UNIVERSITI PUTRA MALAYSIA

IMPROVED CRITERIA DETERMINATION OF AN AUTOMATED NEGATIVE LIGHTNING RETURN STROKES CHARACTERISATION USING BRUTE-FORCE SEARCH ALGORITHM

FARANADIA BINTI ABDUL HARIS

FK 2022 37

IMPROVED CRITERIA DETERMINATION OF AN AUTOMATED NEGATIVE LIGHTNING RETURN STROKES CHARACTERISATION USING BRUTE-FORCE SEARCH ALGORITHM

By

FARANADIA BINTI ABDUL HARIS

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

November 2021

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

IMPROVED CRITERIA DETERMINATION OF AN AUTOMATED NEGATIVE LIGHTNING RETURN STROKES CHARACTERISATION USING BRUTE-FORCE SEARCH ALGORITHM

By

FARANADIA BT ABDUL HARIS

November 2021

Chair : Mohd Zainal Abidin Ab. Kadir, PhD
Faculty : Engineering

Over the years, many studies have been conducted to measure, analyse and characterise (i.e. mainly on the negative return strokes) the lightning-generated electric field waveform for a better understanding and conception of the lightning phenomenon and processes. The characterisation also contributes to the lightning protection system and lightning location system development as these systems require measured and validated data of the negative lightning return stroke characteristics. Previous studies mostly performed the characterisation of the negative return strokes using a conventional method, namely manual observations. Nevertheless, this traditional method could compromise data analysis accuracy due to human errors. The processing time to analyse the data would also be longer, especially for larger sample sizes. Therefore, this study proposed an automated negative lightning return strokes characterisation using a Brute-Force search algorithm, mainly on seven parameters, i.e. on zero-to-peak rise time, 10-to-90% rise time, zero-crossing time, slow front time, slow front amplitude relative to peak, fast transition 10-to-90% rise time, and width dE/dt pulse at half peak value. For this purpose, the lightning-generated electric field measurement under different seasonal periods, was conducted at the College of Engineering, Universiti Tenaga Nasional (UNITEN), Selangor, Malaysia using a previously researched small-scale prallel-plate antenna. The criteria for each of the negative lightning return strokes parameters were established and defined based on specific mathematical equations. Accordingly, the proposed Brute-Force search algorithm characterised the negative lightning return strokes parameters based on the seven parameters. A total of 206 negative lightning return strokes waveforms were analysed and automatically characterised using the proposed algorithm. Comparisons of different data, including the manual data (i.e. obtained through the conventional method), data (automated) from a previous study, and the automated data (i.e. obtained using the proposed algorithm), were also carried out by evaluating the percentage difference, arithmetic mean, and standard deviation. The statistical analysis showed a good agreement between manual and automated data on each parameter, with a percentage difference observed between 0.08% and 6.88%. Bland-Altman plots analysis also showed that most of the plotted data were within the threshold limits. The results suggest that the proposed algorithm can provide an efficient structure and procedure by reducing the processing time, minimising human error, and eliminating the nonuniformity among users while characterising the lightning negative return strokes. Furthermore, the small-scale parallel-plate antenna that has been tested under real lightning condition can be operated as a portable, lightweight, and easy-to-install device for a lightning measurement system.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENENTUAN KRITERIA YANG DIPERBAIKI BALIK KILAT NEGATIF AUTOMATIK PERCIRIAN MENGGUNAKAN ALGORITMA PENCARIAN BRUTE-FORCE

Oleh

FARANADIA BT ABDUL HARIS

November 2021

Pengerusi : Mohd Zainal Abidin Ab. Kadir, PhD
Fakulti : Kejuruteraan

Selama bertahun-tahun, banyak kajian telah dijalankan untuk mengukur, menganalisis dan mencirikan (iaitu terutamanya pada pukulan pulangan negatif) bentuk gelombang medan elektrik yang dijana kilat untuk pemahaman dan konsep yang lebih baik tentang fenomena dan proses kilat. Pencirian juga menyumbang kepada sistem perlindungan kilat dan pembangunan sistem lokasi kilat kerana sistem ini memerlukan data yang diukur dan disahkan bagi ciri-ciri strok pulangan kilat negatif. Kajian terdahulu kebanyakannya melakukan pencirian pukulan pulangan negatif menggunakan kaedah konvensional iaitu pemerhatian manual. Namun begitu, kaedah tradisional ini boleh menjejaskan ketepatan analisis data akibat kesilapan manusia. Masa pemprosesan untuk menganalisis data juga akan menjadi lebih lama, terutamanya untuk saiz sampel yang lebih besar. Oleh itu, kajian ini mencadangkan pencirian kilat pulangan kilat negatif automatik menggunakan algoritma carian brute-force, terutamanya pada tujuh parameter, iaitu pada masa kenaikan sifar hingga puncak, masa naik 10 hingga 90%, masa lintasan sifar, perlahan. masa hadapan, amplitud hadapan perlahan berbanding puncak, masa naik 10 hingga 90% peralihan pantas, dan nadi dE/dt lebar pada separuh nilai puncak. Untuk tujuan ini, pengukuran medan elektrik janaan kilat di bawah tempoh bermusim yang berbeza, telah dijalankan di Kolej Kejuruteraan, Universiti Tenaga Nasional (UNITEN), Selangor, Malaysia menggunakan antena prallel-plat berskala kecil yang telah dikaji sebelum ini. Kriteria bagi setiap parameter sambaran kilat negatif telah ditetapkan dan ditakrifkan berdasarkan persamaan matematik tertentu. Sehubungan itu, algoritma carian brute-force yang dicadangkan mencirikan parameter pukulan pulangan kilat negatif berdasarkan tujuh parameter. Sebanyak 206 bentuk gelombang kilat pulangan kilat negatif telah dianalisis dan dicirikan secara automatik menggunakan algoritma yang dicadangkan. Perbandingan data yang berbeza, termasuk data manual (iaitu diperoleh melalui kaedah konvensional), data (automatik) daripada kajian terdahulu, dan data automatik (iaitu diperoleh menggunakan algoritma yang dicadangkan), juga dijalankan dengan menilai perbezaan peratusan, min aritmetik, dan sisihan piawai. Analisis statistik menunjukkan persetujuan yang baik antara data manual dan automatik pada setiap parameter, dengan perbezaan peratusan diperhatikan antara 0.08% dan 6.88%. Analisis plot Bland-Altman juga menunjukkan bahawa kebanyakan data yang diplot berada dalam had ambang. Keputusan menunjukkan bahawa algoritma yang dicadangkan boleh menyediakan struktur dan prosedur yang cekap dengan mengurangkan masa pemprosesan, meminimumkan ralat manusia, dan menghapuskan ketidakseragaman di kalangan pengguna sambil mencirikan strok pulangan negatif kilat. Tambahan pula, antena plat selari berskala kecil yang telah diuji dalam keadaan kilat sebenar boleh dikendalikan sebagai peranti mudah alih, ringan dan mudah dipasang untuk sistem pengukuran kilat.

ACKNOWLEDGEMENTS

Alhamdulillah, all praises to Allah s.w.t for giving me patience and strength in completing this thesis. First and foremost, I would like to express my sincere gratitude to my Chairman of the Supervisory Committee; Prof. Ir. Dr. Mohd Zainal Abidin Ab. Kadir for his support, guidance, advice and motivation throughout the completion of this study. I also wish to thank all members of the Supervisory Committee; Dr. Jasronita Jasni and Dr. Dalina Johari for their assistance and valuable comments. Kindest appreciation to my laboratory colleague Nor Hazirah, Noh Hamzah, Farah Adilah, Norhidayu and Haziq for their opinions and assistance in completing this study.

A special appreciation to my beloved parents Abdul Haris Darus and Norhayati Md Darus, my mother-in-law Hajah Kalsom and my beloved husband Sukhairi Sudin that always keep supporting me through thick and thin, for better or worse. Last but not least, thanks to my younger brother, auntie, uncles, cousins and my best friend (Faizatul, Hana, k.gia, k.dana, k.jiji, k.farah) for being my lifeline.

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Mohd Zainal Abidin bin Ab. Kadir, PhD
Professor, Ir
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Gorakanage Arosha Chandima Gomes, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Jasronita binti Jasni, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Dalina binti Johari, PhD
Senior Lecturer
College of Engineering
Universiti Teknologi MARA
(Member)

ZALILAH MOHD SHARIFF, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 14 April 2022

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research and the writing of this thesis were done under our supervision;
- supervisory responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2015-2016) are adhered to.

Signature: ____________________
Name of Chairman of Supervisory Committee: Mohd. Zainal Abidin bin Ab. Kadir

Signature: ____________________
Name of Member of Supervisory Committee: Gorakanage Arosha Chandima Gomes

Signature: ____________________
Name of Member of Supervisory Committee: Jasronita binti Jasni

Signature: ____________________
Name of Member of Supervisory Committee: Dalina binti Johari

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

(b) Bland-Altman Plot for Width dE/dt Pulse at Half Peak Value

LIST OF SYMBOLS

E	Electric Field
F	Flux Density
Q	Charge
λ	Wavelength
V	Wave velocity
f	Frequency
d	Distance
V_g	Input Voltage
V_m	Output/transient Recorder System
R	Resistor
C	Capacitor
C_b	Bypass Capacitor
C_v	Variable Capacitance
t_{z1p}	Zero-to-Peak Rise Time
t_z	Zero-Crossing Time
t_{r10-90}	10-to-90% Rise Time
m	Gradient
θ	Angle
P_{sf}	Slow Front Amplitude Relative to Peak
t_{f10-90}	Fast Transition 10-to-90% Rise Time
P	Peak Amplitude

LIST OF ABBREVIATIONS

AC	Alternating Current
AM	Arithmetic Mean
BNC	Bayonet Neill–Concelman
CG	Cloud-to-Ground
DC	Direct Current
DFT	Discrete Fourier Transform
FFT	Fast Fourier Transform
LDS	Lightning Detection System
LPS	Lightning Protection System
MEMS	Micro-Electro-Mechanical System
NBP	Narrow Bipolar Pulses
OL	Open Loop
PC	Personal Computer
PCB	Printed Circuit Board
SAT	State-of-the-art Boolean Satisfiability
SD	Standard Deviation
SMGT	Meteorological Gradient Tower
TOA	Time of Arrival
TNB	Tenaga Nasional Berhad
TNBR	Tenaga Nasional Berhad Research

CHAPTER 1

INTRODUCTION

1.1 Research Background

In many cultures, lightning has been regarded as part of a deity or even deified [1]-[3]. In physics and engineering, lightning is defined as a transient high-current electric discharge, and its path length is measured in kilometres. Thunderstorms clouds (cumulonimbus) are mainly the source of lightning. Lightning is also referred to as sudden electrostatic discharge caused by an imbalance between electrically charged cloud regions [4]. The imbalance may have occurred between the storm cloud and the ground or within the clouds themselves. Colliding particles of rain, ice, or snow inside storm clouds further increase this imbalance phenomenon. Usually, the lower part of the cloud contains the negative charge that seeks the positive charge from the object on the ground or earth. As the conductive pathway builds up, the surrounding air becomes extremely hot, at almost 20,000 degrees Celsius. As a result, the surrounding air expands, causing the sound of thunder and eventually creates a sonic boom.

The effect of lightning strikes has received considerable critical attention from the electricity industry because of the significant impact of the electrical discharge on the power transmission line. The damage to a power plant is almost certain if lightning struck the transmission line near the station, as the ordinary lightning arrestor probably could not divert such a powerful discharge to earth. Apart from that, the lightning disruption could cause propagation of voltage surges in both directions from the strike point, mainly on the overhead phase-conductor [5]. There would be a potential difference between the top and bottom of the transmission tower due to the direct lightning strike. In this situation, if the value of the potential difference exceeded the basic insulation level, there would be a back flashover as the flashover occurred from the transmission tower to the transmission line.

This lightning disturbance can also result in significant human fatalities. According to Jacob D.Jensen et al. [6], there are approximately 24,000 fatalities with 10 times as many injuries annually worldwide due to lightning strikes - estimated from worldwide/global statistics. There are several categories of lightning injuries, but the most common injury is superficial burns on the human body due to the conversion of electrical to thermal energy. A direct lightning strike may also cause nervous system damages to human beings due to respiratory and cardiac arrest, and worse, death. There are also animal fatalities discovered due to the step voltage from a lightning strike [7].

These lightning implications, especially to the electricity industry, could reduce the reliability of distribution network performance in providing continuous power to consumers and consequently affect human society. Tenaga Nasional Berhad, the largest electricity utility company in Malaysia, reported that lightning incidents cause 70% transient tripping and power interruptions in the transmission and distribution network [11]. Therefore, the electric field characteristic generated from lightning flashes should be assessed and analysed. Furthermore, the characterisation - mainly on the parameters of negative return strokes - should be appropriately identified to maximise the life span and efficiency of power system equipment for the well-being of society. Moreover, the effect from the magnitude of the vertical electric field has been observed to be significantly higher than the horizontal component, which is also difficult to measure [8].

The lightning implications are also significant for countries located in the tropical region, including Malaysia. Due to its location, Malaysia experiences many thunderstorms and lightning activities every year due to frequent rainfall, particularly in Selangor - one of the 13 states of the country [9]. The above concerns indicate that it is crucial to perform research works that cover the lightning electric field measurement and the characterisation of the parameters of negative return strokes by using proper and efficient methods. Therefore, this study developed an automated negative return strokes parameters characterisation, subjected to Malaysia seasonal variation, using the Brute-Force search algorithm. Before commencing this study, field test measurement on the lightning electric field was first carried out using previously researched small-scale parallel-plate antenna.

1.2 Problem Statement

Power distribution parties require lightning location detection to select a new safe power grid site for their system protection. The evaluation of a lightning location is one of the critical issues for lightning mapping and considers the level of lightning risk for power systems protection. Several studies have evaluated lightning locations, usually based on the time of arrival of a measured electric field [10]. The lightning activity produced by thunderstorms can be detected using a lightning detection system (LDS), which can be ground-based, mobile-based as well as space-based (satellite) [11]. Meanwhile, a lightning protection system (LPS) works by providing a path of electric discharge to the ground. The LPS can be operated based on the measured and validated data obtained by the LDS. Developing such systems (i.e. LDS and LPS) requires an understanding of the theoretical background of lightning physics, which is related to technical and engineering matters. Apart from the modern and sophisticated equipment requirement, a proper detection network is also vital in LDS, which is dependent on the characteristic and features of lightning due to its very complex nature/atmospheric phenomenon.

For research purposes, many studies have carried out the lightning-generated electric field measurement and lightning characterisation using a parallel-plate antenna to assess the electrical discharge features [12]–[14]. In most of the studies, the characterisation of negative lightning return strokes based on parameters such as the zero-to-peak rise time, 10-to-90% rise time, zero-crossing time, slow front time, slow front amplitude relative to peak, fast transition 10-to-90% rise time, and width dE/dt pulse at half peak value was performed using a conventional approach [57-59] & [96-97] which is the manual inspection from the eye observation. The output waveform was examined manually one by one through zooming in and out features from the transient recorder system. Nevertheless, the manual approach could compromise the data analysis accuracy due to potential human error in which the nonuniformity among users might affect the assessment during the characterisation process. Furthermore, the processing time to analyse the data would be longer, especially for larger sample sizes. The dataset of a measured output waveform of lightning electric field could be as large as thousands of sample sizes. Besides, no attempts have been made to develop an automated negative lightning return strokes characterisation using a specific algorithm to provide a more feasible analysis approach. From the previous work in [57], the parameters of each negative return stroke were defined by looking into the range from the published literature based on the generic approach.

It is evident from the preceding discussion that the parameters of negative lightning return strokes should be analysed and identified distinctly through a suitable characterisation technique for an effective LDS operation. Apart from that, the existing parallel-plate antennas that have been used for lightning-generated electric field measurement are too bulky, with a minimum height and diameter of 1.5 m and 0.3 m, respectively [15], [16]. Due to the inconvenient size, they are not easily carried or moved for field installation. Therefore, this study proposed to measure the lightning-generated electric field using a new small-scale parallel-plate antenna under seasonal variations in Malaysia and characterise the negative lightning return strokes automatically using the Brute-Force search algorithm. The automated data under Malaysia's climate variations were then compared with the conventional approach characterisation data to validate the efficiency of the proposed algorithm.

1.3 Research Objective

This study mainly aimed to develop a small-scale parallel-plate antenna and automate the negative lightning return strokes characterisation using the Brute-Force search algorithm. Specifically, the developed Brute-Force search algorithm should automatically analyse and characterise the negative lightning return strokes according to the seven parameters: zero-to-peak rise rime, 10-to-90% rise time, zero-crossing time, slow front time, slow front amplitude relative to peak, fast transition 10-to-90% rise time, and width dE/dt pulse at half peak. To achieve these aims, the objectives of this study were formulated as follows:

i) To conduct lightning-generated electric field measurement at a selected site under seasonal variations in Malaysia using a previously researched small-scale parallel plate antenna for lightning-generated electric field measurement.

ii) To establish a set of criteria for each negative lightning return strokes parameters.
iii) To develop new searching algorithm for automated characterisation of negative lightning return strokes using Brute-Force method.

1.4 Scope and Limitation

This study consisted of four essential parts as the main elements: small-scale antenna development, lightning-generated electric field measurement, criteria establishment, and characterisation algorithm development.

1. The antenna development focused on the parallel-plate type of sensor to measure lightning, mainly on the electric field. Further, the antenna development and modification involved reducing the two main dimensions of parallel-plate antennas: height and diameter.
2. The lightning-generated electric field measurement focused on the radiation or fast field measurement using the proposed small-scale parallel-plate antenna and recorded by the transient recorder system of the Picoscope (PC Oscilloscope) 4000 Series with a sampling rate of 25 MS/s (Mega samples per second). The electric field measurement was performed under seasonal variations in Malaysia, which covered the northeast monsoon, first inter-monsoonal period, southwest monsoon, and second inter-monsoonal period. Based on the seasonal variations, the measurement was conducted from August 2019 to March 2020, on the rooftop of the College of Engineering building at UNITEN, Kajang, Selangor, Malaysia.
3. The negative lightning return strokes criteria were established based on each parameter's mathematical equations developed in this study. The algorithm development to automate the negative lightning return strokes characterisation used the Brute-Force search algorithm, which adopted several search concepts: comparative, time-reversal, and time forward. The negative lightning return strokes were characterised according to the earlier mentioned seven main parameters using MATLAB software. This study evaluated the proposed algorithm by using a few statistical performance indicators such as arithmetic mean (AM), standard deviation (SD), percentage difference, and Bland-Altman plot analysis to compare the manual data from the conventional approach with the automated data.

1.5 Significance of Study

The main significances of this study are as follows:

i) Development of a small-scale parallel-plate antenna that is convenient for lightning measurement installation, mainly for research purposes.
ii) Provides an assessment of the features and characteristics of the negative lightning return strokes based on the tropical region, which focuses on Malaysia. The evaluation also involves the details of comparison between the features from the tropical and non-tropical areas.

iii) Establishment of the criteria on each of the negative lightning return strokes parameters.
iv) Development of a suitable technique or algorithm for automated characterisation of negative lightning return strokes using the Brute-Force search algorithm.

The proposed small-scale parallel-plate antenna is beneficial for a lightning-generated electric field measurement setup. With a physical height of 0.555 m, the antenna can be easily carried from one place to another compared to the existing parallel-plate antennas of bigger dimensions. Therefore, it can be operated as a portable, lightweight, and easy-to-install device for a measurement system. The assessment and evaluation provide a better technical understanding and conception of lightning features and phenomena, mainly on the negative lightning return strokes in the tropical and non-tropical regions. Apart from that, the criteria establishment and determination based on the mathematical equations can concisely express /define the seven parameters of negative lightning return strokes. These equations play an important role in the working principle of the algorithm to determine the desired component. The equations can also improve the information accuracy and instruction for any specific algorithm to execute a task, particularly the Brute-Force search algorithm.

Meanwhile, the proposed characterisation method using the Brute-Force search algorithm provides an effective way to identify/search all combinations based on the criteria that have been defined and established on each parameter of negative lightning return strokes. The proposed algorithm also works by considering all the combinations one by one with no limitation on the sample size without missing data from the measured output lightning electric field waveform. Besides, the proposed algorithm also accommodates an essential technique for automated characterisation for negative lightning return strokes parameters, mainly on the zero-to-peak rise time, 10-to-90% rise time, zero-crossing time, slow front time, slow front amplitude relative to peak, fast transition 10-to-90% rise time, and width dE/dt pulse at half peak value. The development of automated characterisation for these parameters using the Brute-Force search algorithm also contributes to the lightning protection system (LPS) and lightning detection system (LDS) as these systems require the measured and validated data of lightning negative return strokes. Apart from that, the processing time to characterise and analyse all the parameters of negative lightning return strokes will be reduced significantly with optimum accuracy by minimising human error. Through this contribution, it is possible to explore and develop advanced lightning protection and detection system on an interconnected network in the future.

1.6 Thesis Structure

This thesis is organised as below:

i) **Chapter 1** gives an overview of the lightning definition and phenomenon from different backgrounds. This chapter also presents a brief discussion of the effect of lightning strikes on power system networks and society. Other topics covered in this chapter include research problem, research objective, scope, limitation, and significance of this study.

ii) **Chapter 2** summarises the literature review on recent studies related to lightning-generated electric field measurement and characterisation. Topics discussed in this chapter include the lightning return stroke phenomenon - mainly on the lightning electric field; the lightning-generated electric field measurement and characterisation based on different geographical backgrounds - tropical and non-tropical regions; and the Brute-Force search algorithm working principle and application.

iii) **Chapter 3** describes the methodology that is associated with the research objectives, with a focus on four essential parts: small-scale parallel-plate antenna fabrication, field test measurement under Malaysia's climate, the establishment of negative lightning return strokes criteria, and Brute-Force search algorithm development for automated characterisation of the negative lightning return strokes parameters.

iv) **Chapter 4** presents the negative lightning return strokes data obtained using the proposed small-scale parallel-plate antenna and data comparisons based on the seven parameters of negative lightning return strokes. These comparisons include between the manual data (of this study) and that of a previous study under the same country as well as studies from different countries, between the manual data and the automated data (i.e. using the proposed algorithm), and between the automated data and that of a previous study.

v) **Chapter 5** concludes the results and performance of the proposed small-scale parallel-plate antenna and the proposed Brute-Force search algorithm. The recommendation to improvise the proposed algorithm for future works is also presented in this chapter.

REFERENCES

[1] A. R. Syakura, C. Gomes, E. Trengove and M. Z. A. Ab Kadir, "Public Beliefs about Lightning in Malaysia," 2019 International Symposium on Lightning Protection (XV SIPDA), 2019, pp. 1-6, doi:10.1109/SIPDA47030.2019.89516.

[2] R. Mawla, M. Shiblee, Z. R. Khan, M. M. H. Mamun, M. Hasan and N. Sultana, "Statistical Analysis of Lightning Myths and Suggestive Measures in Context of Bangladesh," 2018 4th International Conference on Electrical Engineering and Information & Communication Technology (iCEEiCT), 2018, pp. 666-671, doi: 10.1109/CEEICT.2018.8628043.

[3] E. Trengove and I. Jandrell, "Lightning and witchcraft in southern Africa," 2011 7th Asia-Pacific International Conference on Lightning, 2011, pp. 173-177, doi: 10.1109/APL.2011.6111097.

[4] D. Wang, S. Yuan, A. Srivastava, Z. Sun, Z. Chen and J. Li, "Analysis on the Lightning Flash Activities Over Beijing Area Based on Beijing Lightning Network," 2018 34th International Conference on Lightning Protection (ICLP), 2018, pp. 1-4, doi: 10.1109/ICLP.2018.8503346.

[5] Y. Zhang, Z. Li, Y. Guo and Y. Guo, "Calculating the transient electromagnetic phenomena of the truss bridge by direct lightning strikes," 2017 20th International Conference on Electrical Machines and Systems (ICEMS), 2017, pp. 1-4, doi: 10.1109/ICEMS.2017.8056452.

[6] Jensen JD, Thurman J, Vincent AL. Lightning Injuries. [Updated 2021 Jul 29]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2022 Jan-. Available from: https://www.ncbi.nlm.nih.gov/books/NBK441920/.

[7] R. L. Holle and M. A. Cooper, "Lightning Fatalities in Africa From 2010-2017," 2018 34th International Conference on Lightning Protection (ICLP), 2018, pp. 1-4, doi: 10.1109/ICLP.2018.8503315.

[8] S. Visacro, "Recent Advances in Lightning Research and Their Impact on the Protection of Electric Systems," 2018 34th International Conference on Lightning Protection (ICLP), 2018, pp. 1-4, doi: 10.1109/ICLP.2018.8503440.

[9] S. A. Rufus, N. A. Ahmad, Z. Abdul-Malek and N. Abdullah, "Characteristics of Lightning Trends in Peninsular Malaysia from 2011 to 2016," 2019 International Conference on Electrical Engineering and Computer Science (ICECOS), 2019, pp. 15-18, doi: 10.1109/ICECOS47637.2019.8984514.

[10] J. Lai, Y. Liu, J. Du and Q. Li, "Lightning Detection Technology and Application," 2019 International Conference on Meteorology Observations (ICMO), 2019, pp. 1-5, doi:

10.1109/ICMO49322.2019.9026107.

[11] M.A Islam et a, “Importance of lightning detection network development in Peninsular Malaysia,” *Conf. Ser. Earth Environement Sci.*, p. 385, 2019.

[12] W. Kang, C. Yang, S. Jiayun and L. Min, "Electrical measurement of free space electric field sensors," 2016 IEEE Metrology for Aerospace (MetroAeroSpace), 2016, pp. 506-510, doi: 10.1109/MetroAeroSpace.2016.7573267.

[13] P.B Adhikari, “Various Types of Lightning Electric Field Signatures Observed in Kathmandu Nepal,” *J. Astrophys Aerospace Technology* .,vol. 7, no. 1, pp. 1–6, 2019, doi: 10.4172/2329-6542.1000164.

[14] X. Zou, Q. Li, L. Cai, M. Zhou, J. Wang and Y. Fan, "Electric field waveform characteristics of natural cloud-to-ground lightning at different distances," 2019 11th Asia-Pacific International Conference on Lightning (APL), 2019, pp. 1-6, doi: 10.1109/APL.2019.8815962.

[15] A. Hazmi, Z. Hendri, S. Mulyadi, D. Tesal, D. Wang, and N. Takagi, “Characteristics of electric field change preceding negative first return stroke produced by preliminary breakdown,” *Int. Conf. Inf. Technology. Electrical. Engineering. "Intelligent Green Technol. Sustain. Dev. ICITEE 2013*, pp. 322–325, 2013, doi: 10.1109/ICITEED.2013.6676261.

[16] C. L. Wooi, Z. Abdul-Malek, N. A. Ahmad, and M. Mokhtari, “Characteristic of preliminary breakdown preceding negative return stroke in Malaysia,” *2015 IEEE Conf. Energy Conversion, CENCON 2015*, pp. 112–115, 2015, doi: 10.1109/CENCON.2015.7409523.

[17] S.Shivalli, “Lightning Phenomenon, Effects and Protection of Structures from Lightning,” *IOSR J. Electr. Electron. Eng.*, vol. 11, no. 344–50, 2016.

[18] M. Izadi, M. Zainal Abidin Ab Kadir, M. Syahmi Ab Rahman, M. R. Mehrjou and M. Hajikhani, "On the effect of insulator angle with respect to the cross arm on the distribution of lightning electric fields," 2016 33rd International Conference on Lightning Protection (ICLP), 2016, pp. 1-4, doi: 10.1109/ICLP.2016.7791403.

[19] A. Srivastava, S. Yuan, X. Qie, R. Jiang and D. Wang, "Observation on Upward Lightning Induced by Nearby Positive Cloud-to-Ground Lightning based on Highspeed Camera and Radio Frequency Mapping System," 2019 11th Asia-Pacific International Conference on Lightning (APL), 2019, pp. 1-5, doi: 10.1109/APL.2019.8816004.

[20] Z. Ma, M. Liu, R. Jiang, Z. Sun, H. Zhang and Y. Pu, "Characteristics of current pulses in rocket triggered lightning," 2018 34th International Conference on Lightning Protection (ICLP), 2018, pp. 1-4, doi: 10.1109/ICLP.2018.8503354.

[21] V. Cooray, "Latitude Dependence of Peak Lightning Return Stroke Current- A Theoretical Explanation," 2018 34th International Conference on Lightning Protection (ICLP), 2018, pp. 1-3, doi: 10.1109/ICLP.2018.8503328.

[22] M. H. Mohammad Sabri et al., "Very High Frequency and Microwave Radiation Associated with Initial Breakdown Process in CG Lightning Flashes from Tropical Storms," 2021 35th International Conference on Lightning Protection (ICLP) and XVI International Symposium on Lightning Protection (SIPDA), 2021, pp. 1-4, doi: 10.1109/ICLPandSIPDA54065.2021.9627445.

[23] W. Han, D. Zhang, H. Zhao, S. Wei, S. Pang and W. Pan, "Research on the Variation of Lightning Activity Parameters with Land Types Based on Lightning Location System," 2021 IEEE 4th International Electrical and Energy Conference (CIEEC), 2021, pp. 1-6, doi: 10.1109/CIEEC50170.2021.9511064.

[24] A. Sunjerga et al., "On the Classification of Self-Triggered versus OtherTriggered Lightning Flashes," 2018 34th International Conference on Lightning Protection (ICLP), 2018, pp. 1-5, doi: 10.1109/ICLP.2018.8503322.

[25] A. Sunjerga et al., "LMA Observation of Upward Bipolar Lightning Flash at the Säntis Tower," 2019 International Symposium on Lightning Protection (XV SIPDA), 2019, pp. 1-5, doi: 10.1109/SIPDA47030.2019.8951538.

[26] V. Srinivasan, M. Fernando, S. Kumara, T. Selvaraj and V. Cooray, "Modeling and Assessment of Lightning Hazards to Humans in Heritage Monuments in India and Sri Lanka," in IEEE Access, vol. 8, pp. 228032-228048, 2020, doi: 10.1109/ACCESS.2020.3046100.

[27] N. Rameli, M. Z. A. Ab-Kadir, M. Izadi, C. Gomes and N. Azis, "Variations in return stroke velocity and its effect on the return stroke current along lightning channel," 2016 33rd International Conference on Lightning Protection (ICLP), 2016, pp. 1-5, doi: 10.1109/ICLP.2016.7791484.

[28] G. Zhang, M. Chen and Y. Du, "Representation of Lightning Return Stroke Channel in FDTD Code and its Impact on Lightning-Produced Electric Field Calculation," 2018 34th International Conference on Lightning Protection (ICLP), 2018, pp. 1-5, doi: 10.1109/ICLP.2018.8503324.

[29] V.A.Rakov, “Fundamentals of Lightning,” *International Symposium Lightnung Protection.*, pp. 1–61, 2011.

[30] K. P. Naccarato, A. R. de Paiva, M. M. F. Saba, C. Schumann, J. C. O. Silva and M. A. S. Ferro, "Preliminary comparison of direct electric current measurements in lightning rods and peak current estimates from lightning location systems," 2017 International Symposium on Lightning

Protection (XIV SIPDA), 2017, pp. 319-323, doi: 10.1109/SIPDA.2017.8116944.

[31] M. Saito and M. Ishii, "Characteristics of return strokes associated with upward lightning flashes observed in winter," 2018 34th International Conference on Lightning Protection (ICLP), 2018, pp. 1-5, doi: 10.1109/ICLP.2018.8503444.

[32] F.H.Heidler, "Some Return Stroke Characteristics of Negative Lightning Flashes Recorded at the Peissenberg Tower," *Dep. Electr. Comput. Eng. Univ. Munich*, pp. 1–8, 2017.

[33] A. De Conti, "Lightning strikes to towers: An attempt to identify the effect of the channel resistance on wave interactions at the return-stroke front," 2016 33rd International Conference on Lightning Protection (ICLP), 2016, pp. 1-5, doi: 10.1109/ICLP.2016.7791374.

[34] G. Chi, Y. Zhang, D. Zheng, W. Lu and Y. Zhang, "Characteristics of lightning activities in Potala Palace region of Tibet," 2014 International Conference on Lightning Protection (ICLP), 2014, pp. 1992-1994, doi: 10.1109/ICLP.2014.6973455.

[35] Y. Zhu, V. A. Rakov, S. Mallick, and M. D. Tran, "Characterization of negative cloud-to-ground lightning in Florida," *J. Atmos. Solar-Terrestrial Phys.*, vol. 136, pp. 8–15, 2015, doi: 10.1016/j.jastp.2015.08.006.

[36] R. T. v. A. Rakov, M. A. Uman, "Review of lightning properties determined from electric field and TV observations," *J. Geophys. Res.*, vol. 99, pp. 10745–10750, 1994.

[37] M. J. ThoUappillil, R., V. A. Rakov, M. A. Uman, W. H. Beasley and and D. V. S. Master, "Lightning subsequent-stroke electric field peak greater than the first stroke peak and mUltiple ground terminations," *J. Geophys. Res.*, vol. 97, no. 1, pp. 7503–7509, 1992.

[38] A. F. R. Leal, B. R. P. Rocha and V. A. Rakov, "Estimation of ionospheric reflection heights using CG and IC lightning electric field waveforms," 2017 International Symposium on Lightning Protection (XIV SIPDA), 2017, pp. 212-217, doi: 10.1109/SIPDA.2017.8116926.

[39] S. N. M. Arshad, M. Z. A. Ab Kadir, M. Izadi, M. N. Hamzah, C. Gomes, and J. Jasni, "Characterization of measured lightning electric fields observed in Malaysia," *2014 Int. Conf. Light. Prot. ICLP 2014*, pp. 1058–1063, 2014, doi: 10.1109/ICLP.2014.6973281.

[40] H. E. R. and F. R. M. I. Nino, "Characterization of positive return strokes from a thunderstorm day observed in Bogota, Colombia," *2019 Int. Symp. Light. Prot. (XV SIPDA), Sao Paulo, Brazil*, pp. 1–6, 2019.

[41] S. D. Lambert Bodewein, Kristina Schmiedchen, Dagmar Dechent, Dominik Stunder, David Graefrath, Lukas Winter, Thomas Kraus,

"Systematic review on the biological effects of electric, magnetic and electromagnetic fields in the intermediate frequency range (300 Hz to 1 MHz)," *Environ. Res.*, vol. 171, pp. 247–259, 2019.

[42] C. Zhao et al., "Microwave Frequency Dissemination at NTSC," 2019 Joint Conference of the IEEE International Frequency Control Symposium and European Frequency and Time Forum (EFTF/IFC), 2019, pp. 1-2, doi: 10.1109/FCS.2019.8855998.

[43] D. S. C. Jaume Calvo-de la Rosa, Alexandre Locquet, Denis Bouscaud, Sophie Berveiller, "Optical constants of CuO and ZnO particles in the terahertz frequency range," *Ceram. Int. J.*, vol. 46, no. 15, pp. 24110–24119, 2020.

[44] A. Galvan and M. Fernando, "Operative characteristics of a parallel-plate antenna to measure vertical electric fields from lightning flashes," Uppsala University, 2000.

[45] L. Araújo and S. Visacro, "Low-cost Systems for Measurement of Lightning-Currents Provided with Remote Access," 2018 34th International Conference on Lightning Protection (ICLP), 2018, pp. 1-6, doi: 10.1109/ICLP.2018.8503475.

[46] A. A. Basahel, I. M. Rafiqul, M. H. Habaebi and S. A. Zabidi, "Availability modeling of terrestrial free-space-optical links using fade statistics from tropical climate," 2017 IEEE 4th International Conference on Smart Instrumentation, Measurement and Application (ICSIMA), 2017, pp. 1-4, doi: 10.1109/ICSIMA.2017.8312016.

[47] S. Sharma, N. Patel, N. Ojha, V. Joshi and S. Saha, "Satellite and Modelling based Investigations of the Middle Atmospheric Temperature Climatology over the Equatorial Regions," 2019 URSI Asia-Pacific Radio Science Conference (AP-RASC), 2019, pp. 1-1, doi: 10.23919/URSIAP-RASC.2019.8738627.

[48] L. Feifan, M. Dong, Z. Baoyou, M. Ming and L. Peng, "Characteristics of narrow bipolar Events," 2016 33rd International Conference on Lightning Protection (ICLP), 2016, pp. 1-4, doi: 10.1109/ICLP.2016.7791483.

[49] T. A. L. N. Gunasekara, S. P. A. Vayanganie, S. N. Jayalal, M. Fernando, D. U. J. Sonnadara and V. Cooray, "Time-frequency analysis of narrow bipolar pulses observed in Sri Lanka," 2016 33rd International Conference on Lightning Protection (ICLP), 2016, pp. 1-5, doi: 10.1109/ICLP.2016.7791401.

[50] D. T. and J. A. C. A. Nag, V.A. Rakov, "On phenomenology of compact intracloud discharges," *J. Geophys. Res.*, vol. 115, 2010.

[51] Z. Zakaria, N. A. Ahmad, Z. C. L. Wooi, M. R. M. Esa, Abdul-Malek and Z. Zakaria, "Wavelet analysis for negative return stroke and narrow bipolar pulses," 2016 33rd International Conference on Lightning

Protection (ICLP), 2016, pp. 1-5, doi: 10.1109/ICLP.2016.7791410.

[52] L. Feifan, Z. Baoyou, M. Ming and W. wenwei, "A Simple Current waveform model for Narrow Bipolar Pulses," 2018 34th International Conference on Lightning Protection (ICLP), 2018, pp. 1-6, doi: 10.1109/ICLP.2018.8503365.

[53] E. A. Hirsch, J. A. Schrock, S. B. Bayne, H. O'Brien and A. Ogunniyi, "Narrow pulse evaluation of 15 KV SiC MOSFETs and IGBTs," 2017 IEEE 21st International Conference on Pulsed Power (PPC), 2017, pp. 1-4, doi: 10.1109/PPC.2017.8291248.

[54] B. Salimi, K. Mehranzamir, and Z. Abdul-Malek, “Statistical Analysis of Lightning Electric Field Measured Under Equatorial Region Condition,” *Procedia Technol.*, vol. 11, pp. 525–531, 2013, doi: 10.1016/j.protcy.2013.12.224.

[55] Y. Zhu, V. Rakov, and M. Tran, “A Study of Preliminary Breakdown and Return Stroke Processes in High-Intensity Negative Lightning Discharges,” Atmosphere, vol. 7, no. 10, p. 130, Oct. 2016, doi: 10.3390/atmos7100130.

[56] S. L. Cooray, V., “On the characteristics of some radiation fields from lightning and their possible origin in possible origin in ground flashes,” *J. Geophys. Res.*, vol. 87, no. 11, pp. 203–214, 1982.

[57] C. L. Wooi, Z. Abdul-Malek, N. A. Ahmad, and A. I. El Gayar, “Statistical analysis of electric field parameters for negative lightning in Malaysia,” *J. Atmos. Solar-Terrestrial Phys.*, vol. 146, pp. 69–80, 2016, doi: 10.1016/j.jastp.2016.05.007.

[58] M. D. Master, M. J., M. A. Uman, W. H. Beasley, “Lightning induced voltages on power lines: Experiment,” *IEEE Trans. Electromagn. Compability*, vol. 1, pp. 437–445, 1984.

[59] C. Heidler, F., Hopf, “Measurement results of the electric fields in cloud-to- ground lightning in nearby Munich, Germany,” *IEEE Trans. Electromagn. Compability*, vol. 40, no. 4, pp. 463–443, 2000.

[60] C. Paul and F. H. Heidler, "Electric Field Characteristics of Subsequent Return Strokes, M-Components, and ICC-Pulses From Negative Upward Lightning Measured at the Peissenberg Tower," in IEEE Transactions on Electromagnetic Compatibility, vol. 61, no. 4, pp. 1138-1146, Aug. 2019, doi: 10.1109/TEMC.2018.2845686.

[61] Syahrun Nizam Md Arshad, “Characterisation of lightning-generated Electric Fields and Development of Automated Measuring System for Cloud-To-Ground Lightning in Malaysia,” Universiti Putra Malaysia, 2017.

[62] N. K. Challagondla and D. Thummapal, "The study of very fast transient over voltages (VFTO) for the project of 400/220kV GIS substation with one and half circuit breaker configuration," 2016 IEEE International Conference on High Voltage Engineering and Application (ICHVE), 2016, pp. 1-4, doi: 10.1109/ICHVE.2016.7800605.

[63] Z. Qiu, H. Gao, and Y. Yang, “Lightning parameters measurement systems and Instrumentation on meteorological gradient observation tower in Shenzhen China,” *2015 Int. Symp. Light. Prot. XIII SIPDA 2015*, pp. 306–308, 2015, doi: 10.1109/SIPDA.2015.7339294.

[64] J. Huang, Y. Luo, Y. Li, J. Shi, X. Zheng and J. Wang, "Analysis of Sound Speed Profile in the South China Sea based on Empirical Orthogonal Function Algorithm," 2021 OES China Ocean Acoustics (COA), 2021, pp. 166-171, doi: 10.1109/COA50123.2021.9520009.

[65] L. M. Rubio, J. P. Brito Filho and J. R. Henriquez, "Performance of a PV/T Solar Collector in a Tropical Monsoon Climate City in Brazil," in IEEE Latin America Transactions, vol. 16, no. 1, pp. 140-147, Jan. 2018, doi: 10.1109/TLA.2018.8291466.

[66] M. Guimaraes, M. Arcanjo, M. H. Vale, P. Teixeira, and S. Visacro, “Features of negative and positive leaders of negative CG lightning according to simultaneous records of current, E-field, luminosity and high-speed videos,” *34th Int. Conf. Light. Prot. ICLP 2018*, 2018, doi: 10.1109/ICLP.2018.8503347.

[67] M. Guimarães, P. Ramos, R. Sobreiro, and S. Visacro, “Lightning measurements at morro do cachimbo station: New results,” *2014 Int. Conf. Light. Prot. ICLP 2014*, pp. 1695–1700, 2014, doi: 10.1109/ICLP.2014.6973401.

[68] K. Michishita, S. Kurihara and K. Takano, "Measurement and modeling of lightning current at wind turbine in summer," 2016 33rd International Conference on Lightning Protection (ICLP), 2016, pp. 1-5, doi: 10.1109/ICLP.2016.7791462.

[69] S. Grebovic, I. Uglesic, A. Balota and B. Franc, "Analytics of Lightning Data Collected by the Direct Measurement System and Lightning Location System," 2018 IEEE PES Innovative Smart Grid Technologies Conference Europe (ISGT-Europe), 2018, pp. 1-6, doi: 10.1109/ISGTEurope.2018.8571806.

[70] F. H. H. and W. S. C. Paul, “Optical Lightning Measurement System and First Results,” *34th International Conference Lightning Protection..*, pp. 1–5, 2018.

[71] V. C. Norbayah Yusop, Mohd Riduan Ahmad, Mardina Abdullah, Siti Khalijah Zainudin, Wan Nur Arina Wan Mohd Nor, Kemal Maulana Alhasa, Mona Riza Mohd Esa, Muhammad Haziq Mohamad Sabri, Wayan Suparta,Adriana Maria Gulisano, “Cloud-to-Ground lightning

observations over the Western Antarctic region," *Polar Science.*, vol. 20, no. 1, pp. 84–91, 2019.

[72] Tushabe F, "Comparison of COVID-19 Severity Between Tropical and Non-Tropical Countries," *International Journal of Infection.*, vol. 7, no. 3, pp. 104–142, 2020.

[73] J. M. . Smith, "Tropical rainforest," *Encyclopedia Britannica*. 2019.

[74] V. Cooray, F. Rachidi and M. Rubinstein, "Formulation of the Field-to-Transmission Line Coupling Equations in Terms of Scalar and Vector Potentials," in IEEE Transactions on Electromagnetic Compatibility, vol. 59, no. 5, pp. 1586-1591, Oct. 2017, doi: 10.1109/TEMC.2017.2657891.

[75] E. P. K. Weidman, C. D., "The radiation field waveforms produced by intracloud lightning discharge processes," *J. Geophys. Res.*, vol. 84, no. 6, pp. 3159–3164, 1979.

[76] R. E. de Souza, R. M. Gomes, G. S. Lima, F. H. Silveira, A. De Conti and S. Visacro, "Preliminary analysis of the impulse breakdown characteristics of XLPE-covered cables used in compact distribution lines," 2016 33rd International Conference on Lightning Protection (ICLP), 2016, pp. 1-6, doi: 10.1109/ICLP.2016.7791387.

[77] J. C. Willett and E. P. Krider, "Rise times of impulsive high-current processes in cloud-to-ground lightning," *IEEE Trans. Antennas Propag.*, 2000, doi: 10.1109/8.898779.

[78] L. Wang, Z. Guo, Q. Zhao, H. Li, Q. Li and X. Wu, "Research of Atmospheric Electric Field Characteristics in the Process of Lightning in Time and Frequency Domain," 2019 International Conference on Meteorology Observations (ICMO), 2019, pp. 1-4, doi: 10.1109/ICMO49322.2019.9026046.

[79] N. Watanabe, A. Nag, G. Diendorfer, H. Pichler and W. Schulz, "Close and distant electric fields due to lightning attaching to the Gaisberg Tower," 2017 International Symposium on Lightning Protection (XIV SIPDA), 2017, pp. 376-379, doi: 10.1109/SIPDA.2017.8116955.

[80] A. F. R. Leal, V. A. Rakov and B. R. P. Rocha, "Upgrading a Low-Cost System for Measuring Lightning Electric Field Waveforms," in IEEE Transactions on Electromagnetic Compatibility, vol. 61, no. 2, pp. 595-598, April 2019, doi: 10.1109/TEMC.2018.2822695.

[81] W. Beasley, "Positive cloud-to-ground lightning observations," *J. Geophys. Res.*, vol. 90, no. 4, pp. 6131–6138, 1985.

[82] A. Srivastava, S. Yuan, X. Qie, R. Jiang and D. Wang, "Observation on Upward Lightning Induced by Nearby Positive Cloud-to-Ground Lightning based on Highspeed Camera and Radio Frequency Mapping System," 2019 11th Asia-Pacific International Conference on Lightning

(APL), 2019, pp. 1-5, doi: 10.1109/APL.2019.8816004.

[83] V. C. and M. Z. A. A. K. C. Gomes, “Vertical Electric Fields And Field Change Parameters Due To Partly Inclined Lightning Leader Channels,” *Prog. Electromagn. Res.*, vol. 135, pp. 55–80, 2013.

[84] V. A. R. and S. A. C. M. A. Haddad, “New measurements of lightning electric fields in Florida: Waveform characteristics, interaction with the ionosphere, and peak current estimates,” *J. Geophys. Res.*, vol. 117, 2012.

[85] F. Napolitano, F. Tossani, A. Borghetti, C. A. Nucci and F. Rachidi, "Lightning performance of distribution lines due to positive and negative indirect lightning flashes," 2017 IEEE International Conference on Environment and Electrical Engineering and 2017 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe), 2017, pp. 1-5, doi: 10.1109/EEEIC.2017.7977777.

[86] V. A. R. Pavlick, A., D. E. Crawford, “Characteristics of dis- tant lightning electric fields,” *Int. Conf. Probabilistic Methods Appl. to Power Syst.*, 2002.

[87] M. Guimaraes, M. H. Vale and S. Visacro, "Electric Field During Upward Connecting Leader Initiation in Negative Cloud-to-Ground Lightning Measured at a 50-m Distance", IEEE Trans. Electromagn. Compat., pp. 1-4, 2018.

[88] S. Visacro, M. Guimaraes and M. H. Murta Vale, "Striking Distance Determined From High-Speed Videos and Measured Currents in Negative Cloud-to-Ground Lightning", J. Geophys. Res. Atmos., Dec. 2017.

[89] T. Miki *et al.*, “Measurement of lightning currents at TOKYO SKYTREE® and observation of electromagnetic radiation caused by strikes to the tower,” *2012 31st Int. Conf. Light. Prot. ICLP 2012*, pp. 4–8, 2012, doi: 10.1109/ICLP.2012.6344298.

[90] T. Miki, M. Saito, T. Shindo, M. Ishii and N. Sakurai, "Lightning-initiated Upward Lightning Flashes Observed at Tokyo Skytree in April 2017," 2018 34th International Conference on Lightning Protection (ICLP), 2018, pp. 1-6, doi: 10.1109/ICLP.2018.8503275.

[91] M. Saito, M. Ishii, T. Miki, T. Shindo and T. Sonehara, "Reproduction of Electromagnetic Field Waveforms of Downward Lightning Strokes Hitting Tokyo Skytree," in IEEE Transactions on Electromagnetic Compatibility, vol. 61, no. 3, pp. 815-822, June 2019, doi: 10.1109/TEMC.2019.2911691.

[92] F. H. Heidler and C. Paul, “Some return stroke characteristics of negative lightning flashes recorded at the peissenberg tower,” *IEEE Trans. Electromagnetic Compatible.*, vol. 59, no. 5, pp. 1490–1497, 2017, doi:

10.1109/TEMC.2017.2688587.

[93] F. Rachidi, “Modeling Lightning Return Strokes to Tall Structures: A Review,” Journal of Lightning Research, vol. 1, pp. 16-31, 2007.

[94] A. Smorgonskiy, F. Rachidi, M. Rubinstein, G. Diendorfer and W. Schulz, "On the proportion of upward flashes to lightning research towers," 2011 7th Asia-Pacific International Conference on Lightning, 2011, pp. 858-862, doi: 10.1109/APL.2011.6110248.

[95] M. A. Haddad, V. A. Rakov, and S. A. Cummer, “New measurements of lightning electric fields in Florida: Waveform characteristics, interaction with the ionosphere, and peak current estimates,” *J. Geophys. Res. Atmos.*, 2012, doi: 10.1029/2011JD017196.

[96] V. Cooray and S. Lundquist, “On the characteristics of some radiation fields from lightning and their possible origin in positive ground flashes,” *J. Geophys. Res.*, 1982, doi: 10.1029/jc087ic13p11203.

[97] M. J. Master and M. A. Uman, “Lightning induced voltages on power lines: Theory,” *IEEE Trans. Power Appar. Syst.*, 1984, doi: 10.1109/TPAS.1984.318405.

[98] S. Sudin, “Performance Prediction based on Fitness Level for Track Cycling Activity using Artificial Intelligence by Doctor of Philosophy School of Mechatronic Engineering,” 2019.

[99] H. Khaled, "Enhancing Recursive Brute Force Algorithm with Static Memory Allocation: Solving Motif Finding Problem as a Case Study," 2019 14th International Conference on Computer Engineering and Systems (ICCES), 2019, pp. 66-70, doi: 10.1109/ICCES48960.2019.9068158.

[100] S. M. Raafat and D. J. Naji, “Intelligent Optimized Controlled Health Care System Using Brute Force and Heuristic Algorithms,” *Third Sci. Conf. Electr. Eng.*, pp. 134–139, 2018.

[101] S. L. and Y. V. A. M. Thike, “Implementation of brute force algorithm for topology optimisation of wireless networks,” *Int. Conf. Students Appl. Eng.*, pp. 264–268, 2016.

[102] R. Davidrajuh and C. Rong, “Solving Scheduling Problems with Randomized and Parallelized Brute-Force Approach,” *Comput. Sci. Inf. Technol.*, pp. 1–4, 2019.

[103] J. Sannemo, “Principles of Algorithmic Problem Solving,” 2018. Accessedon:Apr.30,2021.[Online].Available:https://www.csc.kth.se/~jsannemo/slask/main.pdf

[104] L. G. Hubner, A. G. Maletzke, B. L. de Nadai, R. L. Schaefer, W. Zalewski and C. A. Ferrero, "FB-DT: An improvement in the Brute Force

algorithm for motifs discovery," in IEEE Latin America Transactions, vol. 15, no. 8, pp. 1542-1546, 2017, doi: 10.1109/TLA.2017.7994804.

[105] S. Aslan, D. Karaboğa and M. Doğruer, "Accelerating search tree based brute force motif discovery technique on a processor cluster," 2016 24th Signal Processing and Communication Application Conference (SIU), 2016, pp. 793-796, doi: 10.1109/SIU.2016.7495859.

[106] S. S. Shenoy, U. S. Nayak and B. Neelima, "SWIFT-A Performance Accelerated Optimized String Matching Algorithm for Nvidia GPUs," 2016 15th International Symposium on Parallel and Distributed Computing (ISPDC), 2016, pp. 80-87, doi: 10.1109/ISPDC.2016.19.

[107] M. Künzli, P. Meier and R. Dornberger, "A memory search algorithm for path finding problems compared with a genetic algorithm," 2016 4th International Symposium on Computational and Business Intelligence (ISCBI), 2016, pp. 66-73, doi: 10.1109/ISCBI.2016.7743260.

[108] Izzat Alsmadi and Maryam Nuser, "String Matching Evaluation Methods for DNA Comparison," *International Journal of Advanced Science and Technology*., vol. 47, 2020.

[109] Y. Cao, B. Wang, W. Zhao, X. Zhang and H. Wang, "Research on Searching Algorithms for Unstructured Grid Remapping Based on KD Tree," 2020 IEEE 3rd International Conference on Computer and Communication Engineering Technology (CCET), 2020, pp. 29-33, doi: 10.1109/CCET50901.2020.9213175.

[110] S. Suzuki, M. Fujiwara, Y. Makino and H. Shinoda, "Radiation Pressure Field Reconstruction for Ultrasound Midair Haptics by Greedy Algorithm With Brute-Force Search," in IEEE Transactions on Haptics, vol. 14, no. 4, pp. 914-921, 1 Oct.-Dec. 2021, doi: 10.1109/TOH.2021.3076489.

[111] S. Khan, S. Anjum, U. A. Gulzari, T. Umer and B. -S. Kim, "Bandwidth-Constrained Multi-Objective Segmented Brute-Force Algorithm for Efficient Mapping of Embedded Applications on NoC Architecture," in IEEE Access, vol. 6, pp. 11242-11254, 2018, doi: 10.1109/ACCESS.2017.2778340.

[112] C. Wu et al., "A multi-objective model oriented mapping approach for NoC-based computing systems", IEEE Trans. Parallel Distribution System, vol. 28, no. 3, pp. 662-676, Mar. 2017.

[113] S. H. and H. Haynal, "Brute-Force Search of Fast Convolution Algorithms," *2013 IEEE Int. Conf. Acoust. Speech Signal Process.*, pp. 2586–2590, 2013.

[114] Q. -L. Nguyen, E. Valea, M. -L. Flottes, S. Dupuis and B. Rouzeyre, "A Secure Scan Controller for Protecting Logic Locking," 2020 IEEE 26th International Symposium on On-Line Testing and Robust System Design (IOLTS), 2020, pp. 1-6, doi:

10.1109/IOLTS50870.2020.9159730.

[115] A. Chakraborty, N. G. Jayasankaran, Y. Liu, J. Rajendran, O. Sinanoglu, A. Srivastava, et al., "Keynote: A Disquisition on Logic Locking", IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems, 2019.

[116] K. Shamsi, M. Li, K. Plaks, S. Fazzari, D. Z. Pan and Y. Jin, "IP Protection and Supply Chain Security Through Logic Obfuscation: A Systematic Overview", ACM Trans. Des. Autom. Electron. Syst, vol. 24, pp. 65:1-65:36, Sept. 2019.

[117] S. Haynal and H. Haynal, "Generating and searching families of FFT algorithms," *J. Satisf. Boolean Model. Comput.*, vol. 7, no. 145–187, 2011.

[118] V. Patil and T. M. Manu, "FPGA Implementation Radix-2 DIT FFT Using Fixed Point Arithmetic and Reduced Arithmetic Complexity," 2021 International Conference on Intelligent Technologies (CONIT), 2021, pp. 1-4, doi: 10.1109/CONIT51480.2021.9498315.

[119] Harsha Keerthan, Shaik Qadeer, Syed Azeemuddin and Zafar Khan, "Parallel and Pipelined VLSI Implementation of the New Radix-2 DIT FFT Algorithm", IEEE International Symposium on Smart Electronic Systems (iSES), 2018.

[120] K. Alizadeh Vahid, A. Prabhu, A. Farhadi and M. Rastegari, "Butterfly Transform: An Efficient FFT Based Neural Architecture Design," 2020 IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR), 2020, pp. 12021-12030, doi: 10.1109/CVPR42600.2020.01204.

[121] V. Chiriaco, A. Franzen, R. Thayil, and X. Zhang, "Finding partial hash collisions by brute force parallel programming," *2017 IEEE Long Isl. Syst. Appl. Technol. Conf. LISAT 2017*, vol. 1, pp. 1–6, 2017, doi: 10.1109/LISAT.2017.8001964.

[122] S. Palit and K. A. Wortman, "Perfect Tabular Hashing in Pseudolinear Time," 2021 IEEE 11th Annual Computing and Communication Workshop and Conference (CCWC), 2021, pp. 0228-0232, doi: 10.1109/CCWC51732.2021.9375992.

[123] I. V. Chugunkov, M. A. Ivanov and B. V. Kliuchnikova, "Hash Functions are Based on Three-Dimensional Stochastic Transformations," 2019 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering (EIConRus), 2019, pp. 202-205, doi: 10.1109/EIConRus.2019.8656708.

[124] K. Rajeshwaran and K. Anil Kumar, "Cellular Automata Based Hashing Algorithm (CABHA) for Strong Cryptographic Hash Function," 2019 IEEE International Conference on Electrical, Computer and

Communication Technologies (ICECCT), 2019, pp. 1-6, doi: 10.1109/ICECCT.2019.8869146.

[125] X. Gou et al., "Single Hash: Use One Hash Function to Build Faster Hash Based Data Structures," 2018 IEEE International Conference on Big Data and Smart Computing (BigComp), 2018, pp. 278-285, doi: 10.1109/BigComp.2018.00048.

[126] Katz and Y. Lindell, “Introduction to Modern Cryptography, 2nd ed,” CRC Press, 2014.

[127] A. C. Robinson and S. D. Quinn, “A brute force method for spatially-enhanced multivariate facet analysis,” *Computer Environment Urban System.*, vol. 69, no. June 2017, pp. 28–38, 2018, doi: 10.1016/j.compenvurbsys.2017.12.003.

[128] X. Liu and H. -W. Shen, "Association Analysis for Visual Exploration of Multivariate Scientific Data Sets," in IEEE Transactions on Visualization and Computer Graphics, vol. 22, no. 1, pp. 955-964, 31 Jan. 2016, doi: 10.1109/TVCG.2015.2467431.

[129] S. Koshman and F. Azhari, "Incorporating Condition Monitoring for Multi-Faceted Decisions," 2019 Annual Reliability and Maintainability Symposium (RAMS), 2019, pp. 1-5, doi: 10.1109/RAMS.2019.8768999.

[130] S. Su, W. Pedrycz, T. Hong and F. D. A. T. De Carvalho, "Guest Editorial Special Issue on Granular/Symbolic Data Processing," in IEEE Transactions on Cybernetics, vol. 46, no. 2, pp. 342-343, Feb. 2016, doi: 10.1109/TCYB.2015.2513258.

[131] S. Noh, J. Han, J. Jo and A. Choi, "Virtual Companion Based Mobile User Interface: An Intelligent and Simplified Mobile User Interface for the Elderly Users," 2017 International Symposium on Ubiquitous Virtual Reality (ISUVR), 2017, pp. 8-9, doi: 10.1109/ISUVR.2017.10.

[132] G. Miao, L. Hongxing, X. Songyu and L. Juncai, "Research on User Interface Transformation Method Based on MDA," 2017 16th International Symposium on Distributed Computing and Applications to Business, Engineering and Science (DCABES), 2017, pp. 150-153, doi: 10.1109/DCABES.2017.40.

[133] T. Thi Xuan Lam, A. Duc Le and M. Nakagawa, "User Interface for Text and Non-Text Classification," 2019 International Conference on Document Analysis and Recognition Workshops (ICDARW), 2019, pp. 1-5, doi: 10.1109/ICDARW.2019.20044.

[134] B. Abibullaev, I. Dolzhikova, and A. Zollanvari, “A Brute-Force CNN Model Selection for Accurate Classification of Sensorimotor Rhythms in BCIs,” *IEEE Access*, vol. 8, pp. 101014–101023, 2020, doi: 10.1109/ACCESS.2020.2997681.

[135] Y. Zhou, S. He, Q. Huang and Y. Li, "A Hybrid Asynchronous Brain-Computer Interface Combining SSVEP and EOG Signals," in IEEE Transactions on Biomedical Engineering, vol. 67, no. 10, pp. 2881-2892, Oct. 2020, doi: 10.1109/TBME.2020.2972747.

[136] M. Eidel, W. Tröger, M. Winterholler, T. Giesler and A. Kübler, "A Tactile Brain-Computer Interface for Virtual Wheelchair Control at Home," 2021 9th International Winter Conference on Brain-Computer Interface (BCI), 2021, pp. 1-3, doi: 10.1109/BCI51272.2021.9385341.

[137] Y. -J. Kim, N. -S. Kwak and S. -W. Lee, "Classification of motor imagery for Ear-EEG based brain-computer interface," 2018 6th International Conference on Brain-Computer Interface (BCI), 2018, pp. 1-2, doi: 10.1109/IWW-BCI.2018.8311517.

[138] J. Ha and L. Kim, "A brain—computer interface-based meal—assist robot control system," 2021 9th International Winter Conference on Brain-Computer Interface (BCI), 2021, pp. 1-3, doi: 10.1109/BCI51272.2021.9385359.

[139] N. A. Bhagat, A. Venkatakrishnan, B. Abibullaev, E. J. Artz, N. Yozbatiran, A. A. Blank, et al., "Design and optimization of an EEG-based brain machine interface (BMI) to an upper-limb exoskeleton for stroke survivors", Frontiers Neurosci., vol. 10, pp. 122, 2016.

[140] “Physionet Motor/Mental Imagery (MMI) Database.” [Online]. Available: https://archive.physionet.org/pn4/ eegmmidb.

[141] F. Lotte, L. Bougrain, A. Cichocki, M. Clerc, M. Congedo, A. Rakotomamonjy, et al., "A review of classification algorithms for EEG-based brain-computer interfaces: A 10 year update", J. Neural Eng., vol. 15, no. 3, 2018.

[142] U. Chaudhary, N. Birbaumer and A. Ramos-Murguialday, "Brain–computer interfaces in the completely locked-in state and chronic stroke", Prog. Brain Res., vol. 228, pp. 131-161, 2016.

[143] G. Dai, J. Zhou, J. Huang and N. Wang, "HS-CNN: A CNN with hybrid convolution scale for EEG motor imagery classification", J. Neural Eng., vol. 17, no. 1, Jan. 2020.

[144] R. T. Schirrmeister, J. T. Springenberg, L. D. J. Fiederer, M. Glasstetter, K. Eggensperger, M. Tangermann, et al., "Deep learning with convolutional neural networks for EEG decoding and visualization", Hum. Brain Mapping, vol. 38, no. 11, pp. 5391-5420, Nov. 2017.

[145] Vernon Cooray and Rachidi-Haeri Farhad, “ELF Electromagnetic Waves from Lightning: The Schumann Resonances,” *Atmosphere (Basel).*, vol. 7, p. 116, 2016.

[146] M. F. U.Sonnadra, V.Corray, “The Lightning Radiation Field Spectra of

Cloud Flashes in the Interval from 20 kHz to 20 MHz," *IEEE Trans. Electromagn. Compat.*, vol. 42, no. 1, pp. 234–239, 2006.

[147] H. N. A. K.Mehranzamir, "Hardware Installation of Lightning Locating System Using Time Difference of Arrival Method," *International Conference Electrical Engineering Computer Science.*, pp. 29–34, 2012.

[148] C. C. H.Rojas, a. Cruz, "Characteristics of lightning-generated electric fields measured in the Bogota Savanna, Colombia," *Electromagnetic Compatible Interference Research.*, vol. 16, no. 2, pp. 243–252, 2017.

[149] M. R. Ahmad et al., "Emission heights of narrow bipolar events in a tropical storm over the Malacca Strait," *International Conference Electrical Engineering Computer Science.*, pp. 305–309, 2017.

[150] Z. Z. and M. R. A. C. Wooi, Z. Abdul-Malek, N. A. Ahmad, M. R. M. Esa, "Wavelet analysis of chaotic pulse trains prior to subsequent return strokes in Malaysia," *33rd International Conference Lightning Protection.*, pp. 1–6, 2016.

[151] V. C. and M. R. M. E. M. R. M. Esa, M. R. Ahmad, "Time-Frequency profile of discharge processes prior to the first return stroke," *2014 International Conference Lightning Protection.*, pp. 1134–1137, 2014.

[152] J. Hojo, M. Ishii, T. Kawamura, F. Suzuki, and R. Funayama, "The fine structure in the field change produced by positive ground strokes.," *J. Geophys. Res.*, 1985, doi: 10.1029/JD090iD04p06139.

[153] C. G. and F. R. F.Santamaria, "Comparison Between the Signatures of Lightning Electric Field Measured in Colombia and that in Sri Lanka," *28th International Conference Lightning Protection.*, 2006.

[154] M. Ishii and J. I. Hojo, "Statistics on fine structure of cloud-to-ground lightning field waveforms," *J. Geophys. Res.*, 1989, doi: 10.1029/jd094id11p13267.

[155] V. Cooray and S. Lundquist, "Characteristics of the radiation fields from lightning in Sri Lanka in the tropics.," *J. Geophys. Res.*, 2005, doi: 10.1029/JD090iD04p06099.

[156] Y. T. Lin *et al.*, "Characterization of Lightning Return Stroke Electric and Magnetic FIelds From SImultaneous Two-Station Measurements.," *J. Geophys. Res.*, 1979, doi: 10.1029/JC084iC10p06307.

[157] G. De Luca, "Brute Force Algorithm in Cybersecurity and String Search,"*Baeldung,* October 21, 2020. [Online]. Available: http://baeldung.com.

[158] Muhammad Noh Hamzah, "Distinct Characteristics of Cloud-to-Ground Lightning Electric Fields Generated in Malaysia," Universiti Putra Malaysia, 2015.