds but below 40 seconds assuring very consistent real-time data observations by viewers around the world.

The time of the horizontal axis is in UTC time format, while the vertical axis is marked with frequency in MHz. The spectrum is dynamic and is refreshed on each new data row (every 120 ms). It is most convenient to attach the spectrum to the right side of the spectrogram thus use the same vertical frequency axis. The spectrum consists of bars, each bar corresponding to three channels of the instrument. The current radioSolariz channel bandwidth is 45 kHz, but the spectrum and spectrogram use one graphical line to represent three channels or 135 kHz, due to lack of screen real estate for show all the channels simultaneously. Having 1536 total channels the display of the spectrum and spectrogram requires 512 pixel rows. The width of the spectrogram is arbitrary and is chosen to be 1024 columns, but may be changed effortlessly per user basis. The spectrum width is 256 columns and is also arbitrary and does not depend on the nature of the visualized data.

The colour scheme is dark, not burdening the eye, further allowing higher contrast and better colour recognition by the viewer. The colour palette of the intensity gradient is depicted in two legends in the lower right corner of the visual interface – one colour palette for the spectrum and another colour palette for the spectrogram respectively. Low intensity events are displayed using blue to cyan colours while medium intensity occupies the white colour. High intensity emissions are show using orange colour.

Conclusions

The need for solar radio-emissions data access constantly presented by the solar physics and space weather scientific communities motivates our team to continue the development of the radioSolariz project. We plan on further improving our software and the hardware. We also envision developing and deploying more stations on separate locations initially in Bulgaria preceding a future worldwide coverage.

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