A SYSTEMATIC ANALYSIS OF DIFFERENT MACHINE LEARNING & DEEP LEARNING TECHNIQUES USED FOR PREDICTING CYCLONES

Mr.Abhishek A K
Saintgits College Of Applied Sciences
Pathamuttom,Kottayam, Kerala – 686532
cptabhishekak47@gmail.com

Mr.Bijesh P B
Saintgits College Of Applied Sciences
Pathamuttom,Kottayam, Kerala – 686532
bijeshpbinu@gmail.com

Mr. Alwin
Saintgits College Of Applied Sciences
Pathamuttom,Kottayam, Kerala – 686532
alwin6000@gmail.com

Mr.Dhananjay Suresh
Saintgits College of Applied Sciences
Pathamuttom,Kottayam,Kerala – 686532
dhananajays75@gmail.com

Ms.Johnsymol Joy
Assistant Professor
Saintgits College of Applied Sciences
Pathamuttom,Kottayam,Kerala – 686532
johnsymol.joy@saintgits.org

Abstract

Cyclones, with their catastrophic potential, pose enormous hazards to coastline communities around the world. Promising outcomes have been observed in the prediction of cyclone behavior through the incorporation of machine learning techniques in meteorological research in recent years. This research paper presents a systematic analysis of various machine learning *methodologies employed for cyclone prediction. This research deals with the collection and preprocessing of extensive meteorological data, spanning historical cyclone occurrences and associated atmospheric conditions. This research paper conducts a comprehensive assessment of different ML methods for cyclone prediction. The main goal is to assess how well these methods work for predicting important cyclone characteristics including intensity, track, and landfall locations. The objective is to shed light on how various algorithms—including SVM, decision trees, neural networks, etc.—perform.*

Keywords— Machine Learning, supervised learning, multi-class classification algorithms, Tropical Cyclones, Deep Learning, Support vector machines, Decision tree

I. INTRODUCTION

The rise in the intensity and frequency of cyclonic occurrences in recent years have highlighted the urgent need for sophisticated and precise prediction techniques. This research paper conducts a thorough analysis of several ML strategies used for cyclone prediction, acknowledging the critical role that ML plays in improving forecasting abilities. As coastal regions grapple with the escalating threats posed by these natural catastrophes, understanding the efficacy of various algorithms in predicting cyclone trajectories, intensities, and landfall locations becomes paramount. This systematic analysis delves into the nuances of neural networks, SVM, decision trees, and ensemble methods, evaluating their performance against rigorous metrics. By shedding light on the strengths and limitations of each approach, this study aims to contribute valuable insights to meteorological research, guiding the refinement of predictive models and fortifying early warning systems to mitigate the impact of cyclones on vulnerable populations.

In the present situation, cyclone prediction is decisive for various reasons- first one is Mitigation of Losses. By enabling authorities to safeguard infrastructure, remove people from high-risk regions, and plan for emergency response, timely and accurate cyclone forecast helps to mitigate possible losses. This lessens the effect on property, life, and the economy. Second one is on humanitarian considerations. Cyclones can cause extensive destruction, uprooting populations, demolishing houses, and interrupting vital services. When human casualties are unlikely, authorities can more accurately plan and execute evacuation procedures. Another one is Infrastructure Planning and Preparedness. Using cyclone forecasts, governments and local authorities can organize and carry out infrastructure projects that are resilient to the effects of cyclones. This entails creating pre-disaster warning systems, enhancing drainage systems, and designing resilient structures. Last one is economic stability. Cyclones can have a serious negative impact on the economy, especially in coastline regions where they are more frequent. Businesses, farmers, and communities can protect their investments, crops, and livelihoods by making educated decisions based on accurate forecasting.

II. Literature Survey

A. *Papers on Cyclone prediction*

Chinmoy Kar et al.[1] This study highlights the need for computational support for effective forecasting as it examines the difficulty of precisely estimating the intensity of Tropical Cyclones in the NIO region. Using TCs' best track data from 2011 to 2020, the study analyzes the effectiveness of various ML classifiers. Naive Bayes, Logistic Regression, Multilayer Perceptron, Sequential Minimal Optimization, C4.5 Decision Trees, Random Trees, and Random Forests are among the classifiers that were assessed. For classification, five predictors are used: maximum sustained wind speed, latitude, longitude, central pressure, and pressure decrease. According to the results, these machine learning classifiers can achieve classification accuracy of 97% to 99%.

Yuqiao Wu et al.[2] Tropical cyclones have a substantial influence on human lives, needing precise and timely forecasting for catastrophe avoidance. Machine learning techniques have the potential to be more advantageous than traditional numerical forecasting methods, which call for substantial resources. However, current approaches frequently miss important details. With the aim to anticipate tropical storm intensity and route, a multitask ML framework is introduced in this letter. It is composed of an estimating module that makes use of two DNN and a prediction module that makes use of an improved GAN. The efficacy of our suggested approach in forecasting tropical cyclones is demonstrated by its 116-kilometer 24-hour path forecast error and 13.06-knot 24-hour intensity forecast error.

G. Vijayakumar et al It can be difficult to identify and predict weather changes, particularly given how frequently and dramatically the weather can change. The Indian subcontinent has seen more frequent and intense cyclones, making accurate detection vital. ML approaches, favored over traditional methods, rely heavily on manual feature engineering. Deep learning, an advanced ML technique, automatically selects features, removing this barrier. It has proven success in weather forecasting and is distinguished from traditional ML algorithms in this study. Three aspects - modeling inputs, methodology, and preprocessing techniques - are examined. Results highlight the performance of different ML algorithms in predicting rainfall based on meteorological data, improving weather awareness and informed decision-making.

Fan Meng et al.[4] This paper introduces a fresh strategy for accurately estimating cyclone size that uses deep CNN. This is a pioneering use of deep learning approaches in estimating TC size. The dataset used includes around 1,000 TC events and approximately 30,000 IR remote sensing photos. A comparison with proven best track archives demonstrates that the suggested model achieves a mean error of 24 nautical miles, beating the National Oceanic and Atmospheric Administration's (NOAA) Multiplatform Tropical Cyclone Surface Winds Analysis. These findings highlight deep learning approaches' significant potential for refining the veracity of TC size prediction.

Ming Xie et al.[5] With multiple techniques created employing cloud photography, wind field data, and sea level pressure, cyclone identification is entrenched yet constantly developing discipline. The data fusion method mentioned in this article integrates information from several remote sensors. An object detection technique based on DL is used to originate an accurate model globally. For training and testing the model, rainfall intensity data from global precipitation measurement is paired with wind field data obtained from the scatterometer measurements. The model comprises two modules: a feature extractor and a region proposal network based on the feature pyramid network (FPN) to detect potential cyclone areas, and a region of interest processor that refines cyclone locations using a fully-connected neural network and bounding box regression. An ablation experiment confirms the importance of data fusion, with wind field data showing more significant contribution to cyclone detection than precipitation data.

Nahruma Mehzabeen Pieu et al.[6] The study's nine ensembles of high-resolution pressure and wind data for 12 historical TCs in the Bay of Bengal (BoB) are supplied by MOUM. Unprecedented devastation and casualties were wreaked by these storms. A reliable coastal model may be created to anticipate the sites of tropical storm landfalls and their surge heights by precisely modelling these storms using high-resolution atmospheric forcing. This would enable the prompt and accurate broadcast of cyclone information. By examining cyclone courses, landfall locations, and forecast periods in the Bay of Bengal, the study streamlines the process of identifying effective ensembles for the creation of coastal models. Every 72 hours, each ensemble is started, the first 60 hours prior to the cyclone's impact, and the others three hours later to determine the forecast's accuracy.

Akshath Mahajan et al.[7] Every year, tropical storms that originate in the NIO basin pose a threat to India and cause extensive property and human damage Accurate prediction of these catastrophes is critical for implementing prompt preventative measures. Utilizing the

CyINSAT dataset spanning from 2014 to 2022, this study compares multiple techniques for wind speed forecasting. Employing recurrent networks and image feature extractors, the models predict future wind speeds from sequential images. Architectural variances focus on handling current wind speed data. The proposed architecture, which prioritizes current wind speed records, outperforms baseline models, achieving an RMSE of 6.31, MAE of 0.093, and MAPE of 4.53. An intercomparison of cyclone tracks among ensembles is conducted 2 to ascertain the most accurate forecasts.

Pavitha N et al.[8] Cyclones are a serious threat to people's lives and property, which makes it crucial to anticipate their severity with accuracy. A methodical technique has been devised to tackle this problem, which involves creating a database of annotated photos that holds crucial information about cyclones, like names, locations, timings, occurrence years, and matching images. Prior to analysis, the data undergoes preprocessing steps including standardization and data augmentation to ensure uniformity and balance representation. A CNN model is then utilized, trained meticulously over 100 epochs using the rmsprop optimizer. The training process yields pertinent metrics, revealing a mean absolute error of 10.83 knots and a root mean square error of 14.49 knots. The model's efficacy is visually assessed through graphical representations of errors. Subsequently, the trained model is applied to make predictions on test images. Additionally, an interactive web application is developed to visualize past cyclones. Users can input specific years and cyclone names to access relevant information. This all-inclusive solution combines rigorous preprocessing, cutting-edge ML methods, and an intuitive user interface to improve our comprehension and readiness for tropical storms.

A.T.R. Krishna Priya et al.[9] Weather forecasters have long studied cyclones, with scientists researching various aspects such as their structure, dynamics, and prediction methodologies. DL has emerged as a promising approach to address the challenges of cyclone prediction, either through purely data-driven systems or by enhancing traditional numerical methods. Intensity estimation, track forecasting, cyclone generation, and related severe weather occurrences are all explored in this study of the use of DL. Despite the potential of DL and the accessibility of vast multi-source data, current utilization for improving cyclone prediction accuracy remains limited. Cyclones' complexity and susceptibility to various factors pose challenges in leveraging DL effectively, which may impact the reliability and duration of cyclone forecasting.

Adam Agus Kurniawan et al.[10] Tropical cyclone events are on the rise as a result of weather patterns becoming more unpredictable due to global warming. A ML algorithm was created to help in the classification of tropical storm intensity. The system uses SVM for classification and GLCM for feature extraction. First, the color spaces of RGB, Ycbcr, and Grayscale are used to extract 14 GLCM features. Feature combinations of 3, 4, and 5 are then tested in the classification stage using SVM with OAO and OAA coding designs and Gaussian, Linear, and Polynomial kernels. Accuracy is assessed in relation to feature combinations. Using infrared photos, the method classifies tropical cyclone intensity with an accuracy rate of 88%, which is consistent with the Saffir-Simpson Hurricane Wind Scale.

Chong Wang et al.[11] In order to forecast the movement direction of cyclones, often called typhoons, in the Northwestern Pacific basin, a deep CNN specifically designed for this purpose was developed using satellite pictures from Himawari-8 (H-8The CNN model was trained on a dataset of 2250 infrared images that included 97 typhoon events that were documented between 2015 and 2018. The study's mean error in forecasting the typhoon movement angle was 27.8°, highlighting the considerable potential of DL approaches in improving the accuracy of tropical storm track prediction. This was achieved by integrating images from various channels as inputs into the CNN architecture.

A. Geetha et al In several domains, including business econometrics, predictive analytics, big data, and statistical studies, the Auto Regressive Integrated Moving Average (ARIMA) model is commonly used, especially for time series researchGiven the substantial effects Tropical Cyclones (TC) have on coastal communities and human life, forecasting TC tracks and intensities with precision is essential to efficient disaster managementIn this study, a statistical time series modeler (TSM) specifically designed for India's cyclonic storm forecasting is presented. The training and testing phases of the TSM of SPSS (Statistical Package for Social Studies) make use of a dataset consisting of 14 attributes that spans six years (2007-2012). The model, developed using training data from 2007 to 2011, is applied to the testing dataset from 2012. The model is built upon the ARIMA model within the TSM framework of SPSS 20.0.

S. Shakya et al.[13] Satellite images are crucial for weather prediction. DL requires diverse annotated data for effective training. Temporal resolution is enhanced using interpolation and data augmentation. Classical approaches are employed in preprocessing. Testing is done on three different optical flow technologies using various optimization strategies and error estimates. The enriched dataset trains a CNN, achieving over 90% accuracy in cyclone classification and over 84% accuracy in cyclone vortex location. Linear regression is explored for path prediction.

S. Gujral et al.[14] Tropical cyclones (TCs), known as typhoons or hurricanes, are significant weather phenomena across five oceans. Traditional monitoring techniques have been ineffective, making accurate TC intensity estimation crucial for reducing human suffering. Recent interest in innovative image processing methods by data scientists and meteorologists shows promise. A modified CNN architecture yields precise results on a benchmark dataset, demonstrating remarkable stability across scenarios and demonstrating data science's promise for meteorological research.

Tushar Paul et al.[15] With over 90 storms annually worldwide,TCs are highly damaging weather systems in tropical oceans. Swift TC detection and tracking are crucial for advanced warnings. Remote sensing is vital due to their origin far from continents. Our novel deep learning-based technique for TC detection from satellite pictures is composed of three phases: a CNN classifier, a wind velocity filter, and a Mask CNN detector. Bayesian optimization tunes hyperparameters for optimal performance. Results show high specificity (97.59%), precision (97.10%), and accuracy (86.55%) in test images.

III. Results and discussions

Review papers used various ML, DL, and ensemble techniques for prediction and analysis. Data from several sources, including as satellite imaging, atmospheric measurements, and pacific data, can be integrated by ML and DL models. The ability to fuse data allows for a more thorough comprehension of the complex atmospheric conditions conducive to cyclone formation With the aim of anticipating cyclones, meteorological data must have the ability to capture both temporal and spatial relationships. The modeling of cyclonic systems can be improved by RNNs, Long Short-Term Memory Networks (LSTMs), and CNNs, which are well-suited for handling time-series data and spatial information. Without the requirement for manual modifications, DL & ML models are very well capable of reacting to shifting circumstances and developing patterns. Climate prediction relies heavily on this flexibility because the climate is subject to variations brought on by factors such as climate change and global warming.

These studies confront a number of difficulties, such as poor data quality and accessibility, imbalances in uncommon occurrences and data, unpredictability in both space and time, and data integration, among other issues. ML and DL model performance can be strongly impacted by the standard of meteorological data, including aspects like accuracy, resolution, and coverage. Obtaining extensive and superior quality datasets might be difficult, particularly in isolated or under-monitored areas, denying to train resilient models. Since cyclones are comparatively uncommon occurrences, the model's capacity to generalize to them may be impacted by imbalances in the dataset. Precise predictions depend on training data having a fair representation of cyclonic events. The temporal and spatial diversity exhibited by cyclones in datasets may be challenging to characterize. Variations in cyclone features across seasons, regions, and climate patterns must be accommodated by models. It is a difficult challenge to combine several data sources, such as satellite imaging, atmospheric measurements, and oceanic data, into a coherent dataset for model training. It is essential to create data assimilation techniques so as to successfully combine information from multiple sources.

IV. FUTURE ENHANCEMENTS

Develop models that not only predict cyclone paths but also assess the associated risks, such as storm surge and wind intensity. Improve communication strategies to convey predictions and risks effectively to communities, aiding in better preparedness and response. Foster collaboration between meteorologists, data scientists, and domain experts to enhance the understanding of meteorological phenomena and integrate it with existing ML/DL strategies.

V. CONCLUSION

Comprehensive modeling, ensemble forecasting, and integration of satellite data are the few advances in cyclone prediction that are highlighted in this literature review. AI and ML have the potential to increase accuracy. Challenges persist in long-term prediction and addressing climate change impacts. Continued research and collaboration are necessary to enhance preparedness and mitigate risks in cyclone-prone areas.

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