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Advancements in Forest Fire Prediction: Integrating Artificial Intelligence and Statistical Inference

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Declaration

I, Mounika Malka, of the Department of Computer Science, Texas A&M University - Commerce, confirm that this is my own work and figures, tables, equations, code snippets, artworks, and illustrations in this report are original and have not been taken from any other person's work, except where the works of others have been explicitly acknowledged, quoted, and referenced. I understand that if failing to do so will be considered a case of plagiarism. Plagiarism is a form of academic misconduct and will be penalised accordingly.

I give consent to a copy of my report being shared with future students as an exemplar.

I give consent for my work to be made available more widely to members of TAMUC and public with interest in teaching, learning and research.

Mounika Malka
March 6, 2024

Abstract

Forest fires pose significant threats to ecosystems, human lives, and infrastructure. Predicting forest fire occurrence is crucial for effective resource allocation, mitigation, and recovery efforts. This paper explores recent advancements in forest fire prediction methodologies, mainly focusing on integrating artificial intelligence (AI) and statistical inference techniques. We discuss the implications of reduced parameter sets in AI-based models for efficient prediction systems, especially pertinent to developing countries. Moreover, we delve into the statistical properties of random forest models, shedding light on their error distributions and potential for statistical inference. Through a comprehensive literature review and comparative analysis, we aim to provide insights into cutting-edge approaches for forest fire prediction, paving the way for more accurate and reliable prediction systems.

Keywords: Forest fire occurrence prediction, Support vector machines, Artificial neural networks, Feature Reduction, Weather data

Acknowledgements

An acknowledgements section is optional. You may like to acknowledge the support and help of your supervisor(s), friends, or any other person(s), department(s), institute(s), etc. If you have been provided specific facility from department/school acknowledged so.

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List of Abbreviations

SMPCS School of Mathematical, Physical and Computational Sciences

Chapter 1

Introduction

1.1 Background

Forest fires represent a significant threat to ecosystems, human lives, and infrastructure world-wide. These catastrophic events result in immediate devastation and long-term environmental and socioeconomic impacts [4]. Forest fires' increasing frequency and severity, particularly in regions with hot, dry climates, have underscored the urgency of developing effective prediction and management strategies [5]. Understanding the factors contributing to forest fire occurrence and progression is essential for mitigating risks and minimizing damages.

1.2 Problem Statement

The challenge of accurately predicting forest fires lies in the complex interactions between various environmental factors, including weather conditions, vegetation types, and human activities. Conventional prediction systems often rely on extensive monitoring features and weather prediction mechanisms, which can be costly and impractical, especially for developing countries. Furthermore, weather prediction inaccuracies can lead to fire risk assessment errors [2]. Therefore, there is a pressing need for cost-effective and efficient forest fire prediction methods that can reliably estimate fire occurrence and progression.

1.3 Aims and Objectives

The primary aim of this study is to investigate and evaluate machine learning techniques for forest fire prediction, focusing on enhancing prediction accuracy and efficiency. The specific objectives of the project are as follows:

- Review and analyze existing forest fire prediction methodologies, including traditional systems and artificial intelligence-based approaches [4].
- To assess the performance of the developed models using real-world forest fire data and evaluate their effectiveness in predicting fire occurrence and progression [5].

1.4 Solution Approach

This project adopts a comprehensive approach to address the challenges associated with forest fire prediction. The methodology involves:

- Reviewing relevant literature on forest fire prediction methods and machine learning techniques.
- Implementing and fine-tuning machine learning models based on the identified methodologies.
- Collecting and preprocessing real-world forest fire data for model training and evaluation.
- Analysing the performance of the developed models and comparing them with existing prediction systems.

1.5 Summary of contribution and achievements

This paper contributes to the field of forest fire prediction by exploring various artificial intelligence-based methods and their applications. Specifically, it examines the genetic programming in predicting forest fire occurrences and estimating the extent of burned areas. By analyzing existing literature and conducting experiments, this paper provides insights into the strengths and limitations of different prediction models, offering valuable guidance for future research and practical implementation.

1.6 Organization of the report

The report starts with an Introduction where we discuss the topic's background, explain the problem we're trying to solve, outline our goals, and describe how we plan to solve the problem. Then, we have a Literature Review section where we review what others have written about our topic and explain how we've cited their work. The Methodology section explains the methods we used in our research. The Results section tells you what we learned from our study. Next, in the Discussion and Analysis section, we carefully consider our results, why they're essential, and mention any limitations we encountered. The Conclusions section summarizes the main things we discovered and suggests ideas for future research. Finally, in the Appendices, we include extra stuff like tables or more details for people who want to know more.

Chapter 2

Literature Review

2.1 Introduction

Predicting forest fire sizes is essential for implementing effective mitigation strategies and minimizing their destructive impact. In recent years, data mining techniques and meteorological data analysis have emerged as promising approaches for forest fire prediction. This literature survey examines notable studies in this domain, which propose various data-driven and climate-based models for predicting forest fire sizes. Through a comprehensive analysis, this survey aims to provide insights into the methodologies employed, their strengths and limitations, and opportunities for further research to enhance forest fire prediction accuracy and facilitate proactive management and mitigation efforts.

2.2 Example of in-text citation of references in LaTeX

A study found that 21.9 Different scales are used for each of the FWI elements, high values suggest more severe burning conditions (Taylor and Alexander 2006)

2.3 Example of "risk" of unintentional plagiarism

Unintentional plagiarism arises when writers neglect to properly acknowledge borrowed information, often due to oversight. One common scenario involves the omission of citations for widely recognized facts or common knowledge within a specific field or context. For example, failing to attribute the fact that "water boils at 100 degrees Celsius at sea level" can inadvertently lead to plagiarism, even though it is widely acknowledged. This oversight, particularly in academic or formal writing, underscores the importance of diligently crediting all sources to maintain integrity and avoid unintentional plagiarism.

2.4 Critique of the review

The review provides an extensive analysis of methodologies employed in forest fire prediction, spanning data mining techniques, meteorological variables, and machine learning algorithms. [6]

notably focused on investigating various data mining techniques, particularly Support Vector Machines (SVM), to forecast forest fire sizes. While their study highlighted the effectiveness of SVM, a deeper critique is warranted regarding the challenges associated with implementing these techniques, including data availability, model complexity, and computational requirements. [7] hybrid model, integrates clustering and classification techniques, presents promising outcomes in forest fire prediction. Their approach, while innovative, lacks a comparative analysis with existing methodologies to fully elucidate its strengths and weaknesses. Furthermore, the review overlooks external factors like climate change and land-use patterns, which could significantly impact predictive accuracy. Additionally [8] explores on the application of Random Forests, emphasizing ensemble methods' potential in capturing intricate relationships between meteorological variables and fire occurrence. While their study offers valuable insights, a deeper examination of the interpretability and robustness of Random Forest models is needed. Furthermore, discussing the scalability of these algorithms and their suitability for real-time prediction in large-scale forest areas would provide practical implications for forest fire management. A research on the influence of climate change on forest fire regimes underscores the importance of incorporating climate projections into predictive models[9]. Their emphasis on considering long-term trends and variability in climate parameters is noteworthy. However, the review could elaborate on the specific methodologies proposed for integrating climate data into predictive models and discuss challenges related to climate model uncertainty and downscaling techniques. Additionally, exploring the implications of changing fire weather patterns on forest fire behavior and the effectiveness of current mitigation strategies would enrich the discussion and provide valuable insights for future research.

2.5 Summary

The exploration of methodologies for forest fire prediction reveals promising avenues through data mining techniques, meteorological variables, and machine learning algorithms. While studies showcase the effectiveness of Support Vector Machines (SVM), hybrid models, and Random Forests, there remains a need for a deeper critique of their limitations and challenges, including data availability, model complexity, and scalability. Moreover, the significance of considering external factors like climate change and land-use patterns is evident, urging the integration of climate projections into predictive models. Addressing these aspects will be pivotal in advancing forest fire management and mitigation strategies.

Chapter 3

Methodology

3.1 Background

- Provide an overview of the significance of forest fires globally.
- Discuss the immediate and long-term impacts of forest fires on ecosystems, human lives, and infrastructure.
- Highlight the increasing frequency and severity of forest fires, particularly in hot, dry climates.
- Emphasize the need for effective prediction and management strategies to mitigate risks and minimize damages.

3.2 Problem Statement

- Identify the challenges in accurately predicting forest fires, attributed to complex interactions between environmental factors.
- Discuss the limitations of conventional prediction systems, such as reliance on extensive monitoring and weather prediction mechanisms.
- Highlight the need for cost-effective and efficient forest fire prediction methods to address inaccuracies and mitigate risks effectively.

3.3 Aims and Objectives

- Clearly state the primary aim of the study: to investigate and evaluate machine learning techniques for forest fire prediction. Specify the objectives:
- Review and analyze existing forest fire prediction methodologies.
- Assess the performance of developed models using real-world forest fire data.
- Evaluate the effectiveness of models in predicting fire occurrence and progression.

3.4 Solution Approach

- Describe the comprehensive approach adopted to address the challenges of forest fire prediction.
- Outline the methodology, which includes:
 - Reviewing literature on forest fire prediction methods and machine learning techniques.
 - Implementing and fine-tuning machine learning models.
 - Collecting and preprocessing real-world forest fire data.
 - Analyzing model performance and comparing with existing prediction systems.

3.5 Code

Code snippet in LATEX and this is a Python code example

```

1 from ucimlrepo import fetch_ucirepo
2 import numpy np
3 import pandas pd
4 forest_fires = fetch_ucirepo(id=162)
5 X = forest_fires.data.features
6 Y = forest_fires.data.targets
7 df = pd.DataFrame(data=X, columns=forest_fires.feature_names)
8 df['target'] = Y
9 print(forest_fires.metadata)
10
11 print(forest_fires.variables)
12
13 print(df.head(10))
14
15 print("Statistical Description:", df.describe())
16
17 print("Data Types:", df.dtypes)
18
19 print("Correlation:", df.corr(method='pearson'))
20 import matplotlib.pyplot as plt
21 plt.figure(figsize=(6.5, 6.5))
22 df['target'].hist()
23 plt.title('Histogram of Target Column')
24 plt.xlabel('Target Values')
25 plt.ylabel('Frequency')
26 plt.show()
27 n_cols = len(df.columns)
28 layout = (n_cols // 2, 2)
29 plt.figure(figsize=(6.5, 6.5))
30 df.hist(layout=layout, figsize=(6.5, 6.5))
31 plt.tight_layout()
32 plt.show()
33 import numpy as np
34 fig, ax = plt.subplots(figsize=(6.5, 6.5))
35 cax = ax.matshow(df.corr(), vmin=-1, vmax=1)
36 fig.colorbar(cax)

```

```

37 ticks = np.arange(0, len(df.columns), 1)
38 ax.set_xticks(ticks)
39 ax.set_yticks(ticks)
40 ax.set_xticklabels(df.columns, rotation=45, ha='left')
41 ax.set_yticklabels(df.columns)
42 plt.show()
43 import matplotlib.pyplot as plt
44 plt.figure(figsize=(6.5, 6.5))
45 sns.barplot(x='month', y='target', data=df)
46 plt.title('Average Target by Month')
47 plt.xlabel('Month')
48 plt.ylabel('Average Target')
49 plt.show()

```

3.6 Tables

First 10 rows of Data frame

	X	Y	month	day	FFMC	DMC	DC	ISI	temp	RH	wind	rain	target
0	7	5	mar	fri	86.2	26.2	94.3	5.1	8.2	51	6.7	0.0	0.0
1	7	4	oct	tue	90.6	35.4	669.1	6.7	18.0	33	0.9	0.0	0.0
2	7	4	oct	sat	90.6	43.7	686.9	6.7	14.6	33	1.3	0.0	0.0
3	8	6	mar	fri	91.7	33.3	77.5	9.0	8.3	97	4.0	0.2	0.0
4	8	6	mar	sun	89.3	51.3	102.2	9.6	11.4	99	1.8	0.0	0.0
5	8	6	aug	sun	92.3	85.3	488.0	14.7	22.2	29	5.4	0.0	0.0
6	8	6	aug	mon	92.3	88.9	495.6	8.5	24.1	27	3.1	0.0	0.0
7	8	6	aug	mon	91.5	145.4	608.2	10.7	8.0	86	2.2	0.0	0.0
8	8	6	sep	tue	91.0	129.5	692.6	7.0	13.1	63	5.4	0.0	0.0
9	7	5	sep	sat	92.5	88.0	698.6	7.1	22.8	40	4.0	0.0	0.0

3.7 Summary of Contribution and Achievements

- Summarize the contributions of the study to the field of forest fire prediction. Highlight the exploration of artificial intelligence-based methods, specifically genetic programming.
- Mention insights provided by analyzing existing literature and conducting experiments. Discuss the significance of the study's findings for future research and practical implementation.

Chapter 4

Results

The results chapter tells a reader about your findings based on the methodology you have used to solve the investigated problem. For example:

- If your project aims to develop a software/web application, the results may be the developed software/system/performance of the system, etc., obtained using a relevant methodological approach in software engineering.
- If your project aims to implement an algorithm for its analysis, the results may be the performance of the algorithm obtained using a relevant experiment design.
- If your project aims to solve some problems/research questions over a collected dataset, the results may be the findings obtained using the applied tools/algorithms/etc.

Arrange your results and findings in a logical sequence.

4.1 A section

...

4.2 Example of a Table in \LaTeX

Table 4.1 is an example of a table created using the package \LaTeX “booktabs.” do check the link: wikibooks.org/wiki/LaTeX/Tables for more details. A table should be clean and readable. Unnecessary horizontal lines and vertical lines in tables make them unreadable and messy. The example in Table 4.1 uses a minimum number of liens (only necessary ones). Make sure that the top rule and bottom rule (top and bottom horizontal lines) of a table are present.

Table 4.1: Example of a table in \LaTeX

Bike		
Type	Color	Price (£)
Electric	black	700
Hybrid	blue	500
Road	blue	300
Mountain	red	300
Folding	black	500

4.3 Example of captions style

- The **caption of a Figure (artwork)** goes **below** the artwork (Figure/Graphics/illustration). See example artwork in Figure ??.
- The **caption of a Table** goes **above** the table. See the example in Table 4.1.
- The **caption of an Algorithm** goes **above** the algorithm. See the example in Algorithm ??.
- The **caption of a Listing** goes **below** the Listing (Code snippet). See example listing in Listing ??.

4.4 Summary

Write a summary of this chapter.

Chapter 5

Discussion and Analysis

Depending on the type of project you are doing, this chapter can be merged with “Results” Chapter as “ Results and Discussion” as suggested by your supervisor.

In the case of software development and the standalone applications, describe the significance of the obtained results/performance of the system.

5.1 A section

Discussion and analysis chapter evaluates and analyses the results. It interprets the obtained results.

5.2 Significance of the findings

In this chapter, you should also try to discuss the significance of the results and key findings, in order to enhance the reader’s understanding of the investigated problem

5.3 Limitations

Discuss the key limitations and potential implications or improvements of the findings.

5.4 Summary

Write a summary of this chapter.

Chapter 6

Conclusions and Future Work

6.1 Conclusions

Typically a conclusions chapter first summarizes the investigated problem and its aims and objectives. It summarizes the critical/significant/major findings/results about the aims and objectives that have been obtained by applying the key methods/implementations/experiment set-ups. A conclusions chapter draws a picture/outline of your project's central and the most significant contributions and achievements.

A good conclusions summary could be approximately 300–500 words long, but this is just a recommendation.

A conclusions chapter followed by an abstract is the last things you write in your project report.

6.2 Future work

This section should refer to Chapter 4 where the author has reflected their criticality about their own solution. The future work is then sensibly proposed in this section.

Guidance on writing future work: While working on a project, you gain experience and learn the potential of your project and its future works. Discuss the future work of the project in technical terms. This has to be based on what has not been yet achieved in comparison to what you had initially planned and what you have learned from the project. Describe to a reader what future work(s) can be started from the things you have completed. This includes identifying what has not been achieved and what could be achieved.

A good future work summary could be approximately 300–500 words long, but this is just a recommendation.

Chapter 7

Reflection

Write a short paragraph on the substantial learning experience. This can include your decision-making approach in problem-solving.

Some hints: You obviously learned how to use different programming languages, write reports in \LaTeX and use other technical tools. In this section, we are more interested in what you thought about the experience. Take some time to think and reflect on your individual project as an experience, rather than just a list of technical skills and knowledge. You may describe things you have learned from the research approach and strategy, the process of identifying and solving a problem, the process research inquiry, and the understanding of the impact of the project on your learning experience and future work.

Also think in terms of:

- what knowledge and skills you have developed
- what challenges you faced, but was not able to overcome
- what you could do this project differently if the same or similar problem would come
- rationalize the divisions from your initial planned aims and objectives.

A good reflective summary could be approximately 300–500 words long, but this is just a recommendation.

Note: The next chapter is “**References**,” which will be automatically generated if you are using BibTeX referencing method. This template uses BibTeX referencing. Also, note that there is difference between “References” and “Bibliography.” The list of “References” strictly only contain the list of articles, paper, and content you have cited (i.e., refereed) in the report. Whereas Bibliography is a list that contains the list of articles, paper, and content you have cited in the report plus the list of articles, paper, and content you have read in order to gain knowledge from. We recommend to use only the list of “References.”

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Carvalho et al. (2008)

Appendix A

An Appendix Chapter (Optional)

Some lengthy tables, codes, raw data, length proofs, etc. which are **very important but not essential part** of the project report goes into an Appendix. An appendix is something a reader would consult if he/she needs extra information and a more comprehensive understating of the report. Also, note that you should use one appendix for one idea.

An appendix is optional. If you feel you do not need to include an appendix in your report, avoid including it. Sometime including irrelevant and unnecessary materials in the Appendices may unreasonably increase the total number of pages in your report and distract the reader.

Appendix B

An Appendix Chapter (Optional)

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