IONOSPHERIC TOTAL ELECTRON CONTENT (TEC) FORECASTING USING DEEP LEARNING APPROACH

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This report is submitted in partial fulfilment of the requirements for the degree of Bachelor of Electronic Engineering with Honours

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DEDICATION

I would want to thank my supervisor for all the assistance and guidance they given me when I was writing my report. Not to mention the assistance I obtained from my friends in order to properly complete my work. In conclusion, I would want to convey my gratitude to my parents for their unwavering support throughout my life.

ABSTRACT

Total Electron Content (TEC) is one of the physical quantities that can be derived from global positioning system (GPS) data and provides an indication of ionospheric variability. TEC variations have significant effects on radio communications, applications involving navigational systems, GPS surveying and space weather. In order to understand these effects, there is a need to develop forecasting techniques. Therefore, this study aims to determine the Total Electron content (TEC) in the Ionosphere at a particular time. It also aims to develop a deep learning model utilizing MATLAB for forecasting the Ionospheric Total Electron Content (TEC) and investigate the relationship between Ionospheric Total Electron Content (TEC), solar activity, and geomagnetic field. In conclusion, a model capable of reliably predicting the Total Electron Contain (TEC) using a deep learning algorithm has been developed. Radio operators can use the predicted value to determine the ionospheric condition in advance, especially during ionospheric disturbances.

ABSTRAK

Jumlah Kandungan Elektron (TEC) adalah salah satu kuantiti fizikal yang boleh diperolehi daripada data sistem kedudukan global (GPS) dan memberikan petunjuk kebolehubahan ionospherik. Variasi TEC mempunyai kesan yang ketara terhadap komunikasi radio, aplikasi yang melibatkan sistem navigasi, tinjauan GPS dan cuaca di angkasa. Untuk memahami kesan ini, terdapat keperluan untuk membangunkan teknik ramalan. Oleh itu, kajian ini bertujuan untuk menentukan kandungan Total Electron (TEC) dalam Ionosphere pada masa tertentu. Ia juga bertujuan untuk membangunkan model pembelajaran mendalam menggunakan MATLAB untuk meramalkan Kandungan Elektron Total Ionospheric (TEC) dan menyiasat hubungan antara Kandungan Elektron Total Ionospheric (TEC), aktiviti solar, dan medan geomagnetik. Kesimpulannya, model yang mampu meramalkan Total Electron Contain (TEC) dengan pasti menggunakan algoritma pembelajaran mendalam telah dibangunkan. Pengendali radio boleh menggunakan nilai yang diramalkan untuk menentukan keadaan ionospheric terlebih dahulu, terutamanya semasa gangguan ionospherik.

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LIST OF SYMBOLS AND ABBREVIATIONS

TEC	:	Total Electron Content
GPS	:	Global Positioning System
f_1, f_2	:	Frequency at L1 and L2
NN	:	Neural Networks
RBF	:	Radial Basis Functions
CNN	:	convolutional neural networks
LSTM	:	long short-term memory
VTEC	:	Vertical TEC
sTEC	:	Slant TEC

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CHAPTER 1

INTRODUCTION

This chapter will explain briefly about introduction, problem statement, objectives, scope of works and outline for this thesis project.

1.1 Introduction

GPS signals delivered from satellites to Earth undergo a time delay that is precisely proportional to the number of free electrons along the signal path from a satellite to an Earth-based GPS receiver. The temporal delay introduced by this GPS signal enables researchers in the ionosphere field to determine the number of electrons in the Ionosphere at any given time. TEC is one of the physical metrics collected from GPS data that provides insight into the Ionosphere's diversity.

In addition, knowledge of the value of TEC is also of importance in the field of telecommunications engineering, especially radio communications, involving navigation systems, GPS measurements, and weather in space. To understand the impact, developing a TEC forecasting model is needed. Ionosphere affects the radio signal for all frequencies caused by scattering radio waves propagating into the Ionosphere receive different effects.

TEC values in the ionospheric layer are constantly changing with daily changes, seasonal changes, geographical locations, solar activity, and Earth's magnetic field activity. TEC data from the receiver dual-frequency GPS network were calculated using the single model layer (single layer mapping, SLM). Daily and seasonal changes are represented by hours (hour, HR) and days (day number, DN). This solar activityis represented by the number of black dots on the surface of the Sun (sunspot number,SSN). This geomagnetic disturbance is caused by particle radiation from the Sun's source. K-index data represent the activity of the magnetic field.

This study aimed to forecast the ionospheric total electron content (TEC) value obtained from the receiver GPS using a deep learning approach. Signal GPS is mainly influenced by the ionosphere layer while propagating from GPS satellite to GPS receiver on the Earth's surface. This ionosphere research uses TEC data from selected GPS receiving stations. The Ionosphere is one layer in the upper atmosphere and is located between altitudes of 48 km to 965 km above the Earth's surface and affects wave propagation radio[1]. Therefore, the study of this thesis aims to develop a TEC value forecasting model using a deep learning approach.

1.2 Problem Statement

Radiofrequency (RF) and global navigation satellite systems (GNSS) are mostly affected due to adverse space weather conditions. As the RF and GNSS L-band transionospheric frequency signals pass through the Ionosphere, they undergo the time delay in signals because of refractive index variations of the ionospheric dispersive medium. The ionospheric time delay is a function of total electron content (TEC) in the Ionosphere. The TEC varies with day, season, annual, and geomagnetic conditions.GNSS signals provide an opportunity to monitor ionospheric behavior with the help of either ground or space based GNSS receivers. Deep learning algorithms can characterize ionospheric state using past ionospheric data under various space weather conditions. The ionospheric activity recognition is classified with solar activity (solarflux index for 10.7 cm, F10.7) and geomagnetic activity (disturbed storm time index,Dst) to forecast the ionospheric delays. Low latitude ionospheric behavior is highly random and dynamic. Hence, much attention is needed for developing ionospheric forecasting algorithms[2].

1.3 Objectives

1. To determine the Total Electron Content (TEC) in the Ionosphere at aparticular time.
2. To investigate the relationship between Ionospheric Total ElectronContent (TEC), solar activity, and geomagnetic field
3. To develop a deep learning model utilizing MATLAB for forecastingthe Ionospheric Total Electron Content (TEC).

1.4 Scope of Work

This project aims to develop a model for TEC value prediction using a deep learning approach. As a result, this study depends entirely on GPS data to determine TEC levels in the L1 and L2 frequency bands. This analysis only includes GPS data from May 1 to May 11, 2022, a period of 11 days. Based on the value of the TEC that have been calculated, a model can be created to forecasts the change in TEC value using an artificial neural network forecasting algorithm.

1.5 Thesis Outline

The thesis consists of five chapters. The first chapter provides a project overview. Deep learning is utilized to develop a model for forecasting Ionospheric Total Electron Content (TEC) using the calculated TEC value derived from GPS data.

Chapter 2 contains the information gathered for this project. This section is a summary of the literature review and contains a summary of multiple journal articles.

Beginning Chapter 3 is a flowchart detailing the beginning to end of the project. The calculations performed on the GPS data to determine the TEC value were also discussed. MATLAB is utilized to construct models and generate simulations.

Chapter 4 presents the results and discussions about the findings for various approaches that use in creating the model in MATLAB. It also demonstrates how to construct the model.

Finally, chapter 5 concludes the work and suggests future expansion. It will describe the project's limitations and make suggestions for improving the upcoming technological revolution.

CHAPTER 2

BACKGROUND STUDY

In this chapter, important research findings from a previous study are listed. These studies, with their theoretical foundations, methodology, and interpretations, serve as the primary source of information for the project.

2.1 Ionosphere Formation

The atmosphere is separated into various layers, including the hemisphere, Ionosphere, exosphere, troposphere, stratosphere, mesosphere, each of which has a specific temperature and height profile relative to the Earth's surface. The ionospherelayer is generated when ultraviolet energy in gamma rays and X-rays ionizes neutral atoms and molecules in the Earth's atmospheric layer, producing the free electrons required for radio communication. This layer is a portion of the atmosphere between 48 and 965 kilometers above the Earth's surface[1]. At this height, the major gases inthe atmosphere are nitrogen (N2), oxygen (O2), and minor gas atoms. Three distinct ionospheric layers exist.

This ionization is influenced by the Sun's ever-changing activity, namely the pace at which its radiation intensity increases. As a result, there are some distinct effects onthis ionization process as the local time changes due today and night shifts, seasonal changes, and the solar cycle. During the day, the incredible intensity of the Sun's radiation generates many free electrons due to ionization, which is directly proportional to the Sun's zenith angle. At night, when the Sun's source radiation is very low, and no ionization occurs, free electrons combine with ions, reducing the total electron density.

The change of seasons is caused by the Earth's rotation around the Sun; thus, the angle at which the Sun's rays strike the Earth changes with the seasons. For instance, a place that experiences winter receives less sunlight, resulting in a comparatively mild ionization process. Geographic location also affects the ionization process, regardlessof whether the area is in a high latitude region (polar), a middle latitude region, or a low latitude zone (Equator). Additionally, the ionization process fluctuates with the eleven-year solar cycle, which is inversely proportional to the number of black dots on the Sun's surface (sunspot number, SSN). The solar process is a periodic measurement of the Sun's activity. During the solar cycle maximum, the higher quantity of radiation from the Sun increases the number of free electrons in the Ionosphere and vice versa.

The ionosphere layer operates as a reflecting conductive region, transmitting radiowaves to the Earth's receiving station at specific frequencies. The ionosphere layer will reflect radio signals with less than 30 MHz When radio waves with a high ultraviolet frequency, such as GPS, propagate through the ionosphere layer, their signal velocity is altered by these free electrons. This layer many contribute importance, and one of the characteristics that affect the sound of a radio wave signal is the content of electrons in the layer concerning which varies depending on solar activity, the geographical position of something place, and the magnetic activity of the Earth. This significant effect is shown during daytime with a high level of ionization process effects of solar radiation strong. Malaysia's position is in the Equatorregion, making this area very suitable for studying and understanding the Ionosphere'sproperties.

2.2 Structure Of the Ionospheric Layer

In general, this ionosphere layer is composed of many layers with varying chemical compositions, altitude above sea level, and electron density. The ionosphere layer is being studied because it is one of the layers of the Earth's atmosphere that contains free electrons and affects the propagation of electromagnetic waves, most notably the global positioning system (GPS). The ionospheric layer of the Earth is frequently studied in terms of its total electron concentration (TEC). The TEC parameter is crucial for detecting disturbances in the ionospheric layer. The Ionosphere comprisesthree distinct layers: D, E, and F. This layer is classified according to its ionic and molecular composition, absorption radiation, chemical processes, and electron density, depending on the day and night conditions[3].