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Development of Very Low Frequency Data Acquisition System using Raspberry Pi

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Abstract—**Space studying has become one of the most informative and popular areas of the new era. Monitoring the space and studying its phenomena was started a long way back. To make the study cheaper and more portable, the Stanford SOLAR Center first presented with a Space Weather Monitoring program called the sudden ionospheric monitors (SID). This monitoring system was used to monitor the Earth's ionosphere changes, which affected the very low frequency (VLF) radio propagations. This low cost but sensitive detection system is used all around the globe via various modifications. This paper presents the monitoring system's design and implementation using Raspberry Pi for a smaller and compact base with less power usage and higher sensitivity. Raspberry Pi will be used as the base platform connected to a loop antenna and preamplifier. The acquisition system was written in a Python platform and ran through a Linux system. As a result, an efficient and more portable VLF data acquisition system to detect sudden ionospheric disturbance using Raspberry Pi has been developed. The developed version was able to detect a monitor frequency transmitted from NWC-Australia (19.8kHz), Australia, and VTX3-India (18.2 kHz).**

Keywords—VLF, ionosphere, Python, Sudden Ionospheric Monitor, Raspberry Pi.

I. INTRODUCTION

Various solar activities, namely coronal mass ejection, solar flare, solar wind, and other hazardous events in space, caught the researchers' attention on how to solve such occurrences, which can cause a threat to both astronauts and human beings living on the surface. Sudden Ionospheric Disturbance (SID) occurs when the electron density varies in the ionospheric layers. The electron density in the ionospheric layers varies mainly with the X-ray radiation created during the solar flares. This occurrence influences the propagation of VLF waves [1].

Attempts like the Stanford Solar Center with an idea of creating and distributing an inexpensive (SID) monitoring system to detect solar flares and other disturbance in the Earth's ionosphere have seen some progress. Currently, most people worldwide are using the low cost but sensitive space weather monitor, named Super SID, developed by the Stanford Solar Center for SID detection [1]. In this era of modern technologies and advanced equipment, past research's limitations can be further improved for more effectiveness and portability. For more than a decade, solar weather research through VLF has shown a massive interest by researchers. Researchers believe that space weather is a progressively necessary area for analysis due to the recent study in the sun's effects in the environment of the Earth and other communication systems [2, 3].

Some typical reasons threaten the idea of a portable VLF data acquisition. For instance, the VLF radio wave propagation is usually treated as a waveguide problem, with the ionosphere and the Earth's surface acting as the boundary surfaces [4, 5]. Other issues like diurnal, seasonal, and transient variation within the structure of the lower part of the sky will produce giant amplitude within the radio frequency and electromagnetic field at a given location, which eventually affects the communication system performance [4]. Much research suggests that the distribution of radiofrequency propagation parameters has a noticeable distinction in several regions of real-time, space, and frequency. Therefore, to achieve perfect detection is not always achievable as it changes dynamically.

Data acquired using the very low frequency can enhance the ability to research more about the space and other atmospheric issues. Scientists on the ground can use this enhancement to detect solar flares by monitoring a distant VLF transmitter's signal strength. SIDs are recorded and indicated when solar flares had taken place [6-8]. Space weather is a vast area of study, especially the ionosphere layer, where VLF waves reflectance occurs.

Measuring the VLF radio propagation using low-cost equipment is an ultimate challenge. For many years the researchers are using bulky and sensitive space monitoring tools with less portability and effectiveness. Many areas of this research are yet to be desired in terms of accuracy, processing time, portability, and cost-effectiveness. Therefore, this paper aims to make a more portable and effective VLF detection system using Raspberry Pi equipped with a loop antenna, high-quality analog to digital converter (ADC), and LCD output. First, the loop antenna to capture VLF and its preamplifier were designed. Next, a high-quality USB sound card was used as an ADC connected to the Raspberry Pi. The acquired data was then processed and logged in Raspberry Pi, and the detection result was presented on LCD or further analyzed using a computer. Frequency spectrum was obtained and utilized to identify the detected VLF from nearby transmitters.

II. DATA ACQUISITION SYSTEM DEVELOPMENT

Traditional VLF data acquisition flow is illustrated in Fig. 1. As for this frequency processing system, the very low-frequency extraction marks the start of the VLF data acquisition. This process includes the antenna selection, SID monitoring, and the development of SID analysis, which is known as Super SID. Data logging and processing and analyzing the data were conducted on the single-board computer Raspberry Pi.

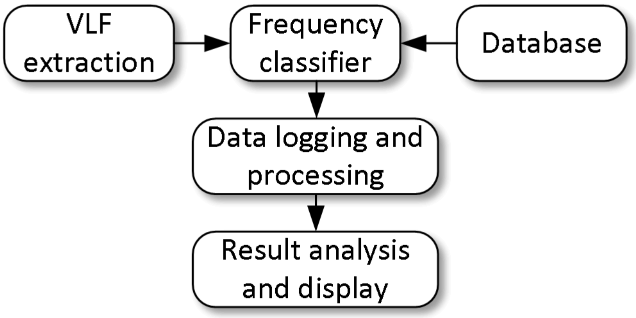

Fig. 1. The general flow of VLF data acquisition

A. VLF Extraction

The radio signals from all over the Earth reach the ionosphere, which reflects the VLF radio signals. The reflected radio signal changes according to the intensity of the ionosphere ionization. The ionosphere is divided into several regions as D-layer, E-layer, and F-layer with their respective altitude levels. The electron density or the X-radiation occurs likewise as the height changes. The ionization gives rise to the change in all propagating parameters. Therefore, the propagated signals' wavelength change paves the way to research in such a field, between 3-30 kHz and an estimated altitude of 70 to 90 km. Hence to locate this sudden change in the space weather, a new monitoring system was introduced named the SID monitoring.

For capturing a frequency generated from a transmitter, an antenna is a vital component. The receiver side should be perfectly able to capture the desired frequencies without any flaws. The loop antenna is a radio frequency-based antenna that consists of a loop, coil, or other electrical components usually fed by a balanced source or feeding a balanced load to get full accuracy in capturing the frequency of interest. Loop antennas have a two-lobe radiation pattern that is sensitive towards radio waves in two broad lobes in the opposite directions, which has 180^{o} apart. Thus, they can easily distinguish the directional pattern to locate the place of the transmitter. This criterion will be helpful to locate the solar disturbance identification.

B. Frequency Classifier

After the SID and ionization have been detected, the information is passed to the set of classifiers. There are many classifier models for this purpose, such as the finite-difference frequency (FDFD) model, the finite-difference time-domain (FDTD) model, and the minimum shift keying (MSK) model. The classification process evaluates more about finding out the relationship between the phase and the ionospheric state of captured VLF signals. The FDFD model describes the frequency domain finite difference, but typically, it resolves the scattering problems. The FDTD model is time-domain-based, and the model can provide solutions that can cover a wide frequency range with a single simulation by treating the nonlinear material properties naturally. The MSK model is typically a continuous phase-frequency shift-keying process.

C. Data Logging and Processing

The data logging mechanism mainly emphasizes on the processing of data captured by the preamplifier. Then using sophisticated software tools and processing methodologies, the actual results are obtained where the solar flayer events are captured. There are some methodologies which are used generally for such purpose. Most effective results were found in the Super SID monitoring software. The data processing operation consisted of data transformation, analog to digital conversion, Sampling, local time conversion, peak detection process, and storage. As a data logger, sound cards and Raspberry Pi were used in this process. The sampling rate of the project was set to 48 kHz. Therefore, the maximum frequency acquired is 24 kHz.

III. DESIGN AND IMPLEMENTATION

The project was divided into two main parts, including hardware and software development. In the hardware part, a loop antenna, a preamplifier, a USB sound card, and an LCD were developed and utilized. On the software side, the SuperSID software [9] written in Python has been installed in Raspberry Pi. Moreover, it has been adopted and modified for coping with the conditions and specific hardware used.

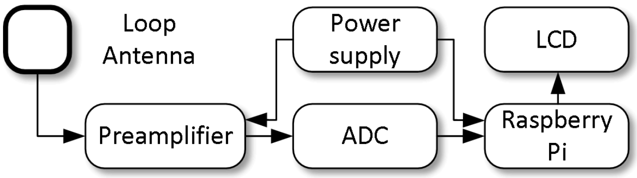

Fig. 2. Block diagram of the proposed data acquisition system

Fig. 2 shows the block diagram of the proposed system. First, the loop antenna will receive very low frequency at the receiver side. Next, the preamplifier will amplify the received signal. Moreover, the ADC will convert the analog signal into digital, processed, and saved in the SD card. Finally, the processed data will be shown on the LCD screen.

A. Loop Antenna Design

Fig. 3. Loop antenna designed for VLF data acquisition

One of this project's main criteria is to capture the VLF signals transmitted from several stations using a loop antenna. PVC pipes were used for the antenna design's mainframe for effective results and cost-efficient. The frame is covered by 22 or less AWG #26 wiring with a size of half to one meter square space. Furthermore, RG58 coaxial cable was used for connecting the preamplifier with the antenna using a terminal block. The complete loop antenna design is shown in Fig. 3.

B. Preamplifier Design

In this research, the preamplifier will be guiding the frequency captured by the loop antenna to get stored in the SD card, which directly connects with the Raspberry Pi. The preamplifier design is inspired by the Stanford Solar Center's first attempt to acquire data in this field. The design consists of a single-sided stripboard (10cm×12.5cm). Surface-mounted devices (SMD) components are chosen to solder the PCB as there is a small form factor for the board. A function generator providing frequencies from 2-200kHz was used to maintaining an amplitude of 20 mV. A 3.5mm TRS microphone jack was used to connect the preamplifier to the sound card connected to Raspberry Pi. A 9V adapter powered this circuit. The schematic diagram and the developed circuit is shown in Fig. 4.

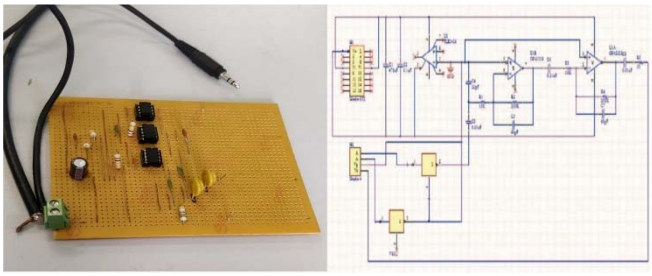

Fig. 4. Schematic diagram and implementation of the preamplifier circuit

C. Raspberry Pi

The single-board computer called Raspberry Pi is the base of this research where all the software operation is done. Raspbian Wheezy OS will be operating all the analytical software to detect the frequency peaks. A Class 10 SD card with a 32 GB space and speed of 10 MB/s on fragmented sequential writing was used [10, 11].

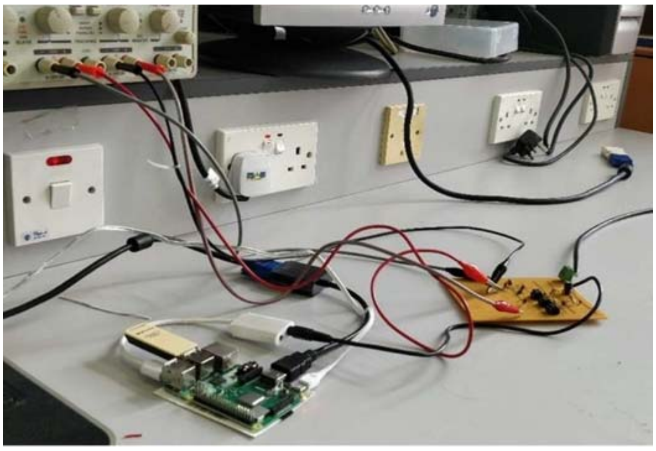

Fig. 5. VLF data acquisition using Raspberry Pi

A high-quality sound card was chosen for the project with a sampling rate of 44100 kHz. An LCD monitor was used to display the necessary information on the screen via the HDMI connection. The Raspberry Pi was connected to the Wi-Fi, and a 5V adapter powered the single board computer. The full experimental setup is shown in Fig. 5.

D. Software Design

The Super SID monitoring software is the main software to analyze the solar flare events. This open-source software can be downloaded from the GitHub website [9]. As the software is written based on Python language, some modules must be installed to the Raspberry Pi to run the SID software properly [11, 12]. The modules are AlsaAudio, wxPython (wxgtk2.8), NumPy, Matplotlib. The Matplotlib module is used for plotting the SID data, while the AlsaAudio module uses an Advanced Linux Sound Architecture for capturing and playing back the saved audio signal. On the other hand, the NumPy module is a general-purpose array processing package to control a huge multidimensional set of arrays. For the GUI, we have used the wxPython module toolkit to create a highly functional graphical interface for this project.

Before executing the Super SID software program, the configuration files (supersid.cfg) needs to be well configured to show VLF indicators from the desired station. Command "viewer=wx" is written to allow the graphical consumer interface (GUI) mode. The GUI mode calls for greater resources from Raspberry PI compared to the text mode that is well enabled via the command "viewer = textual content". The command line "audio_sampling_rate" inside the (sampler.py) and (supersid.cfg) files ought to be changed to 48000 Hz relying on the sampling frequencies supported by the sound card used in the project. The acquired records can be saved within the pre-configured "data_path" listing. The USB sound card was summed in the configuration file using "Card =Pro" input. Finally, two transmitters, including NWC (Australia) and VTX3 (India), were chosen for the primary transmitter locations. Later, the received signal is converted to local time and then through software analysis, given an absolute peak frequency to detect the atmospheric disturbance.

IV. EXPERIMENTAL RESULTS AND ANALYSIS

Based on the software's parameters at 18200 Hz for the VTX3 (India) and 19800 Hz for the NWC (Australia), transmitters provided a vertical red line to indicate a cutoff frequency level. The specific data acquisition was run for 6 hours from 2:00 to 5:00 for the first day and another 2 hours the next day.

Fig. 6 shows the signal strength on its y-axis, where the sudden peaks are shown. In this same way, hourly simulations were done and then merged in the compilation frame with the other files to understand the signal strength from transmitted stations as the graph's peaks indicate improved results.

The compilation of those six hours of data automatically generated ".csv" file. Now by using the plot.py software, the acquisition data were presented Fig. 7. The 24-hour duration in the compilation figure clearly states that there was no data captured rather than those specific hours, so the value remains 0. On the other hand, the two separate stations produce different peak values according to their signal strength. Nevertheless, Fig. 8 indicates a better performance of the merged compiled files acquired from the data acquisition from the prototype.

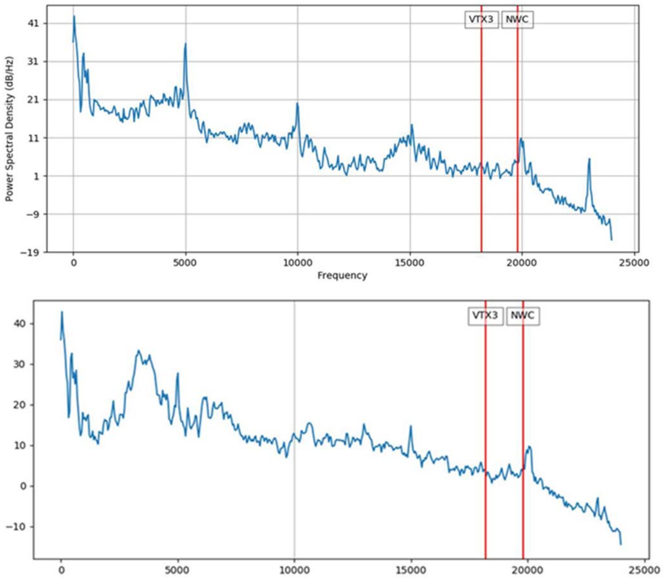

Fig. 6. Captured data with an interval of 5 seconds

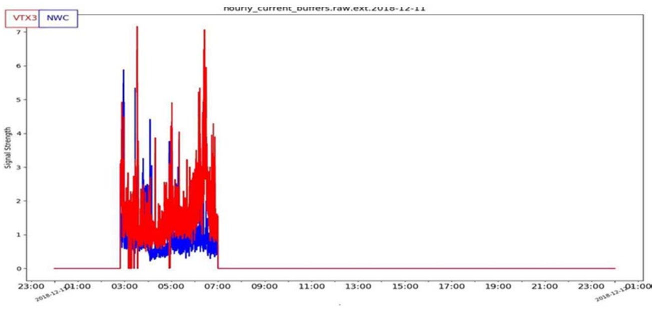

Fig. 7. Hourly captured data compiled in a UTC frame

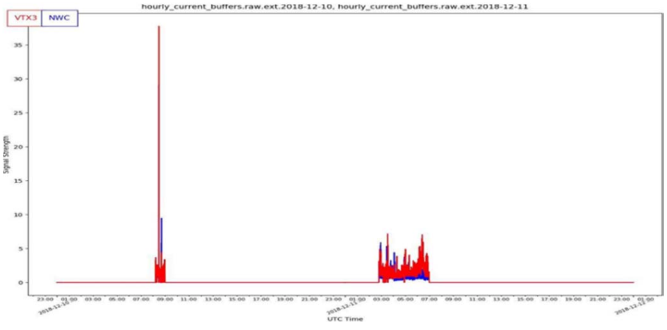

Fig. 8. Combined .csv file graph for two separate days

At the early stage of the simulation process, the data acquired from the prototype device showed a minimum range of signal strength, which was in the negative region. However, as the enhancement of the procedures carried on, the results were more improved and optimized. Fig. 8 clearly shows the system's very low signal strength as in the early data acquisition sessions. The figure also indicates that between 8:00 to 10:00, the VTX3 station transmitted a higher signal strength up to 40dB. Nevertheless, the peaks at the lower strength signal levels were more visible in the simulation process as the data acquisition surroundings were emitting low-frequency noises, which were reflected in the other portion of the figure. One of the figures for the live acquisition is shown in Fig. 9.

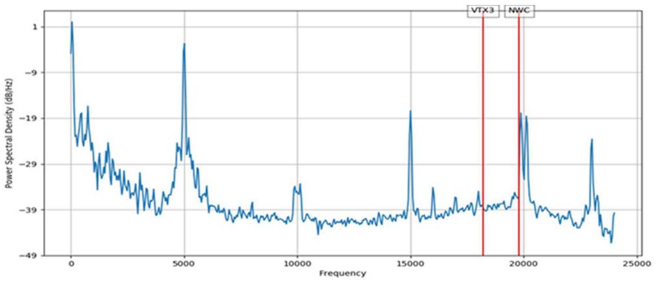

Fig. 9. A single data acquisition procedure captured in the lower strength region

The compiled plot of the lower frequency in Fig. 10 represents the peaks in lower frequency. A sudden ionospheric signal's footprint was captured in a 5-second time frame of the monitoring system, which gave a sudden peak near to 18200 Hz. Moreover, the monitoring system was capturing the 19800 Hz transmitter as well, and the sound card caught the transmitted data in the Raspberry Pi system. Fig. 11 shows a sudden peak of higher frequency strength nearly to the transmitted frequency.

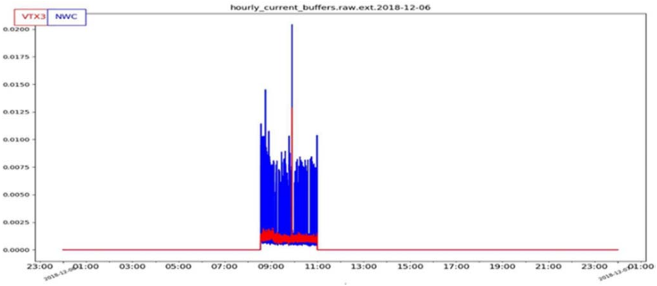

Fig. 10. The lower strength signal rates

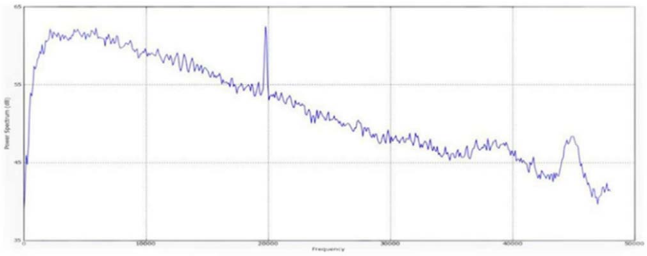

Fig. 11. A sudden peak near to 18kHz in the acquisition time frame

The collected primary data is captured from the space research station. The frequency selected for this operation was 18200 Hz and 19800 Hz. On the other hand, the software and hardware were enhanced for detecting the desired data having a clear spike confirming a solar flare event at a time boundary of two hours in the daytime. Nevertheless, as the full procedure was done under a small-time schedule and closed environment, precise results were not generated. The main reason behind this is the Instrumentation and Measurement Laboratorium at IIUM, where all other electrical devices were operating simultaneously, causing noise and disruption toward the monitoring system.

Furthermore, the loop antenna should be able to capture more accurate signals if it can be set up in an open place much higher than the ground. Besides, more hours of the data acquisition process are needed to gather accuracy and effectiveness. Most of the days in our simulation sessions, there was rain and cloudy weather. Therefore, it will be more efficient if the simulations can be run during a clear sky day so that the sudden ionization can be detected seamlessly.

V. CONCLUSIONS AND FUTURE WORKS

This paper has presented the design and implementation of VLF data acquisition using Raspberry Pi. First, the loop antenna was designed to capture the transmitter frequency efficiently. Then, the preamplifier circuit was then designed and connected to the antenna and the high-quality USB sound card. The digitized signal was then processed, logged, and displayed using Raspberry Pi equipped with related software libraries. Experimental results showed that the proposed system could detect atmospheric disturbance. However, more experiments should be conducted in various weather conditions and more extended experiments to capture various sudden ionospheric disturbances.

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REFERENCES

[1] Y. Soon, K. Gan, and M. Abdullah, "Development of very low frequency (VLF) data acquisition system using Raspberry Pi," in *2015 International Conference on Space Science and Communication (IconSpace)*, 2015: IEEE, pp. 485-488.

[2] M. Abdullah *et al.*, "Development of UKM-SID teaching module for space science education," *Procedia-Social and Behavioral Sciences,* vol. 102, pp. 80-85, 2013.

[3] P. Alexander, C. Alexander, and G. Kirill, "Software of the system for long-term ionospheric monitoring in very low frequency range," in *2015 International Siberian Conference on Control and Communications (SIBCON)*, 2015: IEEE, pp. 1-2.

[4] G. Li and Y. Wang, "Research on evaluation method of VLF communication support capability," in *2017 IEEE International Conference on Signal Processing, Communications and Computing (ICSPCC)*, 2017: IEEE, pp. 1-4.

[5] R. A. Marshall, T. Wallace, and M. Turbe, "Finite-difference modeling of very-low-frequency propagation in the earth-ionosphere waveguide," *IEEE Transactions on Antennas and Propagation,* vol. 65, no. 12, pp. 7185-7197, 2017.

[6] G. Adesunloro and K. Gbadegesin, "Tracking Solar Flares Using the SuperSID Monitor," *American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS),* vol. 15, no. 1, pp. 96-108, 2016.

[7] K. Cresswell-Moorcock, C. Rodger, and M. Clilverd, "Detecting space weather events with subionospheric VLF observations: Producing quiet day curves from AARDDVARK data," in *2014 XXXIth URSI General Assembly and Scientific Symposium (URSI GASS)*, 2014: IEEE, pp. 1-1.

[8] D. Scherrer, M. Cohen, T. Hoeksema, U. Inan, R. Mitchell, and P. Scherrer, "Distributing space weather monitoring instruments and educational materials worldwide for IHY 2007: The AWESOME and SID project," *Advances in Space Research,* vol. 42, no. 11, pp. 1777-1785, 2008.

[9] SuperSID. "Cross-platform Sudden Ionospheric Disturbances (SID) monitor." https://github.com/ericgibert/supersid (accessed September 2020).

[10] S. J. Cox and S. J. Johnston, *Raspberry Pi Technology*. MDPI, 2018.

[11] T. S. Gunawan, M. H. H. Gani, F. D. A. Rahman, and M. Kartiwi, "Development of face recognition on raspberry pi for security enhancement of smart home system," *Indonesian Journal of Electrical Engineering and Informatics (IJEEI),* vol. 5, no. 4, pp. 317-325, 2017.

[12] T. S. Gunawan, Y. M. S. Munir, M. Kartiwi, and H. Mansor, "Design and implementation of portable outdoor air quality measurement systemn using arduino," *International Journal of Electrical and Computer Engineering,* vol. 8, no. 1, p. 280, 2018.