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SEAIONO: A Windows software tool to extract ionogram dataset from South East Asia Low-Latitude Ionospheric Observation Network

S A Bello1,2, M Abdullah2,3, N S A Hamid4 and T Yokoyama5
1Department of Physics, Faculty of Physical Sciences, University of Ilorin, Nigeria
2Space Science Centre (ANGKASA), Institute of Climate Change, Universiti Kebangsaan Malaysia, Malaysia
3Centre of Advanced Electronic and Communication Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia
4School of Applied Physics, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia
5National Institute of Information and Communication Technology, Tokyo, Japan.

*shazana.ukm@gmail.com

Abstract. Analysis of the ionospheric parameters on the ionogram is important for the study of ionospheric physics and related field. This paper introduces an application program tool used for extracting ionospheric profile parameters on the ionogram from the South East Asia Low-latitude Ionospheric Network FMCW ionosonde measurement. The software runs under Windows operating system and has a user-friendly graphical user interface to accept alphanumeric input entry. In addition to the parameters on the ionogram dataset, the SEAIONO reader program is capable of computing the maximum height of the ionospheric F2 layer and the bottomside ionospheric F2 layer (B0).

1. Introduction
The ionosphere is a region of the Earth’s upper atmosphere that affects the propagation of radio signal [1]. For many decades, the ionospheric observations are explored by high frequency radar known as ionosonde. The ionosonde typically works by sending pulses of a radio signal into the ionosphere. The reflected pulses that return to the ground are recorded by measuring the time delay between the transmission and reception of the sent radio pulses. By observing the fluctuating carrier frequency of short pulses of radio energy from 1 to 20 MHz, the time delay at different frequencies is recorded as an ionogram [2]. The ionogram graphs the virtual height of the reflected frequency following the equation:

$$\Delta t = \frac{2}{c} h'$$

where $\Delta t$ is the time delay, $h'$ is the virtual height and $c$ is the speed of light in space of the electromagnetic field.

With the advent of digital techniques, the automation of the scaling of the ionogram and characterization of the uncertainty in determining the confidence scale of the autoscaled results are
now incorporated in the latest digital ionosonde [3] (e.g. digisonde DPS-4 sounder). The challenges of analyzing ionogram from an analogue ionosonde are cumbersome and complex due to the need for manual scaling in order to extract the details of ionospheric parameters. Increasing efforts to facilitate the automatic scaling of ionogram from analogue ionosonde resulted to a new algorithm for an ionogram generation and analysis using periodograms that are filtered and fused, utilizing an “automatic edge-detection-based time-frequency detector”[4]. In another development, Pezzopane, (2004) [2], developed a semiautomatic ionogram scaling Windows software. In recent work of Jiang et al. (2017) [5], ionogram scaler (“ionoScaler”) software was developed that perform both manual and automatic ionogram scaling routines which uses the Simulate Annealing (SA) inversion algorithm that has been applied to Quasi-Parabolic Segments (QPS) model. Similarly, a software application has also been developed by Ivanov et al. (2018) [6] for ionogram image processing which implements an algorithm for determining a signal-to-noise ratio for an oblique ionosonde. Most of these ionogram-scaling approaches are designed for a specific type or brand of ionosonde. Hence, scalability of these software applications is another existing challenge.

The current paper describes an application program named SEAIONO- South East Asia IONOgram reader developed for extracting ionospheric parameters from an ionogram dataset for the ionosondes installed at the South East Asia Low-latitude Ionospheric Network (SEALION). The ionosonde of the Frequency Modulated Continuous Wave (FMCW) type is a portable analogue ionosonde that enables low transmitting power for ionospheric observation. The full description of FMCW ionosonde designed for SEALION has been reported in the work of Nozaki, 2009 [7]. The developed SEAIONO software is mainly designed for the analysis of an ionogram dataset where manually scaled ionospheric parameters extraction and computation are executed.

2. SEAIONO: Description of the Software program

The structure of SEAIONO program is in three main sections namely; input graphical user interface section, ionogram parameter extraction algorithm and output parameters. The process flow of the program is shown in figure 1. The section 1 developed using MATLAB GUI development environment first read a file named “SEAIONORender.m” to initialize the necessary user input needed by the ionogram parameter extraction algorithm. The visualized program GUI (see figure 2) can be modified to accept user date (start and end) of the ionogram dataset, station code, and specified path to the dataset directory.

The inputted information is handled by the “SeaLionFileReader.m” function that uses a combination of looping and “datenum.m” function in generating a dummy filename that the program lookup in the specified directory. If data file exists, the program goes to the next section where the file is opened and ionospheric parameter on the ionogram can then be extracted. However, if the filenames do not exist, the program terminates and gives a “NaN” (not a number) output file.

Ionogram parameters extraction algorithm coded as “SeaLionReader.m” function is the core of the program describing the section 2 of the program flow process. Using the predefined filenames addresses, the “fopen.m” function reads files into the program as a cell array. The locations of the ionospheric parameters on the dataset (see figure 3) are tabulated in table 1. A total number of lines for complete ionogram dataset is 1536 lines. Since the FMCW ionosonde typically sounds every fifteen minutes, each sounding is thus classified as a block containing 16 lines with a distinct header showing the timestamp. The location of each parameter is constant in each block (see table 1 and figure 3) and repeats every 16 lines. Hence, a sequence of extracting the parameter is determined using the syntax expressed as:

\[ p[1, i] = \text{Data}[(i - 1) * 16 + n, 1] \]  

where \( p \) is the ionospheric parameters, \( i \) gives the number of iteration and \( n \) is the line number of the parameter and \( j \) is a property of the cell array to indicate the number of column \( (j = 1) \). Note that the curly parentheses used in equation (2) indicate the output file is in a form of the cell array. The
numbers of iterations are calculated by dividing the total number of lines on the dataset by 16 (lines in a block).

After a set of iterations over the number of blocks existing on the dataset, the cell array is split to get the equivalent reading of the parameter. Appropriate variable type conversions are made to get the final data matrix. The data matrix can be saved directly and as well serves as an input variable for the computation of the maximum height of ionospheric F2-layer (hmF2) and ionospheric thickness parameter (B0). It is worthy to note that B0 is a parameter introduced by the International Reference Ionosphere (IRI) model [8] to describe the thickness of electron density below the ionospheric F2 layer height.
In order to calculate hmF2, “hmF2Cal.m” function is created using a set of equations which input is from the extracted parameters (foF2, foE and MUF(3000)F2) on the ionogram dataset. The computation of hmF2 involves the use of Shimazaki (1955) [9] formula given by:

$$hmF2 = \frac{1490}{M(3000)F2} - 176$$  \hspace{1cm} (3)

where M(3000)F2 is the propagation factor defined as

$$M(3000)F2 = \frac{MUF(3000)F2}{foF2}$$  \hspace{1cm} (4)

The “hmF2Cal.m” function computes hmF2 using an improved version of the Shimazaki (1955) [9] formula developed by Bilitza et al. (1979) [10] given by:

$$hmF2 = \frac{1490MF}{M(3000)F2 + \Delta M} - 176$$  \hspace{1cm} (5)

where \(\Delta M\) is the correction term for the underlying ionization and expressed as
\[ \Delta M = \frac{f_1 \times f_2}{(f_5 - f_3) + f_4} \] (6)

\[ f_1 = 0.00232 \times R_{12} + 0.222 \] (7)

\[ f_2 = 1 - \frac{R_{12}}{150} \times \exp \left( -\left( \frac{\Psi}{40^\circ} \right)^2 \right) \] (8)

\[ f_3 = 1.2 - 0.116 \times \exp \left( \frac{R_{12}}{41.84} \right) \] (9)

\[ f_4 = \frac{0.096 \times (R_{12} - 25)}{150} \] (10)

\[ f_5 = \begin{cases} \frac{fof2}{foE} & \text{if } foE = 0, \\ -0.012 & \text{otherwise} \end{cases} \] (11)

where \( R_{12} \) is the annual average of the sunspot number and \( \Psi \) is the magnetic dip latitude. The condition of equation (11) for \( foE \) was applied from the work of Nava et al. (2008) [11]. These conditions become necessary due to multiple data gaps for the scaled \( foE \) data on the SEALION ionogram dataset. Days with sporadic E (Es) are removed from \( foE \) data set using values > 3.6 MHz as inferred from the study of Wongcharoen et al. (2015) [12].

The thickness parameter (B0) is computed using the bottomside NeQuick 2 model and scripted as “B0Cal.m” function. The NeQuick 2 model reproduces the electron density profile of the ionosphere and has become a widely used empirical model for estimating ionospheric electron density over a region [13]. A semi-Epstein layer [14] analytically defines the bottomside of the F2 layer and the inflexion point of the electron density profile describes the B0 parameter:

\[ B_0 = 0.385 \frac{N_{mF2}}{(dN/dh)_{max}} \] (12)

where \( N_{mF2} \) is the maximum electron density of F2 layer and \( (dN/dh)_{max} \) is the maximum value of the derivative of the height of the electron density which is computed using the empirical relation [15] given as

\[ \ln \left( \frac{dN}{dh} \right)_{max} = -3.467 + 1.714 \ln(foF2) + 2.202 \ln(M(3000)F2) \] (13)

Section 3 entails the saving of the extracted and computed ionospheric profile parameters into three file formats; *.mat (MATLAB MAT-file), *.txt (text file) and *.csv (comma-separated values). The overall ionospheric parameters processed by the SEAIONO program are six and they are the \( foE \), \( foF2 \), \( h'F2 \), \( MUF(3000)F2 \), \( hmF2 \) and B0.

3. Software Packaging and Installation

The execution of the function scripts described in the preceding section is done by the use of a graphical user interface (GUI) to support “point-and-click” control of the designed software application. The final function scripts are packaged as a single installer file using MATLAB application compiler that collect all the necessary libraries to install and run the software. The installation (or execution) of the SEAIONO application program relieve user the need of using MATLAB software to run the ionogram extraction toolbox. The SEAIONO program is written to run under on Windows operating system. The minimum system requirements are 240 MHz processors speed with at least 200 MB of RAM, VGA graphics of 1024 x 768 system resolution. In the specified dataset directory defined by the user, the shortcut of the “SEAIONOREader.exe” must be present.
4. Conclusion
In this paper, an application software toolbox packaged to run under Windows operating system, named SEAIONO, capable of extracting ionospheric profile parameters on the SEALION ionogram dataset was described. The ionogram extraction algorithm and the application GUI was coded in MATLAB. However, the execution the SEAIONO software is independent of MATLAB. The GUI of the software enables alphanumerical input data entered by the user and gives the option to compute hmF2 and B0 parameters. The output files are essentially save using different file formats (e.g. text format, MATLAB format and spreadsheet file format).

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