Selected Ph.D. Thesis Abstracts

This Ph.D thesis abstracts section presents theses defended in 2022 and 2023. These submissions cover a range of research topics and themes under intelligent informatics, such as prophylactic treatments to misinformation and disinformation, fatal disease detection using hybrid deep learning, geriatric care monitoring, graph model, interactive visualization, machine learning-assisted corpus exploration, large scale data exploration, remote patient monitoring, representation learning, secure content delivery in IoT, soft biometrics-based person retrieval, and safety solutions in smart cities.

Advancing Tropical Cyclone Forecasting through Data-driven Machine Learning

Fan Meng
meng@nuist.edu.cn
Nanjing University of Information Science and Technology, China

Tropical cyclone is one of the extreme natural disasters with the greatest impact on human beings, and timely and accurate forecasting is of great significance to safeguard people's lives and properties. Traditional tropical cyclone forecasting methods commonly use numerical models based on the set of dynamical equations, which are inefficient in operation and have huge computational demands. Additionally, there is a bottleneck in forecasting due to the lack of clarity in the physical mechanism of tropical cyclone intensity and other related parameters. With the accumulation of modern meteorological and oceanographic data, and the development of artificial intelligence technology, data-driven machine learning methods can be a way to solve the problem.

Based on the practical needs of tropical cyclone forecasting operations, this paper focuses on the key scientific issues and technical problems in tropical cyclone intensity, track and wave height forecasting, and comprehensively applies the research method of cross-disciplinary integration of meteorology, oceanography and machine learning, and researches a set of robust and lightweight forecasting methods using multi-source meteorological and oceanographic data, while focusing on the forecast uncertainty. The main research work includes:

(1) A machine learning model incorporating distributed gradient boosting and natural gradient boosting is proposed for probabilistic forecasting of tropical cyclone intensity. According to the literature, this is the first time that a machine learning approach has been used to quantify the uncertainty in tropical cyclone intensity forecasts. Although studies using machine learning for intensity forecasting have emerged in recent years, these models can only provide single-point forecasts. Due to the complexity and uncertainty of the atmospheric system, relying exclusively on machine learning models for single-point forecasts of natural hazards can lead to catastrophic consequences. The probabilistic intensity prediction method proposed in this study addresses the shortcomings of traditional single-point prediction that cannot quantify uncertainty by combining the advantages of two types of gradient boosting methods and obtaining a calibrated model through a Bayesian approach, which improves prediction accuracy while providing reliable prediction distributions and intervals. In this paper, a machine learning model is trained using predictors from a statistical hurricane intensity prediction scheme of more than 30 years for forecasting intensity changes of tropical cyclones in the next 24 hours. During the evaluation period from 2010 to 2020, the model's deterministic forecasts can outperform the current state-of-the-art operationally run dynamical-statistical model, and more importantly, interval forecasts and reliable probabilistic forecasts can be obtained, which are critical for disaster warning. In this paper, two of the strongest hurricanes in 2020 are used as examples to verify the effectiveness of the proposed method in practical applications. An interpretable machine learning method is constructed to provide an in-depth analysis of the importance of predictors, which provides a deeper understanding of tropical cyclone intensity forecasting.

(2) A deep learning model for multimodal data fusion is proposed for probabilistic forecasting of tropical cyclone intensity. This study is an extension of the previous study in the spatio- temporal dimension, which was motivated by the fact that the previous study required a large number of forecast factors as model inputs. This study makes full use of the superiority of deep learning techniques in feature extraction, proposes heteroskedastic regression as the overall framework, takes the normal distribution as the forecasting objective, adopts three-dimensional environmental field data as well as easily accessible statistical features as inputs, and realizes the full mining of implied modes through the construction of multiple feature extraction and fusion modules to obtain accurate deterministic forecasts and reliable probabilistic forecasts. In this paper, probabilistic forecasts of tropical cyclone intensity are made 6-24 hours in advance. The experimental results show that the performance of the proposed method in deterministic forecasting is comparable to that of the major global weather forecasting organizations in a sustained 4-year independent testing phase. In addition, several uncertainty quantification methods are constructed in this study for comparing the performance of probabilistic and interval forecasts. The results show that the proposed method yields more reliable forecast intervals and forecast distributions. In this paper, two super typhoons are used as examples to examine the performance of the model in actual forecasting.

(3) It is the first time to propose the uncertainty forecasting of tropical cyclone paths based on Conformal prediction (CP), which provides new methods and ideas in this field. The

uncertainty prediction of tropical cyclone paths in operational operation is usually based on super ensemble forecasts formed by multiple runs of complex dynamical models with adjusted parameters, and large-scale and long-time calculations are performed using supercomputers. In contrast, the conformal prediction method proposed in this paper is a model-independent machine learning approach that is able to construct rigorous uncertainty regions for path forecasts with very low computational effort.

In this paper, we jointly examine the path forecasting performance of 10 machine learning models, as well as 10 conformal prediction methods by means of a comparative study. The research work is modeled for 6-, 12-, and 24-hour forecast horizons, and the study covers hurricanes in the Atlantic Ocean from 1975 to 2021. The experimental results show that the model's deterministic forecasts are comparable to the skill level of the operationally run benchmark model, demonstrating that the proposed model possesses forecast skill while also providing tight uncertainty intervals about the path forecasts. Another contribution of this study is the proposed "track forecast ellipse" method, which can obtain the ellipse intervals of the future track of a tropical cyclone in a map by using the latitude and longitude intervals predicted by the machine learning method. In this study, the effectiveness of conformal prediction in solving this problem is examined by taking three major hurricane track forecasts as examples.

(4) A tropical cyclone wave height forecasting method based on ensemble empirical mode decomposition and long and short-term memory neural networks is proposed. Wave height prediction due to tropical cyclones is one of the key factors in tropical cyclone forecasting, which is of great significance for offshore operations and coastal safety. Previous studies have hardly considered the nonlinear and nonsmooth characteristics of tropical cyclone wave heights. In this study, we propose to combine an adaptive time-frequency decomposition method with a deep learning method to solve this problem, and realize robust, accurate, and interpretable tropical cyclone wave height forecasts. The study is based on wave height data obtained from 14 buoy sensors distributed around offshore China, involving 28 tropical cyclone events in the Northwest Pacific Ocean over a period of 9 years. The experimental results show that the method proposed in this paper is significantly better than the baseline model and previous studies. By comparing the operational results with those of the state-of-the-art operational numerical models, the present method has certain advantages in short-range forecasting. In addition, the prediction performance of wave height caused by Super Typhoon Connie is further examined.

This paper systematically provides new ideas and methods for tropical cyclone forecasting, and solves the problems of lack of uncertainty quantification, high computational cost, and low forecast performance. It is expected to be an effective complementary program for the actual operational forecasting of tropical cyclones.

Automating Moderators' Actions in Online Question-Answering Communities

Issa Annamoradnejad
i.moradnejad@gmail.com
Department of Computer Engineering, Sharif University of Technology, Tehran, Iran

Online question-answering (Q&A) communities have specific rules to maintain their content quality and to remain as reliable sources for a topic. Due to the large sizes of these systems in terms of the number of users and posts, manual control and approval of all posts by administrators are not possible or scalable. The current dominant solution is the use of crowdsourcing and relying on user reports, which itself has serious problems, including the slow speed of handling violations, the waste of regular and experienced users' time, the low quality of user reports, and discouraging feedback to new users from the community. Furthermore, the previous efforts to automate moderation actions via AI failed to replace the crowdsourcing method, mostly due to their low accuracy, limited scope of target actions (mostly tag recommendation), and limitations on target users (mostly fit for experienced users).

In this thesis, by examining the problems of current approaches and considering the recent NLP advances, a six-component process is proposed to classify questions based on their accordance with user guidelines on the target community. We utilized a recent NER model [1], BERT sentence embedding, and neural networks to form three feature extraction components that depend only on the textual content of the post and do not use features from user profiles or community feedback. These techniques, in conjunction with several state-of-the-art visualization and exploration [2] approaches were utilized to increase the accuracy and speed of the proposed solution. The evaluation results for classifying questions based on quality and suggesting edits show precisions between 79 and 92 percent. The results based on the F1-score metric indicate a 9-19% improvement compared to the baseline models and a 7-16% positive impact as a direct result of the feature extraction components related to the system context and questions' subjective features.

By using our proposed solution in real Q&A platforms, violations would be instantly detected or prevented from publication, new users would have a safe training system, and all users would benefit from a higher-quality forum. Future research can utilize the overall process, as well as the individual feature extraction components, to solve similar tasks of content moderation. The methodology and results of this thesis are published in [3]. The model and data for extracting subjective features of questions are detailed in [4]; and the overall requirements for automating moderation in community question-answering websites are discussed in [5]. A broader scope of the research is published as a book chapter in the Encyclopedia of Machine Learning and Data Science [6]. Furthermore, the original dataset accompanying the research is made publicly available on Kaggle.

Link to the official soft-copy version (in Persian): http://library.sharif.ir/parvan/resource/496181/a

COMPUTATIONAL APPROACHES FOR CROWD BEHAVIOR UNDERSTANDING IN REAL SCENES

Bhawana Tyagi
bhawana1988@gmail.com
Department of Computer Science, Banasthali Vidyapith,
Rajasthan-304022, India

THIS thesis is a comprehensive study of computational approaches for crowd behaviour understanding in real-life scenes. It has numerous applications in the real world, such as crowd management, public space design, crowd security, video surveillance, etc. There are many challenges associated with these tasks, including severe occlusion, complex backgrounds, illumination effects, scale variation, non-uniformity, feature similarity, and a lack of labelled data for training. Deep learning-based methods available for crowd modelling have commendable performance, but the problems associated with these approaches are feature representation and computational parameters. This thesis provides a detailed implementation and analysis of crowd behaviour understanding models, which primarily include crowd counting and density estimation, object detection and tracking, and behaviour detection. For crowd counting and density estimation, a deep learning-based model is proposed to count the crowd and estimate its density. The proposed model incorporates the features of multi-scale, multi-column, and attention-based networks. We have proposed a Modified Pyramid Scale Network and a Scale-Aware Deep Convolutional Pyramid Network to deal with two major challenges, i.e., scale variation and feature similarity associated with crowd counting. The proposed model incorporates message passing and global attention mechanisms into a multi- column network to tackle scale variation. A multi-column variance loss function is used to minimise feature similarity. The analysis of the model was demonstrated on the UCF_CC_50 and ShanghaiTech datasets for sparse and dense crowds, respectively. For comparison among the models, MAE and RMSE metrics were used.

For object detection, a deep learning-based algorithm, i.e., You Look Only Once (YOLO), is used. We have only focused on the detection of the person in an image. Here, we have used transfer learning to generate the person detection system using the YOLOv3 model. We have generated the content-specific and customised dataset and annotated the dataset manually by using the Label Tool. Further, an improved architecture for object tracking is proposed. It is built on fine-tuned YOLOv3 and DeepSORT algorithms. DeepSORT, along with the Kalman filter and Hungarian algorithm, is used for object tracking. The Kalman filter is used to deal with the occlusion challenge. The performance of the proposed models has been demonstrated on the COCO-person, MOT16, and MOT17 datasets. Performance metrics used for comparison for object detection and tracking methods were mean accuracy precision, multiple object tracking accuracy, false positive, false negative, and switch identity.

We have implemented a MobileNetv2-based model for violence detection in videos, which has a smaller number of computational parameters. The model was compared with other state-of- the-art methods such as InceptionV3, VGG-19, MobileNet, and MobileNetv2. The proposed model reports the minimum number of computational parameters and comparable accuracy with other existing methods. To demonstrate the performance of the model, two publicly available datasets, Real Life Violence Situations and Hockey Fight Detection, were used. Precision, recall, accuracy, and F1-Score were used to compare the models, along with their computation parameters.

DEEP LEARNING BASED APPROACH FOR CLOUD REMOVAL IN REMOTE SENSING DATA

Jaya Saxena
jayasaxena@nrsc.gov.in
NRSC, ISRO, Hyderabad, India

I. REMOTE SENSING

Remote sensing is one of the key technologies which have transformed the social and economic parameters of many countries. Remote sensing data are being utilized to understand the features of earth surface. Due to the extensive spatial and temporal coverage of satellites, the information received from them is enormous and have many advantages for the society. In the undeveloped world, agricultural remote sensing applications, especially for crop statistics and soil mapping, have proven challenging to implement. Using remote sensing accurate image interpretation can yield samples that truly reflect the agricultural growing conditions. Also, Remote Sensing is immensely useful in disaster management and data generated by models helps in providing pre-warning information for many disasters like forest fire, cyclones, earthquakes which helps in saving precious human life and valuable goods.

II. RESEARCH AGENDA

Many times satellite imagery has gap areas, mainly due to cloud presence, which largely affects their quality and limits their usability for Earth Observation purpose. Further, several times the data may be of low quality due to technical glitches and get a miss for some unavoidable human errors or due to environmental factors. Remote Sensing data acquired from satellites often shows gaps and the data is not continuous. Further, as clouds are the main hindrances in optical remote sensing imagery and India having a tropical climate with agriculture contributing significantly in the Indian economy, removing clouds and reconstructing remote sensing imagery is a major area of concern and poses a significant challenge even today.

Our study in this thesis is aimed to explore deep learning technology for a novel work of removing gaps, mainly clouds, from remote sensing data. This will enhance the usability and quality of images for Earth observation, natural resource management and planning, disaster management and support, whereby significantly contributing towards societal benefits and improvement of Indian economy and world at large.

III. METHODOLOGY & OUTCOME

In order to conduct this work we collected the spatial data pertaining to different locations of varying terrains and topography between time periods 2017 to 2020 from open sources of Landsat and Sentinel satellites. The area of interest

and scenes covered with clouds were extracted. The scenes were chosen with different types of clouds and varying cloud cover percentage for vast applicability of algorithms. Near real time temporal cloud free images were selected for comparison and accuracy evaluation of the algorithms and models applied. We started with traditional approaches for cloud removal in distorted images and reconstructing the spatial data. Further, different deep learning algorithms were applied them. The reconstructed output image was compared with ground truth (temporal cloud free image) to evaluate the performance of these algorithms and models. Visual observations and evaluation metrices were used for evaluation. Upgraded models and algorithms were proposed as a outcome of the study for cloud removal and reconstruction of remote sensing data. One of the future prospects could be to explore alternative architectures and parameters.

Towards Effective Performance Diagnosis for Distributed Applications

Ruyue Xin
xinryxx@gmail.com
Multiscale Networked Systems (MNS), University of Amsterdam, Netherlands

Cloud computing provides elastic and on-demand resources for distributed applications to deliver high-quality ser- vices. However, the dynamism of underlying cloud infrastructures and complex dependencies between services introduce abnormal performance phenomena, e.g., degradation, which severely affect the quality of services and the user experience. To make services in applications continuously operational, performance diagnosis systems aiming to detect performance anomalies, such as slow response times, and localize their root causes are required. Such kinds of systems have been studied in recent years. A typical performance diagnosis system comprises components for collecting and pre-processing monitoring data, detecting performance anomalies, and localizing root causes. The data collection and pre-processing components reduce noise in the monitoring data and make it available for the performance anomaly detection component to diagnose the system, e.g., using statistical or machine learning methods. To be effective, anomaly detection has to be accurate, robust in fitting different data distributions in real scenarios, and predictive to prevent potential application violations. The root cause localization component aims to accurately identify the underlying causes of performance anomalies, such as resource-related metrics in faulty services. However, a large number of anomalous metrics and complex anomaly propagation paths make it challenging to determine the root cause.

To tackle the above challenges, we first review the state-of-the- art research and methods for creating a reliable performance diagnosis system from a technical perspective. Based on the review, we propose a comprehensive performance diagnosis system that can effectively detect performance anomalies with existing detection methods and localize their root causes based on anomaly propagation paths to provide actionable insights to oper- ators [1]. We also observed that existing detection methods have varying performance for different datasets because they focus on different features in the data. Furthermore, effective anomaly detection methods should meet challenging requirements, in- cluding high accuracy in detecting anomalies and robustness to changing data patterns, while few studies have addressed both challenges simultaneously. To address these issues, we propose an ensemble learning-based detection (ELBD) framework that integrates well-selected existing methods, including three classic linear ensemble methods and a novel deep ensemble method. Our deep ensemble method, which is weakly supervised, achieves the highest accuracy and robustness for performance anomaly detection in distributed applications [2]. In addition, we propose an unsupervised detection method called CGNN-MHSA-AR for multivariate time series anomaly detection [3]. This method leverages temporal and feature information to achieve superior accuracy compared to baseline detection methods. As for root cause localization, considering that currently used CI methods have limitations, such as the linear causal relations assumption and strict data distribution requirements, we propose a root cause localization framework working with gradient-based causal inference and named CausalRCA [4]. The CausalRCA uses a gradient-based causal structure learning method to generate weighted causal graphs and a root cause inference method to localize root cause metrics, achieving fine-grained, automated, and real-time root cause localization. We conduct coarse- and fine-grained root cause localization to evaluate the localization performance of CausalRCA. Experimental results show that CausalRCA significantly outperforms baseline methods in localization accuracy.

Towards a Smarter Healthcare: The Role of Deep Learning Supporting Biomedical Analysis

Moiz Khan Sherwani
mk_sherwani@hotmail.com
Information Systems Group, Hasso Plattner Institute at the University of Calabria, Italy

Medical imaging has always been increasingly relevant in modern healthcare, and tremendously progressed in the last few decades. In addition, the latest years also witnessed the incredibly fast rise of Artificial Intelligence (AI) and its application in a wide range of application domains. Interestingly, AI techniques proved to be quite effective at tackling tasks in the healthcare sector, and are considered crucial, for instance when applied to medical imaging, in the journey towards more precise diagnoses and more effective treatments. Among all AI techniques industry, academia and popular culture have all recently taken a particular interest in Machine Learning (ML), largely due to very effective developments like the breakthroughs in Deep Learning (DL), that allow one to locate patterns in vast amounts of data by applying a proper set of algorithms and methodologies. Several image analysis techniques are subject of constant attention by the scientific community, including image synthesis, segmentation, disease diagnosis and computerized surgeries.

In this thesis, we present the findings of our studies in the field along with our research activities, that have been mainly focused on two important topics: Image synthesis for MR-only radiotherapy and Lesion segmentation. Our first topic is related to image synthesis. In image synthesis, images are artificially generated that contain specific content. An analogy would be generating an image containing the visual content associated with any given label as the inverse of the classification problem. Medical images can be produced using diverse imaging protocols, each with unique characteristics. A medical image synthesis method has been extensively explored for clinical applications owing to the high costs associated with scanning high-quality single modalities of images or homogeneous multiple modalities of images. For medical image synthesis, deep learning approaches, particularly convolutional neural networks (CNNs) and generative adversarial networks (GANs), have become increasingly popular over the past few years. MR-based CT synthesis is the objective of this thesis as it pertains to MR-only radiotherapy. Using clinically relevant quality measures, we evaluated different categories of CT synthesis methods. For the brain images specifically, we have implemented a Deep Convolutional Neural Network (DCNN) based method and provided a variety of loss functions, which compare favorably to state-of-the-art methods. Next, we review recent methods of image synthesis through systematic literature reviews. In our next effort, we substantially improved our model by using the attention mechanism to improve the quality of images not only in terms of intensities but also based on structural similarity. Since the scientific community is more focused towards the intensities of the images but the structure and borders of the image are also important for the synthetic image accuracy.

The second topic of this thesis explores how to segment lesion patterns in Computed Tomography (CT) scans. Segmentation is an important operation in Computer Vision. By segmenting images, we group objects that belong to the same class in an image. It is also referred to as pixel-level classification. Another way to describe it is splitting an image (or video frame) into multiple segments or objects. In medicine, image segmentation is often used to estimate tissue volumes or extract tumor boundaries. For example, image databases can be created that can be used to analyze pandemics and fast-spreading diseases. Medical imaging data for emerging infectious diseases is constrained by a limited size of publicly available datasets, which requires large scale annotations for better performance. Using convolutional neural networks (CNN) the thesis proposes an unsupervised method that combines Generative Adversarial Network (GAN) with a Convolutional Neural Network (CNN) ensemble to overcome data constraints and effective lesion segmentation. Using Cycle-GAN, we develop an unsupervised method for converting infected images into healthy ones. In our proposed adversarial network, an attention-based mask generator is used to improve this method. Data infected with COVID-19 was used to demonstrate this. Comparatively to state-of-the-art approaches, this method gives us a more accurate representation of lesions. Lesion segmentation can be done efficiently with this approach since it does not require annotated data and it is completely unsupervised. This manuscript is presented in two parts: the first one illustrates some background theoretical concepts and reports about our studies of the state-of-the-art in medical imaging and DL, while the second one presents the results of our works on biomedical image analysis via DL techniques. In this thesis, we have provided all the contribution to the scientific community using DL techniques in details.

Wildlife-Vehicle Collisions Mitigation Measures using Road Ecological Data and Deep Learning

Irene Nandutu
irenenanduttu@gmail.com
Department of Mathematics, Rhodes Artificial Intelligence Research Group, Rhodes University, South Africa

The typical mitigation measures for wildlife-vehicle collisions (WVCs) include traditional methods such as overpasses, underpasses, and wildlife fencing. Other measures are intelligent systems like break-the-beam, area-cover, buried cable animal detection systems and machine learning approaches, which have been increasingly successful due to advancements in computational facilities. These methods have the potential to mitigate WVC, improve road safety, and enhance biodiversity by redirecting wildlife to non-hotspot areas and alerting drivers of wildlife presence on high- ways. However, these advanced techniques are not widely implemented in Africa, especially in South Africa, where WVC incidents are increasing due to difficulties in identifying wildlife concentration areas. This multidisciplinary thesis investigated the application of machine learning on road ecological data to ad- dress the challenge of WVC through different types of interventions.

Firstly, an ethically aligned framework was developed following an inductive method using grounded theory. The framework guides stakeholders on what to consider when implementing machine learning wildlife monitoring tools. Secondly, an error correction-based deep neural network was implemented to model and predict WVC using data collected in Limpopo region in South Africa as WVC cases, taking into account the immersive non-linear tendencies of wildlife crossing patterns. Finally, a novel approach to create awareness about potential WVC areas was proposed using traditional wildlife fencing and machine learning. This approach introduces a recognition and segmentation algorithm to detect wildlife electric fences and associated features to alert road users about potentially unsafe and insecure WVC areas, in turn improving the safety of road users and mitigating WVC incidents. This approach could also positively influence tourist destinations and tourism in the country. Future research opportunities are discussed.