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Editorial Comments for JCMM Volume 2 Issue 1

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The Journal of Computers, Mechanical and Management is pleased to introduce the first issue of the second volume of our esteemed journal. This issue encompasses a diverse collection of scholarly works, comprising six original full-length research articles and two insightful review articles that explore various compelling subjects.

The first article, "Comprehensive Study of Machine learning Algorithms for Stock Market Prediction during COVID-19," by Saxena et al. [1], presents an extensive study of machine learning algorithms for stock market prediction amid the COVID-19 pandemic. The authors analyze the performance of various machine learning algorithms and identify the most effective algorithm for stock market prediction. This study's outcomes will provide valuable guidance for investors and traders in making informed decisions during times of uncertainty, such as the COVID-19 pandemic. The second article, "Sentiment Analysis using Latent Dirichlet Allocation for Aspect Term Extraction" by Rajput et al. [2], introduces a novel approach for sentiment analysis utilizing latent Dirichlet allocation for aspect term extraction. The authors propose a new method that effectively extracts aspect terms from text data, contributing to applications such as opinion mining and customer feedback analysis.

In the third article, conducted by Sikandar and Sikandar [3], an investigation into the Quality of Work Life (QWL) of women officers working in publicly funded Higher Educational Institutions (HEIs) in India is presented. The study reveals that the respondents experience equitable treatment in the workplace, possess autonomy in their roles, foster good reporting relationships, and maintain a healthy work-life balance. Examining the impact of COVID-19 on the well-being of teachers in higher education institutions, the fourth article by Pavitra et al. [4] emphasizes the significance of supporting teacher well-being during the pandemic. The study highlights the importance of prioritizing physical health, fostering relationships, and engaging in meaningful activities to enhance the well-being of teachers. The fifth article, authored by Verma [5], proposes an enhanced algorithm for the Low-Energy Adaptive Clustering Hierarchy (LEACH) protocol in wireless sensor networks. This proposed method significantly enhances the protocol's performance, leading to improved network lifetime, throughput, and the number of living nodes. As a result, it holds great promise for efficient routing in wireless sensor networks. Presenting a numerical analysis of p-type CdTe and n-type TiO_2 heterojunction solar cells, the sixth article by Chougale et al. [6] conducts simulations to investigate the effects of varying parameters such as the

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thickness of the p-type CdTe layer, temperature, and band gap on the efficiency of the solar cell. The outcomes of this research offer theoretical guidelines for fabricating efficient p-CdTe/n-TiO2 heterojunction solar cells.

The first review article, by Kumar [7], conducts an in-depth examination of software testing models and optimization techniques. This comprehensive review assesses the advantages and limitations of various software testing models and optimization techniques, providing valuable insights for researchers and practitioners in the field.

In the second review article, Shetty et al. [8] propose leveraging Hofstede's Cultural Dimensions to devise COVID-19 control strategies in India and other countries. The authors employ the Cultural Compass to quantify and evaluate the cultural dimensions of India, applying Hofstede's model to formulate effective measures, policies, and plans for controlling the pandemic. This approach, considering citizens' cultural backgrounds, holds potential for more efficient pandemic management. We hope that this comprehensive compilation of research articles and review papers will enrich the knowledge and understanding of our readers.

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Comprehensive Study of Machine Learning Algorithms for Stock Market Prediction During COVID-19

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Abstract

The stock market has always drawn investors' attention. Stock trend forecasting tools are in high demand because they facilitate the direct acquisition of profits. The more precise the results, the greater the likelihood of generating a greater profit. Statistically, only 3% of the Indian population invests in stocks, and at the time of COVID-19, that number was even lower, as the stock market was not based on general patterns and equations but rather on the emotional quotient of the people. Such a circumstance increased the stock market's vulnerability. The pandemic factor, such as the case of COVID-19, influences the stock market's trends. Technical analysis of market trends is a technique for interpreting past and present prices to forecast likely future prices. Several deep learning and machine learning algorithms are utilized to generate stock market forecasts, wherein LSTM and ARIMA models have been proven to produce reasonably accurate results. The prior works focused on individual models and their components to provide forecasts. Thus, this paper aims to compare the two well-established models and provide investors with models that work well with data and have appropriate parameter values. The LSTM and ARIMA models are presented because they provide appropriate results using technical analysis of the data set, and the results are to be compared. The closing values from the historic stock prices of the top three Indian hospitality industries were used as the data set. The results show that the individual models work well when the data matches the model and the appropriate parameter is used.

Keywords: Machine Learning; Stock Predicts; COVID-19; Market Analysis; ARIMA; LSTM

1 Introduction

A stock market is the assembly of buyers and sellers of commodities which represents stock sold to investors through various platforms or the commodities privately traded (stocks of private companies) [1, 2]. The stock market is highly incoherent and non-static, so predicting a stock's future value is always difficult for the people trading or investing in the market. There have been 24 major market crashes, among which the most significant occurred in 2007 (Global financial crisis). Due to these variations, some people consider investing in the stock market equivalent to betting. Furthermore, one indeed faces a loss in investing in the stock market if one is not knowledgeable enough about it. This reason itself makes stock forecasting an important need. Indians began investing in stocks, which have outperformed all other asset classes by as much as 60% since 2001. However, due to stock market volatility, only 3% of the Indian population invests directly in stocks [3]. Multiple variables, such as news, social media data, fundamentals, company production, government bonds, historical price, and the country's economics, make it difficult to construct an accurate model. In addition, the COVID-19 pandemic severely impacted the factors above, negatively impacting the stock market, as decisions during the pandemic period largely depended on the public's emotional quotient [4]. Stock market forecasting has become increasingly popular due to its complexity.

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Collections from the stock market are typically dynamic, non-parametric, chaotic, and noisy. Consequently, the rate of change in the stock market is regarded as a random process. Technical analysis, time-series forecasting, machine learning and data mining, and modeling and predicting volatility of Stocks are among the most prominent techniques used to forecast stock market prices [5, 6]. From the list of several techniques, the autoregressive integrated moving average (ARIMA) method, a statistical approach and the deep learning method, namely long short-term memory (LSTM), have been proven to give the best results concerning market prediction [7]. Several researchers have worked in the area of stock prediction while proving the efficiency of the abovementioned models. Considering the application of the ARIMA model, Khanderwal and Mohanty presented [8] an in-depth method for developing it for stock price prediction and demonstrated experimentally its indisputable ability to predict stock costs using data from three national stock exchange (NSE) sectors over three years. Almasarweh and Wadi [9] utilized the ARIMA model to forecast the stock market for the Jordanian banking sector using daily data from 1993 to 2017. The results showed that the ARIMA model has significant results for short-term prediction and will thus be useful for investments. Wadi et al. [10] demonstrated that the ARIMA model has significant results for short-term prediction while predicting the stock market based on closing price data sets for the selected firms over 8 years. Wahyudi [11] used the ARIMA model to predict the volatility of Indonesian stock prices in his study, taking into account its capability, simplicity, and wide acceptability for predicting stock price volatility. Babu and Reddy [12] used the ARIMA model to examine the behavior of daily exchange rates of the Indian Rupee (INR) against various foreign currencies over 5 years. The results were compared with the results obtained using certain complex models. The proposed ARIMA model outperformed several complex nonlinear models and produced acceptable results.

Likewise, the LSTM model application also gained interest among researchers working in stock prediction. Hochreiter and Schmidhuber created LSTM, an RNN architecture that better stores and retrieves information and serves as the foundation for subsequent models, in 1997. Since then, it has been utilized in several prediction challenges, including stock market forecasts [13, 14]. Roondiwala et al. presented, modeled, and projected the NIFTY 50 stock returns using the LSTM technique and five years of historical data. The acquired findings were outstanding, with a prediction accuracy of approximately 98% [15]. Chen et al. modeled and forecasted China stock returns using LSTM, utilizing historical China stock market data turned into 30-day-long sequences with 10 learning features and 3-day earning rate labeling. The model was calibrated using 900000 sequences for training and 311361 sequences for testing. The LSTM model enhanced the accuracy of stock return forecasts by 13% compared to random prediction [16]. Liu et al. utilized the LSTM approach to filter, extract feature value, evaluate stock data, and establish the prediction model for the associated stock transaction. The experimental findings indicate that the created model's prediction accuracy was greater than 70% [17]. Mehtab et al. utilized LSTM regression models to anticipate the future NIFTY 50 open values utilizing four distinct models that varied in their architecture and input data format. The results demonstrated that the LSTM-based models produce accurate outcomes. Though several research documents deal with ARIMA and LSTM models for prediction problem-solving, they have mostly been used individually. Thus, the current work aims to develop the best model for predicting and analyzing stock market values while considering the datasets of the selected three top firms in the Indian hospitality industry. The paper presents the comparative results of the two majorly used stock forecasting models, LSTM and ARIMA, to assist investors and buyers in making more informed decisions.

2 Methods

2.1 ARIMA model

ARIMA modeling is fundamentally an exploratory data-oriented method that allows for the adaptability of a model based on the data's structure. With the aid of the autocorrelation function and partial autocorrelation function, the stochastic nature of a time series can be modeled approximatively; information such as trends, random variations, periodic components, cyclic patterns, and serial correlation can be determined. Consequently, it is possible to predict the future values of the series with a certain degree of precision [18]. Model identification, parameter estimation, and diagnostic testing are the steps in developing an ARIMA predictive model [19]. In the statistical literature, the Box-Jenkins Autoregressive Integrated Moving Average (ARIMA) technique is well-established [20]. It combines the differenced autoregressive and moving average models [21]. The model has proven to be one of the most prominent methods for financial forecasting and has demonstrated the ability to generate accurate short-term projections. The future value of a variable in the ARIMA model is a linear combination of past values and past errors [18, 20, 21], as expressed in Eq. [1].

$$Y_t = \varphi_0 + \varphi_1 Y_{t-1} + \varphi_2 Y_{t-2} + \cdots + +\varphi_p Y_{t-p} - \theta_1 \varepsilon_{t-1} - \theta_1 \varepsilon_{t-1} - \theta_1 \varepsilon_{t-1} - \cdots - \theta_q \varepsilon_{t-q} + \varepsilon_t \tag{1}$$

where Y_t is the actual value, ε_t is the random error at t, φ_i and θ_j are the coefficients, and p and q are integers often referred to as autoregressive and moving averages, respectively. The Algorithm [1] isused for the ARIMA model in the current study:

2.2 LSTM model

Long short term memory (LSTM) is one of the most widely used deep learning models currently, especially for time series prediction, which is a difficult problem to solve due to long-term trends, seasonal and cyclical fluctuations, and random noise [22]. The ability of the LSTM to memorize data sequences distinguishes it from other RNNs [23]. LSTMs have longer memories and can learn from inputs separated by lengthy time lags.

Algorithm 1 ARIMA Model Algorithm

Require: Historical stock price dataset
Ensure: Stock price prediction based on stock price analysis

1: Import/load libraries (NumPy, Pandas (lag_plot), matplotlib, Stats models (ARIMA))
2: Read NSE- Hotel Leela Venture Limited/InterContinental Hotels Group (IHG)/Marriott International Incorporation (MII) dataset.
3: Plot the autocorrelation graph with a lag of 3 to check if there is any correlation in the data.
4: Plot the historic data in the date-time format.
5: Split the data into two variables, train_data (80%) and test data (20%).
6: Build the ARIMA model with the parameters (4, 1, 0).
7: Fit the model using the training dataset, generate prediction for each element on the test dataset.
8: Evaluate the model using RMSE (root mean squared error) loss function.
9: Plot the final output as the predicted price.

An LSTM consists of three gates: an input gate that determines whether to accept a new input, a forget gate that deletes irrelevant information and an output gate that determines what information to output. These three gates are analog gates based on the sigmoid function that operates between 0 and 1 [22]. Figure 1(a) represents the simplest form of a recurrent neural network (RNN), which considers not only its current input but also the output of the preceding RNNs. Figure 1(b) represents the LSTM cell, a special type of RNN capable of handling long-term dependencies compared to simple RNN. Figure 1(c) represents three interconnected cells of LSTM (used in the present work). Figure 1(d) represents the exploded view of the single LSTM cell. The Algorithm [2]is used for the LSTM model in the current study

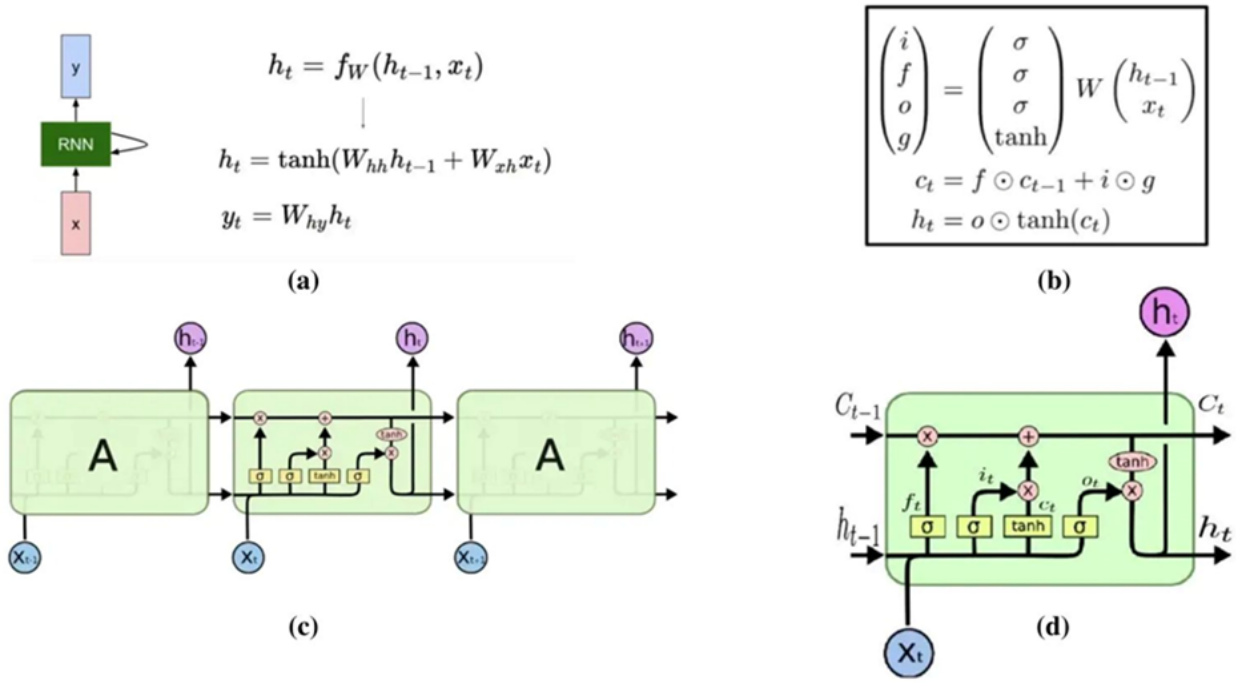

Figure 1: **(a)** Simple RNN cell representation; **(b)** LSTM cell representation; **(c)** Visual representation of interconnected LSTM cells; **(d)** Visual representation of single LSTM cell.

2.3 Data collection

The literature showed that during COVID-19, the hospitality sector faced the worst and steep downfall. Moreover, the current study is focused on the hospitality sector of India. Thus, the data focused are from Hotel Leela Venture (HLV) Limited, InterContinental Hotels Group (IHG) and Marriott International Incorporation (MII). Generally, two sources publish companies' stock prices in India: the Bombay stock exchange (BSE) and the National stock exchange (NSE). Also, the literature shows that closing price forecasting is an important rule in finance and economics, which has prompted researchers to develop a fit model for forecasting accuracy [10]. Thus, in the present study, the data concerning the closing stock prices of the selected firms is collected from NSE. Data were directly downloaded using YAHOO FINANCE and filtered by the date.

Algorithm 2 LSTM Model Algorithm

Require: Historical stock price dataset
Ensure: Stock price prediction based on stock price analysis

1: Import/load libraries (NumPy, Pandas, matplotlib, Keras models (Sequential), Keras layers (LSTM, Dropout, Dense), Scikit learn).
2: Read NSE- Hotel Leela Venture Limited/InterContinental Hotels Group (IHG)/Marriott International Incorporation (MII) dataset.
3: Plot the historic data of the dataset in date-time format.
4: Sort the data in ascending order according to the date.
5: Scale the data using MinMaxScaler, split the data into two variables, train_data (90%) and valid_data (20%).
6: Create training dataset, convert them into a Numpy array, reshape into 3-dimensional data.
7: Create testing dataset, convert them into a Numpy array, reshape them into 3-dimensional dataset, undo scaling of the model.
8: Build and compile the model using the training data set.
9: Use the output of the last layer as a prediction of the next time step.
10: Repeat steps 8 and 9 until optimal results are achieved.
11: Plot the final output as the predicted price.
12: Evaluate the accuracy using the RMSE (root mean squared error) function.

2.4 Data analysis

Initially, the prediction results obtained using two technologies: Random forecasting and the ARIMA model, were compared (during the pilot study), wherein the ARIMA model proved to be efficient. Moreover, considering the complexity of financial time series, combining deep learning with the concept of financial market prediction is regarded as one of the most efficient ways. Thus, an algorithm is proposed for predicting future values wherein the special type of RNN, namely LSTM, is implemented. The results obtained using ARIMA are compared with those obtained using the proposed LSTM model, and the same has been discussed in the present article. Values from the beginning in the first sliding window are used to predict the price in the following window.

3 Results and Discussion

For the implementation of the discussed ARIMA model, the closing time series data were first decomposed into three components: trend, seasonality and noise. The two-year ARIMA result concerning the stationary graph for HLV, one of the selected firms, is represented in Figure 2.

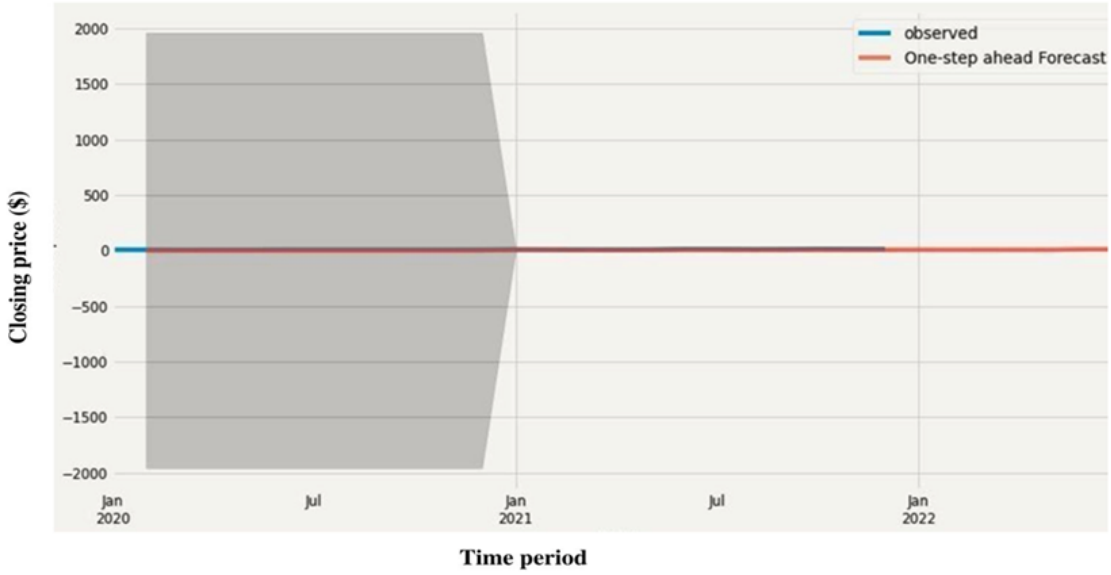

Figure 2: ARIMA results for one of the selected firms.

For LSTM, the data obtained were initially preprocessed, wherein only the stock's closing value was taken and mapped with the indexes. The values were transformed in a range between 0 and 1, using the minmax scalar, as the LSTM is known to be sensitive to the data scale. After the accomplishment of the transformation, the data was split into test and train. The split data was converted to a dataset matrix per the LSTM model requirements. The root mean square error (RMSE) values were calculated, and the predicted future values were plotted, as shown in Figure 3. The accuracy of the calculated value was determined as, Accuracy $= 100 - \text{RMSE}$.

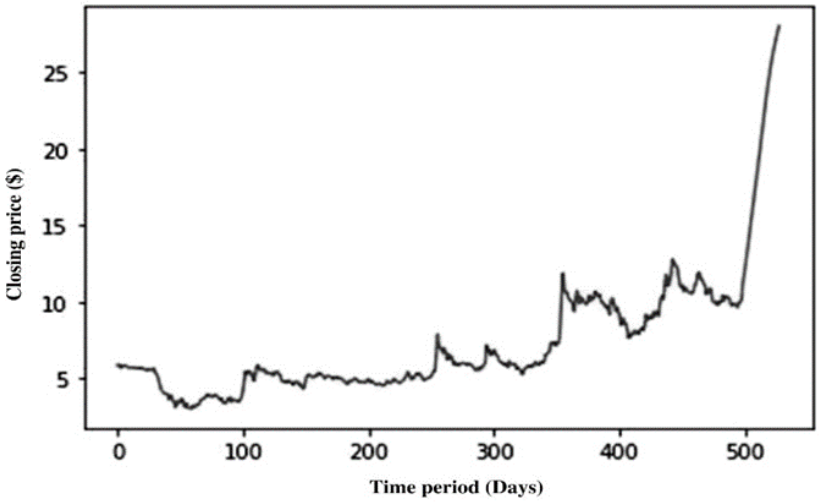

Figure 3: LSTM results for one of the selected firms.

The consolidated results concerning the RSME values obtained using ARIMA and LSTM models for the selected data set of the hospitality industry are given in Table 1. The same has been depicted graphically in Figure 4. From the results; it is evident that the results obtained using the LSTM model outperform the results obtained using the ARIMA model. The average accuracy level of values obtained using the LSTM model is 97.31%, and that obtained using the ARIMA model is 82.73%. The outstanding effectiveness of the RNN machine learning-based LSTM method to the chosen stock market prediction issue is attributable to the "iterative" optimization technique employed by these approaches to get optimal outcomes. Iterative refers to repeatedly obtaining results and selecting the most ideal one, i.e., the iteration that minimizes errors. As a result, iterations aid in the transformation of an under-fitting model into a model that is ideally suited to the data.

Table 1: Closing price and prediction accuracy comparison of LSTM and ARIMA results.

Hospitality sector	**Closing values**		**Actual**	**Accuracy**	
	LSTM	**ARIMA**		**LSTM**	**ARIMA**
HLV Limited	5.11	4.40	5.3	96.42%	83.02%
Intercontinental Hotels Group	58.88	48.46	58.95	99.88%	82.21%
Marriot International Inc.	114.07	98.93	119.28	95.63%	82.94%

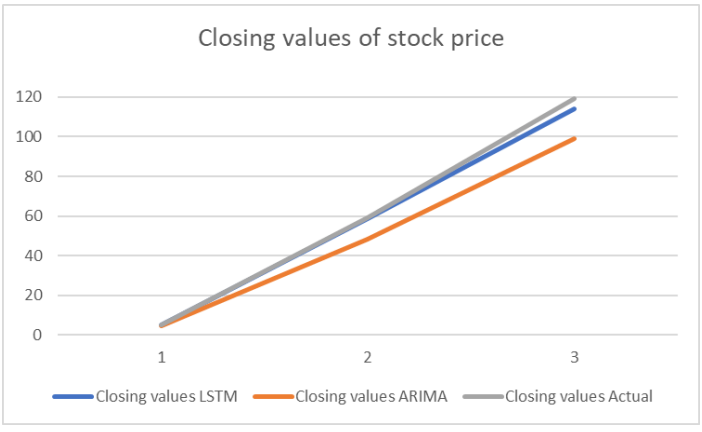

Figure 4: Comparative analysis of RSME values obtained using the ARIMA and LSTM models.

Since ML methods such as LSTM employ gradient descent to enhance their models, it makes sense to put the whole dataset through a single network numerous times to update the weights and achieve a more accurate prediction model. Another possible cause might be the trained model's rolling characteristic. Since a model is refined in a rolling scenario in each round, a whole new LSTM model is being trained, and the weights are updated for each new model. The ARIMA model, though, showed a lower accuracy; it was very well above the acceptable value of 75%. An observation is that the time taken to process the ARIMA model was more. Thus, if faster processing devices are used or a data set with fewer empty values is used, the ARIMA model can produce better results.

4 Conclusion

The impact of COVID-19 on the global hospitality industry was significant. These industries suffered enormous losses during the pandemic, and the irregularity also affected other industries. The objective of this paper was to develop models that can provide investors with an overview of the market's general tendencies. Three datasets were used to construct and evaluate the model for NSE-Hotel Leela Venture (HLV) Limited, InterContinental Hotels Group (IHG), and Marriott International Incorporation (MII), with 80% of the data used for training and 20% for testing. The accuracy achieved was acceptable (nearly greater than 75%). Two models: ARIMA and LSTM, were used. The historical stock data for any given company is extremely extensive. RNNs, particularly LSTM models, have memory cells that only retain relevant information for a specific step and thus produce accurate results. In this regard, LSTM outperformed the ARIMA method because it only considers the most important variables for forecasting. During the analysis, it was discovered that the processing time required for ARIMA is significantly longer. However, if faster processing devices are used or a data set with fewer empty values is used, the ARIMA model can produce better results. The LSTM model made accurate predictions but tended to fail when any attribute values were missing. In simple words, it could be concluded from the work that the LSTM provided a better result than the ARIMA model, but then both models produce reasonably accurate results and could be a great asset for stock traders.

Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Author Contribution

Urvashi Rahul Saxena: Supervision, Writing- Original draft preparation, Writing- Reviewing; Parth Sharma: Conceptualization, Visualization, Investigation, Methodology, Data curation, Writing- Reviewing; **Gaurav Gupta**: Conceptualization, Visualization, Investigation, Methodology, Data curation, Writing- Reviewing.

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Sentiment Analysis using Latent Dirichlet Allocation for Aspect Term Extraction

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Abstract

This work proposes a sentiment analysis approach for decision-making in product design, analysis, and market share. The approach incorporates user-generated text data in the form of consumer reviews to extract product features using topic-based modeling methods. Latent Dirichlet Allocation (LDA) is employed to extract aspect categories from the data and identify the sentiment of each review using the VADER sentiment analyzer. The performance of the proposed method is evaluated in terms of accuracy, with an achieved result of 80%. The extracted topics are also summarized to provide leads for product design and quality assurance. The approach can be used by manufacturers, retailers, and suppliers to understand customers' opinions about their products better and make better decisions. LDA is a powerful unsupervised method that can extract latent topics from a collection of documents; this method has been widely used in text mining, information retrieval, and natural language processing. The accuracy can be improved by using more sophisticated models or more data.

Keywords: Sentiment Analysis; Latent Dirichlet Allocation (LDA); Product Design; User-Generated Text Data; Opinion Mining

1 Introduction

Sentiment Analysis, also known as Opinion Mining, is a rapidly growing research area that aims to extract and analyze the opinions, attitudes, and emotions expressed in unstructured text data, such as consumer reviews, social media posts, and online forums [1–3]. Sentiment Analysis has become an important tool for businesses to better understand consumer perceptions of their products and services and make informed decisions about product design, analysis, and market share [4–6]. One of the most popular techniques used in Sentiment Analysis is Latent Dirichlet Allocation (LDA) [7–9]. LDA is a powerful unsupervised method that can extract latent topics from a collection of documents, providing a way to analyze large amounts of unstructured data [10]. In the context of Sentiment Analysis, LDA has been used to identify and classify aspect categories, such as features or attributes of a product, from consumer reviews [11–13]. By identifying these aspect categories, LDA can provide a more fine-grained understanding of customer sentiment, compared to traditional sentiment analysis that only classifies text as positive, negative, or neutral. Aspect-Based Sentiment Analysis (ABSA) is a specific type of Sentiment Analysis that focuses on identifying the specific features or attributes of a product or service that customers like or dislike [14–16]. ABSA is particularly useful for analyzing consumer reviews and conducting surveys [16]. It provides a more fine-grained understanding of customer sentiment than traditional sentiment analysis, which only classifies text as positive, negative, or neutral. There are several existing methods for ABSA, including rule-based, lexicon-based, and machine learning-based approaches [17, 18]. Rule-based approaches rely on manually defined rules or patterns to identify aspect terms and sentiment [19, 20]. Lexicon-based approaches use pre-existing sentiment lexicons, such as the SentiWordNet, to classify aspect terms and sentiment [21–23].

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Machine learning-based approaches use supervised or unsupervised techniques to learn patterns from labeled data [17, 24]. In this work, we propose a sentiment analysis approach that utilizes Latent Dirichlet Allocation (LDA) for aspect term extraction and the Valence Aware Dictionary for sEntiment Reasoning (VADER) sentiment analyzer to identify the sentiment of each review. LDA is a powerful unsupervised method widely used in text mining, information retrieval, and natural language processing. VADER is a lexicon-based approach that uses a pre-existing sentiment lexicon and is particularly effective in understanding the sentiment of social media text. The proposed approach aims to provide a more fine-grained understanding of customer sentiment and extract leads for product design and quality assurance by combining the LDA and VADER. The performance of the proposed method will be evaluated in terms of accuracy, and the extracted topics will be summarized to provide leads for product design and quality assurance. This research will be important because it provides a new method for aspect-based sentiment analysis that combines the strengths of both LDA and VADER, and it will be a useful tool for business organizations to better understand consumer perceptions of their products and services and make informed decisions about product design, analysis, and market share. The approach can be used by manufacturers, retailers, and suppliers to understand customers' opinions about their products better and make better decisions.

2 Methodology

2.1 Dataset Description

The study uses user-generated text data from smartphone reviews. The smartphone reviews data consists of 20,000 reviews collected from online marketplaces and e-commerce websites. The reviews were collected for several months and included a variety of different models and brands of smartphones. The reviews include positive and negative opinions and cover various topics such as design, performance, camera quality, battery life, and more. The text reviews were preprocessed in the selected data to remove irrelevant information, such as URLs and special characters, and standardize the text format. The data was then split into training and testing sets to evaluate the performance of the proposed approach. The training set was used to train the LDA model, and the testing set was used to evaluate the model's accuracy. The smartphone reviews data was chosen for this study as they are widely available and represent the types of data businesses often encounter in real-world applications. The smartphone reviews data represents a specific product category. The large sample size of the data provides a good representation of customer opinions and preferences and allows for a robust evaluation of the proposed approach.

2.2 LDA for Aspect Term Extraction in Product Reviews

Latent Dirichlet Allocation (LDA) is a topic modeling technique used to extract latent topics from a collection of documents [25]. LDA uses a probabilistic approach to identify the topics present in a set of documents and the words associated with those topics [26]. The technique is particularly useful for finding reasonably accurate mixtures of topics within a given document. The LDA algorithm is an unsupervised method used to identify latent topics in documents without prior knowledge. The algorithm starts by assigning each document to a random topic and then iteratively updates the topic assignments for each word in the document based on the probability of the word belonging to each topic. The algorithm then updates the topic distributions for each document based on the probability of the document belonging to each topic [27]. Algorithm 1 represents the steps in LDA.

Algorithm 1 LDA Algorithm

1: Initialize the number of topics, K, and the number of documents, D.
2: Randomly assign each word in each document to one of the K topics.
3: For each word in each document:
4: Calculate the probability of the word belonging to each of the K topics.
5: Reassign the word to the topic with the highest probability.
6: For each document:
7: Calculate the probability of the document belonging to each of the K topics.
8: Reassign the document to the topic with the highest probability.
9: Repeat steps 3 and 4 for a specified number of iterations or until the topic assignments converge.
10: Output the resulting topic assignments for each word and document.

The LDA algorithm uses a generative model that can discover latent topics in a set of documents, assuming that each document is a mixture of a small number of latent topics. The algorithm uses a probabilistic approach to identify the topics present in a set of documents and the words associated with those topics. The algorithm starts by assigning each document to a random topic and then iteratively updates the topic assignments for each word in the document based on the probability of the word belonging to each topic. The algorithm then updates the topic distributions for each document based on the probability of the document belonging to each topic. It is important to note that LDA requires a pre-specified number of topics, and the number of topics should be chosen based on the complexity of the dataset and the research question. It also requires an appropriate number of iterations or convergence criteria, and the number of iterations should be chosen based on the computational resources available and the desired level of accuracy.

In this study, Latent Dirichlet Allocation (LDA) was used for aspect term extraction from the smartphone reviews data. The dataset was first preprocessed using lower punctuation, stopping word removal, tokenization, and lemmatization. This preprocessing step was necessary to convert the raw text data into a format that the LDA algorithm could understand. Count-Vectorizer, a tool available in the sci-kit-learn library in Python, was used to convert the tokenized text data into a vector representation based on the word frequency for a tokenized review. This vector representation was then used as input for the LDA algorithm. The LDA algorithm could extract latent topics from the dataset based on the frequency of words in the documents. These topics represented the aspect categories that were present in the data. The LDA algorithm identified a product's features or attributes, such as camera quality or battery life, discussed in the reviews. The resulting aspect categories were used to understand the customer opinions about different aspects of the product and make better decisions about product design, analysis, and market share.

2.3 VADER for Sentiment Analysis in Product Reviews

VADER (Valence Aware Dictionary and sEntiment Reasoner) is a powerful sentiment analysis tool specifically tuned to understand the sentiments of social media text. It is a lexicon and rule-based method that can understand and interpret the meaning of text data and classify it as positive, negative, or neutral. VADER employs a combination of techniques to achieve this. One of these techniques is the use of a sentiment lexicon. A sentiment lexicon is a collection of lexical features, such as words pre-classified as positive or negative based on semantic orientation. By using this lexicon, VADER can quickly identify the sentiment of a piece of text. In addition to identifying the overall sentiment of a piece of text, VADER also provides a measure of the degree to which the sentiment is favorable or negative. This means it can determine whether a review is slightly positive or extremely positive. After applying VADER, the aspect categories are summarized based on their sentiments. This helps to understand the overall sentiment of a review and identify which aspects of the product are being discussed in a positive or negative light. This information can then be used to make better product design, analysis, and market share decisions.

In this work, the VADER sentiment analyzer was used to identify the sentiment of each review in the smartphone reviews dataset. By using VADER, the sentiment of each review in the dataset was quickly identified as positive, negative, or neutral. It also provided a measure of the degree to which the sentiment is favorable or negative. This information was used to summarize the aspect categories of the reviews based on their sentiments. This helped to understand the overall sentiment of a review and identify which aspects of the product are being discussed in a positive or negative light, which proved beneficial for decision-making in product design, analysis, and market share.

2.4 Performance Evaluation Criteria

In this work, the performance of the proposed sentiment analysis approach using LDA for aspect term extraction was evaluated in terms of accuracy. Accuracy is a commonly used metric in machine learning and natural language processing to evaluate the performance of a model. It measures the proportion of correctly classified instances out of the total number of instances. The predicted sentiments' accuracy was calculated to evaluate the proposed method's performance using a set of test data, which was not used during the training of the model. The test data was labeled with the correct sentiments, and the model's predictions were compared to these labels. The accuracy was calculated as the proportion of correctly classified instances out of the total number of instances in the test data.

3 Results and Discussion

The proposed work was implemented using the Python programming language, and the results obtained were analyzed. The smartphone review dataset was preprocessed to fit the needs for implementing the Latent Dirichlet Allocation (LDA) technique. Sentiments of the reviews were then identified using the VADER sentiment analyzer, and dominant topics were obtained by applying this technique. The relevance score of the selected topics was also generated, as shown in Figure 1(a). The final step in the process was to extract aspect categories from the consumer review dataset, as illustrated in Figure 1(b). The Latent Dirichlet Allocation (LDA) topic modeling technique was used for this purpose, and it proved to be a valuable tool for further project analysis. Out of the total five aspect categories extracted from the dataset, four were identified with high accuracy. Figure 2(a) illustrates the sentiment polarity of aspect categories extracted from the smartphone reviews dataset. The aspect categories are classified as positive, negative, or neutral based on the sentiments identified by the VADER sentiment analyzer. Figure 2(b) illustrates the summary of aspect categories extracted from the smartphone reviews dataset in a stacked bar graph.

The obtained results indicate that the model correctly identified four out of five categories, resulting in an accuracy of 80%. While the achieved accuracy may not be very high, it is important to note that sentiment analysis is a challenging task, especially when dealing with user-generated text data, which can be very subjective and difficult to classify. Additionally, the accuracy can be improved by using more sophisticated models or more data. The performance can also be evaluated using other metrics such as precision, recall, and F1-score, which are also commonly used in NLP and Sentiment Analysis tasks. However, the proposed approach extracted aspect categories from the data and identified each review's sentiment using the VADER sentiment analyzer with an acceptable level of accuracy. It can be considered a starting point for further development of sentiment analysis methodologies. In the future, the proposed method can be expanded to other domains with the help of more data and sophisticated models.

(a)

	topic	relevance_score
10 read	Topic1	1.199999
1900mah enough	Topic4	1.199989
570 today	Topic4	1.199983
80 le	Topic2	1.199971
_____ source	Topic5	1.199998
...	...	...
zune speaker	Topic5	1.199999
zune use	Topic5	1.199997
zune yeah	Topic2	1.199990
zx5 purchased	Topic4	1.199995
zzzs rate	Topic3	1.199997

402892 rows × 2 columns

(b)

	Dominant_topic	Aspect
0	1	[work great]
1	4	[sound quality]
2	2	[battery life]
3	5	[cell phone]
4	3	[screen protector]

Figure 1: **(a)** Generated relevance scores for the selected topics; **(b)** Extracted aspect categories for smartphone reviews

Additionally, it can be used in various applications such as customer relationship management, product design, and marketing. Therefore, the proposed method has many potential applications and can be a valuable tool for businesses and organizations that rely on customer feedback to make decisions.

(a)

sentiment	Negative	Neutral	Positive
Aspect			
battery life	605	162	2941
cell phone	697	198	3307
screen protector	601	176	3168
sound quality	641	173	3201
work great	667	272	3191

(b)

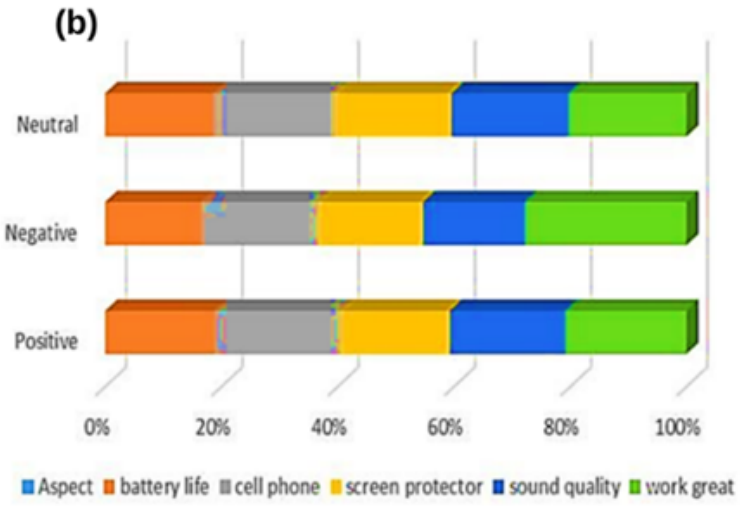

Figure 2: **(a)** Sentiment polarity of obtained categories; **(b)** Aspect summarization

4 Conclusion

In this article, we proposed a method for extracting aspect categories and identifying the sentiment of customer reviews for smartphone products. The proposed method used a combination of preprocessing steps, such as lower punctuation, stop words removal, tokenization, and lemmatization, to prepare the dataset for analysis. The Latent Dirichlet Allocation (LDA) technique was then used to extract aspect categories from the data, while the VADER sentiment analyzer was used to identify the sentiment of each review. The model correctly identified three out of five categories, thus having an accuracy of 80% on this dataset. The achieved accuracy result of 60% indicates that the proposed method could correctly classify the sentiment of 60% of the instances in the test data. While this accuracy may not be very high, it is important to note that sentiment analysis is a challenging task, especially when dealing with user-generated text data, which can be very subjective and difficult to classify.

In conclusion, the proposed approach extracted aspect categories from the smartphone review data and identified each review's sentiment using the VADER sentiment analyzer with an acceptable level of accuracy. This method can be a starting point for further developing sentiment analysis methodologies for smartphone products.

Declaration of Competing Interests

The author declares that she has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Author Contribution

Lovish Rajput: Conceptualization, Visualization, Investigation, Methodology, Data curation, Writing - Original draft preparation, Writing - Reviewing **Shilpi Gupta**: Conceptualization, Visualization, Investigation, Methodology, Data curation, Writing - Reviewing

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Impact of COVID-19 on Teacher Well-Being In Higher Education Institutions

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Abstract

The COVID-19 pandemic has created significant challenges for higher education teachers, especially their well-being. A study was conducted to explore the well-being of teachers in higher education institutions and understand the impact of the pandemic. The study utilized a quantitative approach, surveying teachers and analyzing the data using PLS-SEM and CB-SEM. The results revealed three key factors impacting teacher well-being: accomplishment, physical health, and relationships. The study highlights the importance of supporting teacher well-being during the pandemic by prioritizing physical health, building relationships, and engaging in meaningful activities. The findings can inform the development of policies and programs that promote teachers' physical and emotional health in higher education institutions. In conclusion, this study provides valuable insights into teachers' experiences during the COVID-19 pandemic and highlights the need for greater support for their well-being.

Keywords: COVID-19; Teacher Well-Being; Higher Education Institutions; Work-Life Balance; Stress

1 Introduction

The COVID-19 pandemic has brought unprecedented challenges in all sectors, including education [1–3]. With 94,16,895 teachers in schools and colleges in India, the nationwide lockdown announced by the government has greatly affected the well-being of educators [4, 5]. The sudden shift from in-person teaching to virtual mode has posed various challenges for teachers, including concerns for their safety and health, changes in their work patterns, and difficulties balancing work and family demands.

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Well-being, in this context, refers to the physical, environmental, and social events that influence an individual's response to the situation [6]. The well-being of contemporary teachers is influenced by various factors, including workload, organizational support, job satisfaction, and opportunities for growth and development [7]. However, with the advent of the pandemic, digital experience, technological exposure, and access to digital devices have become critical components in determining the well-being of teachers. The sudden changes brought about by the pandemic have resulted in stress for many teachers, particularly regarding work-life balance [8]. There is a need for interventions that improve teachers' professional well-being and enhance their digital skills to address these challenges. The government and educational institutions must support teachers by reducing their workload, clearly defining their roles and responsibilities, and creating a positive work environment that promotes well-being. By doing so, a happier and healthier workplace can be ensured for teachers, resulting in a better learning experience for students. This paper explores teachers' experiences and identifies opportunities to foster their physical and emotional well-being.

2 Related Works

The teaching profession is facing unprecedented challenges due to the shift to remote teaching and home isolation caused by the COVID-19 pandemic, as well as fear and anxiety about personal health and safety [9]. It is imperative to address the well-being of teachers and foster positive relationships with students to create a supportive learning environment. Teachers with strong connections with students and colleagues tend to have greater well-being [9]. Well-being is an individual's reaction to environmental, physical, and social events and includes mental and physical health, job satisfaction, stress levels, and social connectivity [10, 11]. Mental well-being encompasses mental efficiency, positive emotions and attitudes, healthy relationships with reality, and peace of mind [12]. The lockdown has resulted in increased workloads for teachers with limited experience with online teaching and spending more time on preparation than teaching [13]. Teachers play a crucial role in determining the quality of education, and their well-being is closely tied to student performance [14, 15]. One effective way to promote teacher well-being is establishing Professional learning communities (PLCs). PLCs help build positive relationships and reinvigorate teachers' passion for teaching, leading to improved well-being for teachers and students [16]. The teaching profession is found to be one of the most stressful occupations due to the emotional involvement with students [17]. Several variables contribute to teacher well-being, including workload, organizational support, and relationships with peers and seniors [18–22]. This article aims to assess the well-being of teachers by considering various aspects of life, including accomplishment, engagement, physical health, positive emotion, relationships, work-related satisfaction, and more.

3 Methodology

The present study adopts a positivist paradigm and employs a quantitative approach to explore the impact of the COVID-19 pandemic on teachers' personal and work-related well-being in higher education institutions. Empirical observation and measurement form the cornerstone of this research philosophy, which seeks to provide quantitative evidence for the relationships between the variables of interest. The questionnaire survey method was employed to collect the data from 1,136 academicians from various higher education institutes. Partial least squares-based structural equation modeling (PLS-SEM) and covariance-based structural equation modeling (CB-SEM) were used to analyze the data. These are two well-established multivariate data analysis methods widely adopted in business management research fields, such as operations management, information systems, and marketing. PLS-SEM, in particular, is based on a factor analysis concept, is suitable for theory testing, and uses maximum likelihood estimation. The hypotheses were developed based on earlier studies associated with the variables of interest. The collected data were processed and analyzed to test these hypotheses and achieve the study's objectives, which pertain to the relationship between well-being and various factors affecting higher education teaching professionals during the COVID-19 pandemic. Interpretation of the results is a crucial part of this research, as it calls for a critical examination of the findings in light of all limitations. This is the only way to make the research meaningful and to draw meaningful conclusions from the analysis. One of the challenges in survey research is selecting an appropriate statistical model for the analysis. This study used PLS-SEM and CB-SEM to address this challenge and ensure that the results are reliable and statistically robust.

4 Results and Discussion

The demographic profile of the participants in this study is presented in Table 1. The table provides a summary of the distribution of the respondents based on gender, age, education qualification, marital status, usual living status, and presence of children. Of the 1,136 respondents, 59.9% are male, and 40.1% are female. Regarding age, the largest proportion of respondents (41.2%) falls in the age group of 31-40 years, followed by those in the age group of 41-50 years (23.7%). Regarding education qualification, 55.4% of the respondents hold a post-graduate degree, while 38.6% hold a Ph.D. Most respondents (70.2%) are married, while 28.5% are unmarried.

Table 1: Demographical Profile of the Respondents

Variable	Frequency	Percentage
Total	1136.00	100.00
Gender		
Female	455.00	40.10
Male	681.00	59.90
Age		
25 - 30 Years	277.00	24.40
31-40 Years	468.00	41.20
41 - 50 Years	269.00	23.70
50 - 60 Years	102.00	9.00
$>$ 60 Years	20.00	1.80
Education qualification		
Graduation	69.00	6.10
Ph.D.	438.00	38.60
Post-Graduation	629.00	55.40
Marital status		
Married	797.00	70.20
Separated/Divorced/Widowed	15.00	1.30
Unmarried	324.00	28.50
Usual living status		
Joint family	489.00	43.00
Living alone	101.00	8.90
Nuclear family	546.00	48.10
Do you have children		
No	432.00	38.00
Yes	704.00	62.00
If yes, how many?		
1	315.00	43.70
2	361.00	50.10
$>$2	44.00	0.06

With regards to the usual living status, 48.1% of the respondents are living in a nuclear family setup, while 43% are part of a joint family. Additionally, 62% of the respondents have children, with 50% having 2 children. These results suggest a balanced representation of the population. Table 2 presents the survey results on the participants' perceptions and experiences during the lockdown. The results are organized based on a Likert scale ranging from "Strongly Disagree" to "Strongly Agree." The data shows that most participants (75%) have a positive outlook and mostly agree with the questions, while only 6% disagree.

Table 2: Results of the survey on the participants' perceptions and experiences

Codes	Questions	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
AC1	I achieved the important goals I had set for myself during the lockdown.	02	04	19	32	43
AC2	I know I can find ways to solve the problem, even when others want to quit.	01	02	15	37	46
AC3	I finished whatever I started during the lockdown.	01	05	17	35	42
AC4	I have the sense that I have developed a lot as a person during the lockdown.	01	03	19	34	43
AC5	Whenever I make a plan to get something done, I stick to it.	01	02	17	33	47
AC6	I was competent in my daily activities during the lockdown.	01	03	14	34	48
AC7	I often got a sense of accomplishment from what I did during the lockdown.	01	03	16	34	47
AC8	I work towards accomplishing my goals most of the time.	01	02	15	33	49

Continued on next page

Table 2 – *Continued from previous page*

Codes	Questions	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
ENG1	I often receive constructive feedback on my work during the lockdown.	03	05	16	34	42
ENG2	I have been working for very long periods during the lockdown.	03	05	18	28	46
ENG3	I often get completely absorbed in whatever I do during the lockdown.	02	05	19	31	42
ENG4	I often lose track of how much time has passed when I read or learn something new during the lockdown.	03	07	20	28	42
ENG5	I get so involved in activities that I often forget about everything else during the lockdown.	04	07	22	30	37
ENG6	I feel happy when I am completely absorbed during the lockdown.	03	06	20	30	41
MN1	I enjoy making plans for the future and working to make them a reality.	01	01	12	32	54
MN2	I understand my life's meaning.	01	01	12	29	57
MN3	My life has a clear sense of purpose.	01	01	14	28	56
MN4	Everything that I do in my life is valuable and worthwhile.	00	01	13	29	56
MN5	I have a sense of direction in my life.	01	01	11	30	57
PH1	I meditated/did yoga regularly during the lockdown.	15	13	19	20	34
PH2	I indulged in recreational activities regularly during the lockdown.	06	10	21	28	35
PH3	I was active most of the day during the lockdown.	02	06	19	31	42
PH4	I am physically fit.	01	03	17	27	52
PE1	I generally have been feeling enthusiastic during the lockdown.	04	05	21	28	42
PE2	I generally have been feeling strong during the lockdown.	03	05	19	30	42
PE3	I generally have been feeling inspired during the lockdown.	04	07	20	28	42
RL1	I believe in reinforcing strong interpersonal relationships during the lockdown.	01	02	17	30	49
RL2	I actively contributed to the happiness and well-being of others during the lockdown.	01	02	17	32	48
RL3	During the lockdown, my belief that there are people in my life who genuinely care got reinforced.	01	02	17	33	47
RL4	I am satisfied with my relationships.	01	01	10	31	57

The results highlight the participants' perceptions regarding their personal and professional development, engagement, mental and physical well-being, and relationships. For instance, most participants agreed that they were competent in their daily activities during the lockdown (48%) and often got a sense of accomplishment from what they did (47%). On the other hand, fewer participants disagreed that they often received constructive feedback on their work (5%) or were active most of the day (6%). The frequency distributions reveal that the participants had a positive outlook and experienced personal growth and well-being during the lockdown. The findings highlight the importance of promoting positive experiences and outlooks during difficult times and may have implications for future research. The survey questions' results in Table 3 provide valuable insight into the respondents' opinions on various activities during the lockdown. Regarding inculcating or reviving a hobby, 72% of the respondents confirmed that they have taken up a new hobby, while 28% have not. This highlights the importance of engaging in leisure activities to cope during difficult times. In terms of social media activity, 88% of the respondents reported being active on social media during the lockdown, whereas only 12% reported the opposite. This indicates the significance of social media as a platform for communication and connection during the lockdown.

Regarding the use of sanitizers, there was a near-equal split between those who reported using sanitizers routinely at home (46%) and those who reported not using them (54%). This suggests that there may be varying levels of concern and awareness regarding health and safety protocols during the lockdown. The results also show that 94% of the respondents reported attending or conducting a webinar during the lockdown, while only 6% reported otherwise. This suggests that technology, virtual learning, and professional development platforms were widely adopted during the lockdown. Finally, 79% of the respondents reported calling up their relatives, friends, or colleagues from work during the lockdown, while 21% reported not doing so. Additionally, 51% of the respondents reported noticing a change in their relationship with their family members, 37% reported not noticing a change, and 12% were unsure. These results suggest that the lockdown has significantly impacted interpersonal relationships and highlights the importance of communication and connection during such challenging times.

Table 3: Respondents' opinions on various activities during the lockdown.

Code	**Question**	**No**	**Yes**	**Maybe**
ACT1	Have you inculcated/revived any hobbies during this lockdown?	28	72	-
ACT2	Are you active on social media during this lockdown period?	12	88	-
PM1	Do you use sanitizer (95% isopropyl alcohol) routinely at home?	54	46	-
WR2	During the lockdown, have you attended/conducted any webinars?	06	94	-
RL5	Did you call up your relatives, friends, or work colleagues during this period?	21	79	-
RL6	Have you noticed any relationship changes with your family members during the lockdown?	37	51	12

The results of the relationship dynamics during the lockdown are presented in Table 4. The data shows that the majority of respondents, 62%, reported an improvement in their relationships with their parents, children, or siblings, while only 4% reported a strained relationship with their loved ones. In comparison, 46% of respondents noted an improvement in their relationship with their spouse, while a slightly smaller percentage, 33%, reported that their relationship remained unchanged. Notably, no respondents indicated that the relationship dynamics with their loved ones were not applicable. This data highlights the importance of family relationships during the lockdown and its impact on these relationships.

Table 4: Relationship dynamics during the lockdown

Relationship with	Parents/Children/Siblings	Spouse
Improved	62	46
Remained the same	34	33
Strained	4	5
Not Applicable	0	186

Table 5 sheds light on the change in physical activity levels during the lockdown. The data indicates that while a substantial number of respondents, about 16.4%, reported no physical activity, a significant proportion, about 20.7%, reported engaging in 2-5 hours of physical activity, an increase from 15.2% prior to the lockdown. Additionally, a small but noticeable fraction of respondents, about 3.4%, reported engaging in more than 10 hours of physical activity. The results also highlight the change in screen time and protective measures taken by the respondents. A considerable number of respondents, around 33%, reported spending 2-4 hours daily on digital devices, while a smaller proportion, around 27%, reported spending less than 2 hours. The data shows that most respondents, around 64%, only wore face masks while stepping out, while a smaller number, around 31%, wore both face masks and gloves.

Table 5: Hours/Week of Physical Activity

Hours/week of physical activity	Before	During
Nil	17.9	16.4
$<$ 2 hours	57.8	50.7
2-5 hours	15.2	20.7
5-10 hours	6.3	8.8
$>$10 hours	2.8	3.4

Based on the factor loadings shown in Table 6, it can be seen that physical health (PH1, PH2, PH3, PH4) and positive emotion (PE1, PE2, PE3) have significant factor loadings, suggesting a correlation between these factors and well-being. However, the hours/week of physical activity was not found to have a significant factor loading, indicating a lack of correlation with well-being among higher education teaching professionals during the COVID-19 pandemic.

Table 6: Factor Loadings

(in life)	A	B	C	D	E	F	G	H	I	J
AC1	0.840	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AC2	0.850	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AC3	0.868	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AC4	0.857	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AC5	0.839	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ACT1	0.00	0.921	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ACT2	0.00	0.408	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ACT3	0.00	0.331	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ENG1	0.00	0.00	0.845	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ENG2	0.00	0.00	0.858	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ENG3	0.00	0.00	0.888	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MN1	0.00	0.00	0.00	0.86	0.00	0.00	0.00	0.00	0.00	0.00
MN2	0.00	0.00	0.00	0.915	0.00	0.00	0.00	0.00	0.00	0.00
MN3	0.00	0.00	0.00	0.909	0.00	0.00	0.00	0.00	0.00	0.00
PH1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PH2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PH3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PH4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PE1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PE2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PE3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PM1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PM2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RL1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RL2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RL3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RL4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WR1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.789	0.00
WR2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.787	0.00
WR3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.822	0.00
WR1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.912
WR2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.910
WR3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.907

Note - A: Accomplishment; B: Activities; C: Engagement; D: Meaning (in life); E: Physical health; F: Positive Emotion; G: Preventive Measures; H: Relationships; I: Well-being; J: Work-related

This finding highlights the importance of examining the relationship between physical activity and well-being, as physical activity has been shown to positively impact both physical and mental health, which is in agreement with the view of earlier researchers [23]. It is possible that the lack of correlation between physical activity and well-being among higher education teaching professionals during the COVID-19 pandemic could be due to the limited opportunities for physical activity and increased stress levels related to the pandemic.

Further research is needed to better understand the relationship between physical activity and well-being among higher education teaching professionals during the COVID-19 pandemic. The results of this study provide valuable information for higher education institutions and policymakers, who can use the findings to develop strategies and programs that support the well-being of higher education teaching professionals during the COVID-19 pandemic. By improving the well-being of higher education teaching professionals, institutions can improve the quality of education and the overall academic environment. In order to assess the consistency of the responses, the internal consistency indicator Cronbach's alpha was used to estimate the reliability of the questions. As seen in Table 7, the composite reliability and Cronbach's alpha for most of the constructs are greater than 0.7, indicating a high level of construct reliability. Additionally, the average variance extracted (AVE) for all constructs is greater than 0.5, which confirms convergent validity. All the constructs explain at least 50% of the variation in the corresponding questions, indicating that the data set is valid. The results in Table 7 support the validity of the data collected and allow for further analysis to be conducted confidently.

Table 7: Composite reliability and average variance explained.

	Cronbach's Alpha	rho_A	Composite Reliability	Average Variance Explained (AVE)
Accomplishment	0.905	0.905	0.929	0.724
Activities	0.166	0.330	0.595	0.375
Engagement	0.83	0.833	0.898	0.746
Meaning (in life)	0.876	0.878	0.924	0.801
Physical Health	0.833	0.842	0.888	0.666
Positive Emotion	0.900	0.905	0.938	0.834
Preventive Measures	0.542	0.635	0.804	0.675
Relationships	0.866	0.866	0.909	0.714
Well-being	0.896	0.896	0.935	0.827
Work-related 0.727	0.753	0.842	0.639	

Table 8 presents the discriminant loadings and correlations between the identified constructs. To ensure that the constructs are indeed distinct and not overlapping, the square root of the average variance extracted (AVE) for each construct (the diagonal element in Table 8) was compared with the correlations between the construct and other constructs (non-diagonal elements in Table 8). The results indicate acceptable discriminant validity between each pair of constructs, as all the square roots of AVE are greater than the correlations between the constructs. This suggests that the constructs are indeed distinct from one another and do not overlap significantly.

Table 8: Discriminant loading and correlation.

	A	B	C	D	E	F	G	H	I	J
Accomplishment	0.851	-	-	-	-	-	-	-	-	-
Activities	-0.225	0.612	-	-	-	-	-	-	-	-
Engagement	0.658	-0.164	0.864	-	-	-	-	-	-	-
Meaning (in life)	0.741	-0.226	0.544	0.895	-	-	-	-	-	-
Physical Health	0.682	-0.310	0.542	0.578	0.816	-	-	-	-	-
Positive Emotion	0.611	-0.198	0.651	0.491	0.533	0.913	-	-	-	-
Preventive Measures	0.742	-0.222	0.618	0.752	0.587	0.542	0.822	-	-	-
Relationships	0.712	-0.198	0.612	0.728	0.601	0.613	0.677	0.845	-	-
Well-being	0.842	-0.191	0.570	0.693	0.667	0.531	0.688	0.686	0.910	-
Work-related	0.777	-0.232	0.689	0.762	0.632	0.659	0.809	0.747	0.714	0.800

Note - A: Accomplishment; B: Activities; C: Engagement; D: Meaning (in life); E: Physical health; F: Positive Emotion; G: Preventive Measures; H: Relationships; I: Well-being; J: Work-related

The structural model assessment was conducted to evaluate the validity and reliability of the relationships between the independent and dependent variables. The path coefficients were used to determine the significance and relevance of the relationships between the endogenous and exogenous variables. The R^2 value was also calculated to assess the predictive accuracy of the model and the impact of the exogenous variables on the endogenous variables. The results of the structural model assessment are presented in Figure 1 and Figure 2, which illustrate the relationships between the factors and the dependent variables. This analysis provides crucial information on the validity and reliability of the results and helps understand the causal relationships between the factors and the outcomes. The structural model assessment also includes the evaluation of path coefficients to determine the significance and relevance of the model's relationships between the endogenous and exogenous variables. The path coefficients provide insight into the direct impact of the independent variables on the dependent variables. In our study, the path model was used to examine the relationship between the dimensions of well-being and their influencing factors.

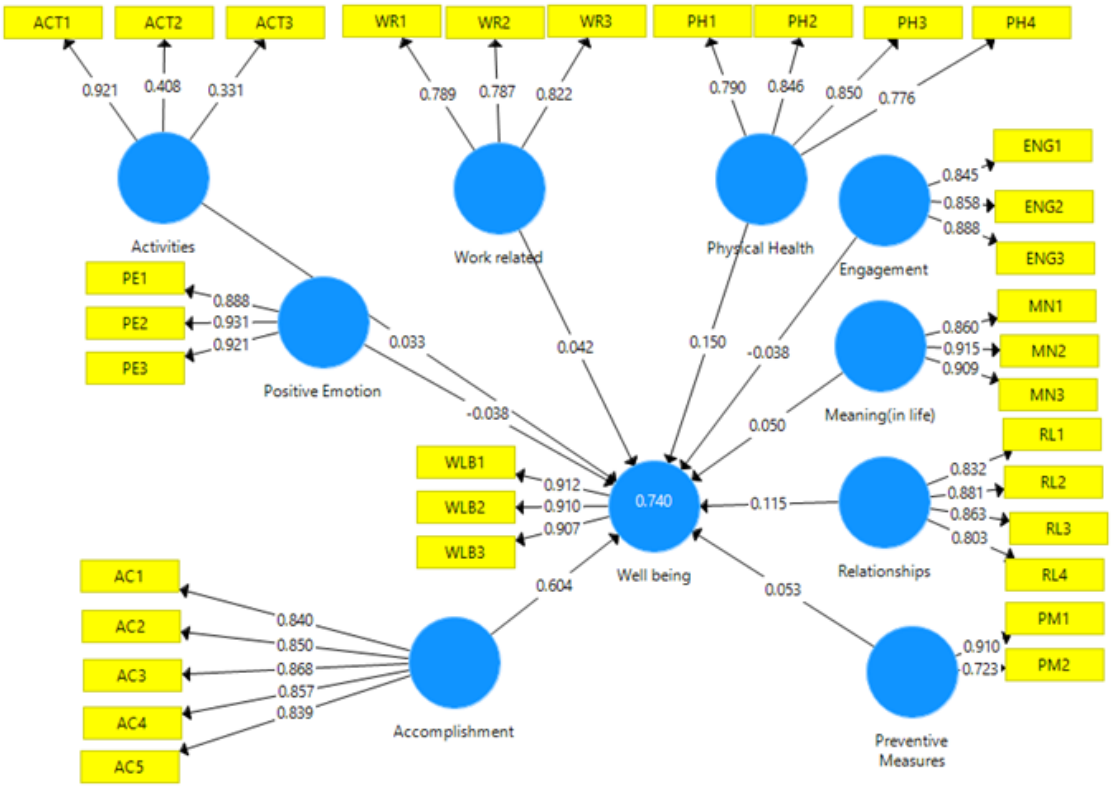

Figure 1: Structural Model Assessment

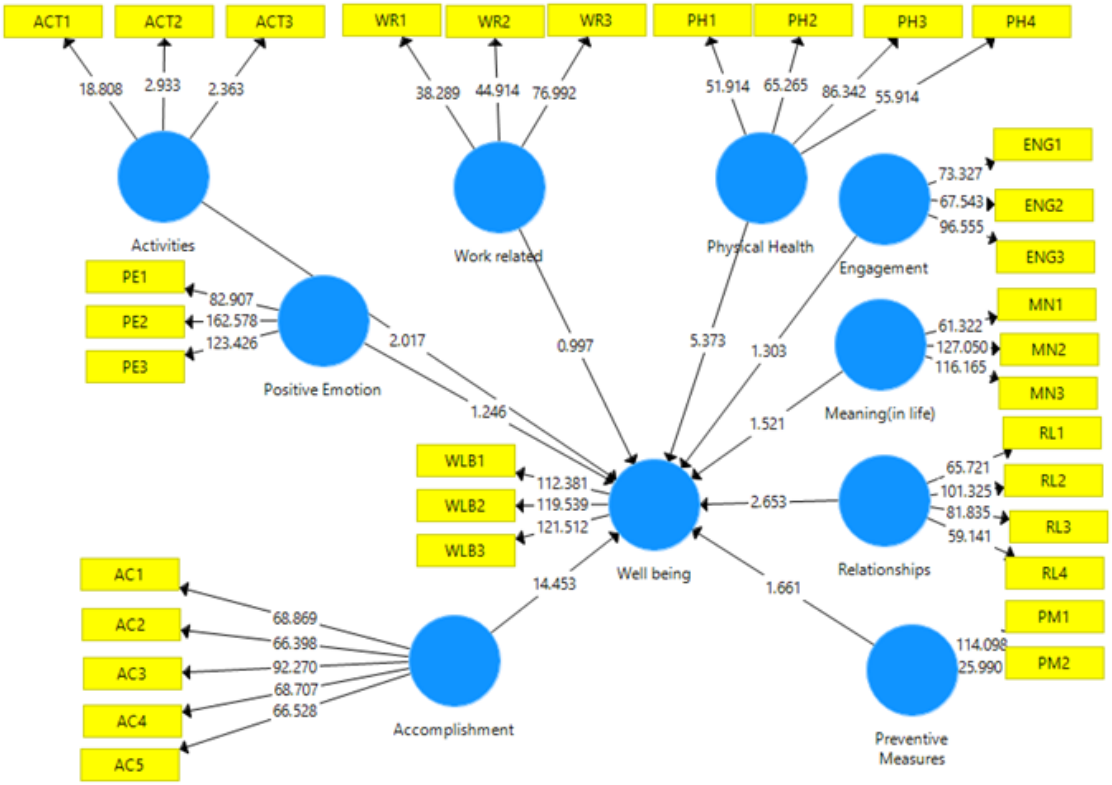

Figure 2: t-statistics

The results show a positive relationship between the dependent and independent variables, with accomplishment being the major contributor to teaching professionals' well-being, physical health, relationships, and activities. This supports the study's hypotheses and provides evidence for the importance of these factors in determining the overall well-being of teaching professionals.

Table 9 presents the results of the hypothesis testing for the relationships between various dimensions of well-being and their influencing factors. The hypothesis was tested using the t-statistics obtained from bootstrapping analysis in SmartPLS3. The results were evaluated based on the p-values, where a p-value less than 0.05 indicates significant results, while a p-value greater than 0.05 suggests that the hypothesis is unsupported. The results showed that hypothesis H1 (accomplishment → well-being) was supported

as the t-statistic was 14.453 with a p-value close to zero. This indicates that accomplishment has a strong and significant impact on well-being. Hypothesis H2 (activities → well-being) was also supported as the t-statistic was 2.07 with a p-value of 0.044, indicating that activities also significantly impact well-being. On the other hand, hypothesis H3 (engagement → well-being) was unsupported as the t-statistic was 1.30 with a p-value of 0.193, which suggests that engagement does not have a significant impact on well-being. Similarly, hypothesis H4 (meaning in life → well-being) was unsupported as the t-statistic was 1.521 with a p-value of 0.129. Hypothesis H5 (physical health → well-being) was supported as the t-statistic was 5.37 with a p-value close to zero, suggesting that physical health strongly impacts well-being. Hypothesis H6 (positive emotion → well-being) was unsupported as the t-statistic was 1.246 with a p-value of 0.213. Hypothesis H7 (preventive measures → well-being) was supported as the t-statistic was 1.661 with a p-value of 0.097, which suggests that preventive measures have a marginal impact on well-being. Hypothesis H8 (relationships → well-being) was supported as the t-statistic was 2.65 with a p-value of 0.008, indicating that relationships significantly impact well-being. Hypothesis H9 (work-related → well-being) was unsupported as the t-statistic was 0.997 with a p-value of 0.319.

Table 9: Statistical Comparison of Hypotheses

Hypothesis	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	t-Statistics	P-Values	Support
H1	0.604	0.607	0.042	14.453	0.000	Supported
H2	0.033	0.030	0.016	2.017	0.044	Supported
H3	-0.038	-0.038	0.029	1.303	0.193	Unsupported
H4	0.050	0.050	0.033	1.521	0.129	Unsupported
H5	0.150	0.149	0.028	5.373	0.000	Supported
H6	-0.038	-0.037	0.030	1.246	0.213	Unsupported
H7	0.053	0.052	0.032	1.661	0.097	Supported
H8	0.115	0.114	0.043	2.653	0.008	Supported
H9	0.042	0.041	0.042	0.997	0.319	Unsupported

5 Conclusion

The results of our study highlight the important role that various factors play in determining the well-being of higher education teaching professionals during the COVID-19 pandemic. Our findings indicate that accomplishment, physical health, and relationships are crucial factors that significantly impact the well-being of these professionals. Additionally, participating in meaningful activities and taking preventive measures were also found to be important contributing factors. However, the obtained results from work also showed no statistical evidence to suggest that work-related aspects, positive emotion, engagement, and meaning in life significantly impact well-being. These conclusions underscore the need for teaching professionals to prioritize their well-being by focusing on accomplishments, maintaining physical health, building and strengthening relationships, engaging in activities that bring meaning, and taking appropriate preventive measures. By doing so, they can better protect their well-being, especially during the challenging times of the COVID-19 pandemic.

Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Author Contribution

S. Pavitra: Conceptualization, Supervision, Writing- Original draft preparation, Writing- Reviewing; **Delaram Mahdaviamiri**: Conceptualization, Visualization, Investigation, Methodology, Data curation; **Nisha S. Tatkar**: Conceptualization, Supervision, Writing- Original draft preparation, Writing- Reviewing; **Namesh Malarout**: Conceptualization, Visualization, Investigation, Methodology; **Babita Singla**: Supervision, Methodology, Data curation, Writing- Reviewing; **Karthikeyan Parthasarathy**: Supervision, Methodology, Data curation, Writing- Reviewing; **Sonia Vaz**: Investigation, Methodology, Data curation; **Prithvi Hegde**: Investigation, Methodology, Data curation; **Annu Duhan**: Investigation, Methodology, Data curation.

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Enhancing Parameters of LEACH Protocol for Efficient Routing In Wireless Sensor Networks

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Abstract

The increasing popularity of wireless sensor networks can be attributed to their unique characteristics, which include high density, low power consumption, software programmability, and long-term accuracy. This paper thoroughly analyzes key parameters for sensor network applications, including network lifetime, packet delivery ratio, energy-efficient transmission, and dead node ratio. This paper examines the effectiveness of clustering in wireless sensor networks for achieving efficiency. The research focuses on the Low-Energy Adaptive Clustering Hierarchy (LEACH) protocol and proposes an enhanced algorithm that improves network lifetime, throughput, and the number of alive nodes. This paper evaluates the performance of the improved LEACH protocol and compares it to other protocols currently in use. The results indicate that the proposed method significantly improves the protocol's performance, making it a promising method for efficient routing in wireless sensor networks. This study is an important contribution to wireless sensor networks and can aid in creating more efficient and effective protocols for various sensor network applications.

Keywords: Wireless Sensor Networks; LEACH Protocol; Clustering; Network Lifetime; Energy-Efficient Transmission

1 Introduction

Wireless networks have revolutionized communication, and wireless sensor networks (WSNs) have brought about significant advancements in ubiquitous computing, smart systems, and the Internet of Things [1]. WSNs comprise several tiny sensor nodes that are densely deployed inside or near the phenomenon to be sensed. These nodes consist of sensing, data processing, and communication components, allowing for random deployment in inaccessible terrains or disaster relief operations. One unique feature of WSNs is the self-organizing capabilities of their protocols and algorithms. This feature is necessary because the position of sensor nodes does not need to be engineered or predetermined. Furthermore, WSNs use cooperative effort, as each sensor node is fitted with an onboard processor that carries out simple computations and transmits only required and partially processed data rather than sending raw data to nodes responsible for fusion [2]. WSNs are highly distributed and self-aware networks that face resource problems, such as power consumption, processing speed, communication range, and available bandwidth [1]. A general form of a WSN architecture is shown in Figure 1.

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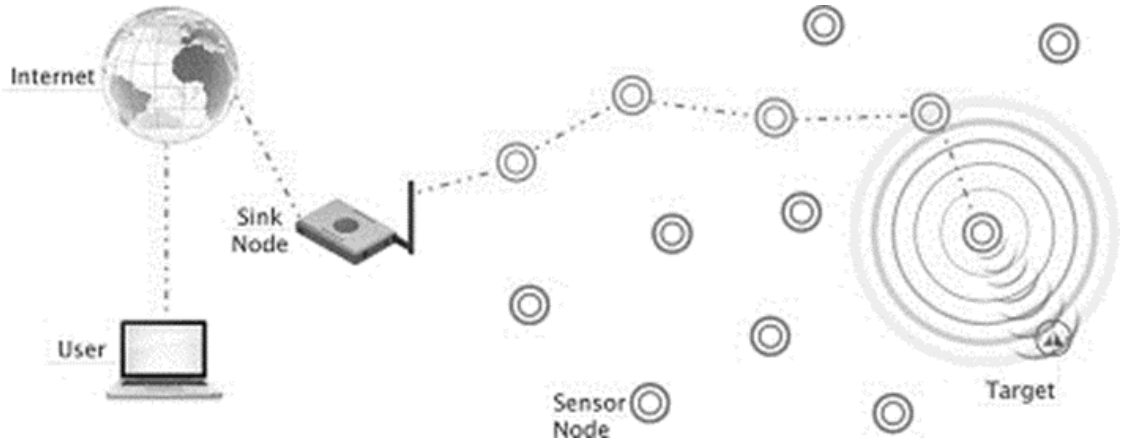

Figure 1: General representation of a wireless sensor network architecture [3].

However, WSNs provide an indispensable sensing and actuation platform in various cyber-physical infrastructure and systems, including smart metering of electric grids, distance and speed monitoring of vehicles in transportation systems, environment and health monitoring, security and surveillance, early warning systems, disaster management. WSNs and auxiliary computation facilities such as clouds can integrate sensing, communication, computation, and control functionalities. These networks facilitate several applications that promote a comfortable and smart-economic life, including energy saving by minimizing rare energy sources, noise and atmospheric monitoring, reducing pollution, and healthcare monitoring promoting health [4]. Wireless sensor networks also make significant strides in enabling distributed sensing functions inside buildings. Concepts such as smart meters and smart appliances rely on wireless sensor networks, highlighting the potential for wireless networks to revolutionize our lives and work. As such, WSNs are an emerging technology expected to impact various aspects of our lives significantly [4, 5].

It is crucial to consider critical parameters such as network lifetime, packet delivery ratio, energy-efficient transmission, and dead node ratio to address the battery constraint issue in WSNs. Energy-efficient routing techniques play a vital role in increasing the network lifetime. The current routing protocols for WSNs are classified into two categories based on their orientation towards either homogeneous or heterogeneous WSNs, further divided into static and mobile protocols. This paper summarizes the characteristics, limitations, and applications of these protocols. Routing in WSNs is a challenging area of research, and packets are forwarded through multiple nodes to the base station. Therefore, sharing the packets in an energy-efficient manner while considering the battery's residual power is crucial to prolong the network lifetime. Energy consumption is a fundamental issue that needs to be addressed to improve energy efficiency. However, it has not been adequately addressed by researchers and practitioners. Despite the efforts to improve energy efficiency in WSNs, some open issues in energy-efficient routing protocol design still need to be addressed [6–8]. Several energy-efficient routing protocols are available, such as low energy adaptive clustering hierarchy (LEACH), Hybrid Energy Efficiency Protocol (HEEP), threshold-sensitive energy-efficient network protocol (TEEN), and power-efficient Gathering in sensor information systems (PEGASIS). Notably, LEACH is considered the father of clustering protocols. It operates in rounds, each consisting of two phases: a setup phase where clusters are formed and a steady-state phase where member nodes send their data to their corresponding cluster heads, which then transfer it to the base station. During setup, nodes exchange messages to form clusters, including cluster head announcements, member node join query messages, and cluster head Time Division Multiple Access (TDMA) schedules. LEACH is a hierarchical routing protocol that is self-adaptive and self-organized, reducing unnecessary energy costs. The steady-state phase is typically much longer than the setup phase. However, the setup phase is more important as it allows sensor nodes to randomly elect themselves as cluster heads and divide themselves into clusters. Each cluster head creates a TDMA schedule for the sensor nodes within the cluster, allowing the radio components of each non-cluster head node to be turned off at all times except during their transmit time [6, 9, 10].

However, LEACH has several limitations, such as uneven distribution of energy among the nodes, premature death of the cluster heads, and a lack of scalability. Therefore, this paper presents a comprehensive analysis of critical parameters for sensor network applications and proposes an improved algorithm that enhances network lifetime, throughput, and the number of alive nodes. The proposed approach is based on the LEACH protocol and addresses its limitations. The research objectives of this paper are to evaluate the performance of the enhanced LEACH protocol, compare it with existing protocols, and demonstrate its effectiveness in improving the critical parameters of WSNs. The contributions of this research are expected to aid in developing more efficient and effective protocols for various sensor network applications. By optimizing energy consumption and reducing the number of dead nodes, the proposed protocol can help extend the network lifetime, increase the packet delivery ratio, and improve energy-efficient transmission.

Furthermore, the proposed algorithm can overcome the limitations of the traditional LEACH protocol by improving the uniformity of energy distribution among nodes, reducing the number of dead nodes, and increasing scalability. In summary, this paper contributes to developing energy-efficient routing protocols for WSNs by proposing an improved version of the LEACH protocol. The proposed protocol addresses the shortcomings of the traditional LEACH protocol, and its effectiveness is demonstrated through simulation experiments. This research provides valuable insights for researchers and practitioners in the field of WSNs and can help in the design of more efficient and effective routing protocols for various WSN applications.

2 Related Works

Wireless Sensor Networks (WSNs) require a decisive feature of an expected lifetime, as the nodes are spread out in the field for months or years without proper post-maintenance [11, 12]. The energy supply is the main limiting factor for the lifetime of a sensor network. Each node must be designed to improve battery utilization for maximum network lifetime. Sensor nodes are densely deployed in a field of interest. The primary advantage of WSNs is their ease of deployment. Coverage and speed are essential characteristics for WSNs, and it is beneficial for the sensor network to cover a larger physical area to increase the network area for sensing.

However, Ad-Hoc communication networks can prolong the network coverage beyond the range of the radio technology alone. Still, Ad-Hoc networking protocols usually increase energy consumption, decreasing the overall network lifetime [4]. A study proposed directed diffusion, a data-centric protocol for wireless sensor networks, which diffuses data based on their communication interest [13]. The protocol establishes paths between the Base Station (BS) and the source node by utilizing interested nodes, and several paths can be established between the sender and receiver. The most efficient path with less power consumption is selected. If the path breaks anywhere between the source and sink, the alternative path is used for transmission. However, the overhead is increased when making alternatives among paths, so the multipath concept may not be applied to larger, complex networks. Hierarchical routing protocols are clustering-based routing techniques that aim to efficiently utilize the energy resources of sensor nodes by usually operating in an Ad-Hoc network fashion. In this type of routing, sensor nodes are organized into clusters, and for each cluster, a responsible node is selected as the cluster head (CH). The CH collects data from its member nodes, and the aggregated data is transmitted to the sink by the CH [14, 15]. The non-CH members are put in sleep mode, preserving energy.

LEACH was the first energy-efficient protocol and inspired other hierarchical routing protocols, including the TEEN one. Clustering Topology uses two threshold values, one sensed from attribute and the other small change in that value, both hard and soft thresholds simultaneously, with the sensed value being the absolute value [16, 17]. HEED is a hybrid protocol that uses residual energy and network topology characteristics (like node degree) to achieve energy balancing in communication networks. The cluster selection of nodes is done by minimizing the network cost, and the CH selection of data is done randomly, but only particular clusters are joined. HEED uses efficient Ad-Hoc networking topology by using adaptive and proactive transmission energy in the cluster-to-cluster transmission. However, the HEED protocol has disadvantages, including creating more cluster heads than expected due to tentative cluster heads that do not become final cluster heads and some uncovered nodes left behind. This protocol also creates more iterations due to the broadcasting and multicasting of packets, resulting in high overhead. Additionally, some nodes may die early because of more energy consumption, mainly the cluster heads near the sink [18–20].

3 Methodology

This research investigates the energy efficiency of wireless sensor networks (WSNs) using a descriptive research methodology. The study assumes that each sensor node is a self-organizing device that is uniformly distributed, stationary, and capable of performing computations and storing information about neighboring nodes. To address the research question of conserving energy in WSNs and the challenge brought by the heterogeneity of nodes, an established routing algorithm based on an existing protocol, the heterogeneous low energy adaptive clustering hierarchy (H-LEACH), is used. The stated algorithm introduces modifications aimed at prolonging the network lifetime and increasing the throughput of the whole network. The key features of the proposed algorithm include adaptive cluster formation, dynamic selection of cluster heads, and energy-efficient data transmission. Simulations were conducted using the NS-3 network simulator to evaluate the performance of the proposed routing algorithm. The simulation environment consisted of 100 sensor nodes deployed randomly in a 100 x 100 m area, each equipped with a 2.4 GHz radio and a battery with an initial energy of 1 J. The simulation ran for 1000 sec, and the parameters used with their respective values are presented in Table 1. The performance of the proposed algorithm was evaluated using four key performance metrics: network lifetime, energy efficiency, packet delivery ratio, and the number of dead nodes. Energy efficiency was measured as the total energy consumption divided by the total data packets transmitted, while the packet delivery ratio was defined as the ratio of the number of data packets received by the base station to the total number of data packets generated.

Table 1: Parameters and the respective values for H-LEACH simulation

Network Parameters for H-LEACH simulation	Values
Field coordinates	$a_{\text{max}} = 100$, $b_{\text{max}} = 100$
Coordinates of the Base Station (BS)	base.x $= 0.5a_{\text{m}}$, base.y $= 0.5b_{\text{m}}$
Number of nodes in the WSN field (m)	100
Probability of a node becoming a cluster head (P)	0.1
Heterogeneity value	$Q = 0.1 \times (10\%)$, $\alpha = 1$
Model for energy in heterogeneous nodes	$E_{\text{o}} = 0.5$ joules, $E_{\text{elect}} = E_{\text{txy}} = E_{\text{rxy}} = 10 \times 1 \times 10^{-9}$ joules, $E_{\text{rxy}} = 10 \times 1 \times 10^{-9}$ joules
Transmission amplifier types	$E_{\text{fx}} = 2 \times 1 \times 10^{-12}$, $E_{\text{mp}} = 0.0013 \times 1 \times 10^{-12}$
Data aggregation energy	$E_{\text{DAG}} = 5 \times 1 \times 10^{-9}$
Maximum number of rounds	$R_{\text{max}} = 2000$

The number of dead nodes was defined as those nodes whose energy was depleted during the simulation. The simulation was designed to measure the network lifetime, which was defined as the time until the last node in the network died. This metric is commonly used to measure the energy efficiency of wireless sensor networks. The evaluation criteria included these performance metrics to compare the performance of the proposed algorithm with that of existing protocols.

4 Results and Discussion

Figures 2(a) and 2(b) represent the simulation results obtained for the performance of the wireless sensor network, considering all alive and dead nodes, respectively. The H-LEACH protocol, based on the existing E3PSC protocol, uses dynamic clustering to prolong the network lifetime and reduce energy consumption. The simulation results show that the H-LEACH protocol outperforms existing routing protocols in terms of network lifetime and energy consumption. One of the key advantages of H-LEACH is its dynamic clustering approach, which optimizes the number of clusters based on the initial specification by the sink node. The simulation results demonstrate that this approach leads to better energy consumption and network lifetime performance compared to the static clustering approach used by E3PSC.

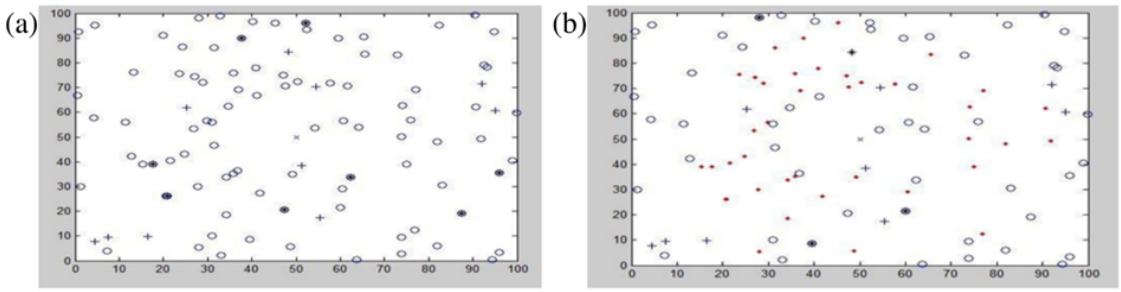

Figure 2: Wireless Sensor Network: **(a)** with alive nodes; **(b)** with dead nodes.

However, the H-LEACH protocol has its limitations. The simulations were conducted for a network with only 100 nodes, and the results may not be generalizable to larger or smaller networks. Additionally, the simulation parameters and assumptions may not accurately reflect real-world scenarios, and further research is needed to validate the protocol's performance in real-world settings. Furthermore, although the protocol was compared with existing routing protocols, it was not compared with all possible protocols, and further research is necessary to compare its performance with other protocols. Moreover, while H-LEACH prolongs the network lifetime, there is room for improvement in terms of energy conservation. Incorporating energy harvesting techniques into the protocol could further prolong the network lifetime while optimizing the network's throughput. Therefore, further research is needed to validate the protocol's performance in real-world scenarios and optimize its energy conservation techniques.

5 Conclusion

The proposed H-LEACH protocol for wireless sensor networks is based on dynamic clustering and the selection of cluster heads using the highest energy of nodes and minimum distance from the average node distribution in each cluster. The simulation results demonstrate that the H-LEACH protocol outperforms existing routing protocols regarding network lifetime and energy consumption reduction. Moreover, the study suggests incorporating energy harvesting techniques could further prolong the network lifetime and optimize network throughput. The H-LEACH protocol was simulated using network parameters such as field coordinates, number of nodes, probability of cluster head election, heterogeneous energy model, transmission amplifier types, and data aggregation energy. The simulation results were based on network lifetime, defined as the time until the last node failed. The H-LEACH protocol shows potential for improving wireless sensor networks' performance and energy efficiency, particularly in applications where network lifetime and energy conservation are critical. Further research can explore integrating energy harvesting techniques and other advanced technologies to optimize the performance of wireless sensor networks.

Declaration of Competing Interests

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Author Contribution

Chandra Prakash Verma: Conceptualization, Visualization, Investigation, Methodology, Data curation, Software, Writing- Original draft preparation, Writing- Reviewing. The author has read and approved the submitted version.

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Simulation of P-CdTe and N-TiO_2 Heterojunction Solar Cell Efficiency

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Abstract

The present study presents a numerical analysis of p-type CdTe and n-type TiO−2 heterojunction solar cells. The simulations were conducted using SCAPS-1D software to investigate the effects of varying the thickness of the p-type CdTe layer, the temperature, and the band gap on the efficiency of the solar cell. The results show that the efficiency of the solar cell increases from 16.81% to 18.28% as the thickness of the p-type CdTe layer is varied from 1.0 to 5.0 μm and decreases from 17.95% to 11.67% as the temperature is varied from 300 to 400 K. The efficiency also increases from 15.29% to 19.26% as the band gap is varied from 1.40 to 1.55 eV. For the p-CdTe/n-TiO_2 heterojunction solar cell, the optimized absorber layer thickness is 3 μm, and the optimized temperature and band gap are 300 K and 1.5 eV, respectively. At these optimized parameters, the highest efficiency (PCE) achieved was 17.95%, with a V_{OC} of 0.766 V, J_{SC} of 27.75 mA/cm^2, and FF of 84.39%. These results provide theoretical guidelines for fabricating efficient p-CdTe/n-TiO_2 heterojunction solar cells.

Keywords: Heterojunction; Numerical Simulation; Photovoltaic Solar Cell; SCAPS Software

1 Introduction

Energy and the environment are two critical and interrelated topics, and using non-renewable energy sources such as oil, coal, and gas contributes to environmental degradation [1]. The need for sustainable energy has led to the development of various experimental procedures for synthesizing and depositing metal oxides to improve solar cell efficiency [2]. However, numerical simulation provides a cost-effective approach to improving solar cell efficiency without requiring extensive lab work and expenses [3]. Metal oxides have unique mechanical and electrical properties, making them easy to synthesize and design, and they are eco-friendly and have a wide band gap [4]. In this study, we investigate the effect of varying the thickness of p-type CdTe, temperature, and band gap on the efficiency of n-type TiO_2 and p-CdTe heterojunction solar cells using Solar Cell Capacitance Simulator (SCAPS-1D) software. The thickness of the absorber layer is a crucial factor in solar cells as it directly affects cell performance [5]. TiO_2 has a direct band gap of 3.2 eV to 3.35 eV, making it n-type and suitable for heterojunctions with most p-type materials [6]. CdTe, on the other hand, is a chalcogenide material with a direct band gap of 1.5 eV and a high absorption coefficient, making it a popular choice for use in solar cells due to its high efficiency, low cost, and long-term stability [7].

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The current study builds on previous work on p-CdTe and n-TiO_2 heterojunctions by investigating the photoelectrical properties of the device and the charge transport mechanism at the interface of the n-TiO_2/p-CdTe heterojunction [8]. The study also considers the effect of thickness variation on device performance. Reduced series resistance and improved shunt resistance led to a high fill factor and enhanced device performance [9]. The thickness of the absorber layer also affects the light-trapping phenomenon at the interface of the semiconductor junction, which directly impacts solar cell efficiency [10], [11]. In addition, surface roughness can affect solar cell efficiency, and therefore, the study also investigates the effect of temperature variation on device performance [12]. In this study, we use SCAPS-1D software to simulate a metal oxide/metal chalcogenide heterojunction device and investigate the effects of thickness, temperature, and band gap on device performance. We record the performance results and aim to enhance the efficiency of the solar cell. Simulations are run using the SCAPS-1D software at AM1.5G [1 sun] lamp illumination. The efficiency of heterojunction solar cell is significantly affected by thickness and band gap of photoactive material, and temperature of the cell. Thus, the effects of variation in the thickness and band gap of CdTe, and temperature of a cell on the device performance were investigated.

2 Methodology

2.1 SCAPS-1D software

The SCAPS-1D software, which was designed by the Department of Electronics and Information Systems (ELIS) at the University of Gent, Belgium [13], was used to simulate the DC and AC electrical characteristics of the thin film heterojunction. This software can numerically fabricate solar cells by adding up to seven layers and is based on semiconducting equations such as Poisson's and continuity equations [14].

2.2 Simulation setup

The simulation was performed using SCAPS-1D software version 3310. The default Left and Right contacts were used, and optoelectrical parameters of every heterojunction layer were input parameters for the simulation. The software provides results and graphs for open circuit voltage (V_{OC}), short circuit current density (J_{SC}), fill factor (FF), and quantum efficiency (QE%) [14].

2.3 Simulation parameters

The material parameters for the heterojunction's window and absorber layers were collected precisely from authentic literature [14]. These input material parameters, including Band gap (Eg) eV, Electron affinity (χ) eV, Relative dielectric permittivity (ϵ_r), Electron mobility (μ_e) cm^2/V.s, Hole mobility (μ_h) cm^2/V.s, Effective density state in C.B. (N_C) cm^{-3}, Effective density state in V.B. (N_V) cm^{-3}, Acceptor density (N_A) cm^{-3}, Donor density (N_D) cm^{-3}, were used for calculations. Table 1 shows the specific material parameters used in this study.

Table 1: Parameters for simulation modeling of (n-TiO_2/p-CdTe)-based thin film solar cells.

Material parameter	**n-TiO_2**	**p-CdTe**
Thickness (μm)	0.5	1.0
Band gap (eV)	3.1	1.5
Electron affinity (χ)	4.2	3.9
Relative dielectric permittivity	10	9.4
CB effective density of states (1/cm^3)	2.00E+17	8.00E+17
VB effective density of states (1/cm^3)	6.00E+17	1.80E+19

2.3.1 Parametric optimization and evaluation

The theoretical analysis of the n-TiO_2/p-CdTe heterojunction was performed using SCAPS-1D software under AM1.5 G, 100 mW/cm^2 illumination ranges. The "set absorption model" and "absorption file" modes were chosen for each heterojunction layer to perform the simulation. The heterojunction's default back and front contacts were set, and the standard solar spectrum of AM1.5 G was used for illumination [14]. The heterojunction solar cell was optimized by varying the thickness of the p-CdTe absorber layer and the temperature of the heterojunction. The simulation results for J_{SC}, V_{OC}, η, and FF of the designed heterojunction were obtained.

Figure 1 (a) shows the schematic presentation of the n-TiO_2/p-CdTe heterojunction, while Figure 1 (b) shows the energy band diagram of n-TiO_2/p-CdTe solar cells. The energy band diagram was used to study the properties of the heterojunction solar cells. Table 2 shows the back and front contact parameters and the working temperature.The band alignment between the absorber layer (p-CdTe) and the window layer (n-TiO_2) is crucial as it affects current transmission across the heterojunction interface and the performance of thin films. The energy band alignment shows that the p-CdTe absorber layer (Eg = 1.5 eV) and n-TiO_2 window layer

(Eg = 3.1 eV) have an excellent band diagram with each other, which can lead to high conversion efficiency for absorbed photons with energy nearly equal to or greater than a band gap of 1.5 eV.

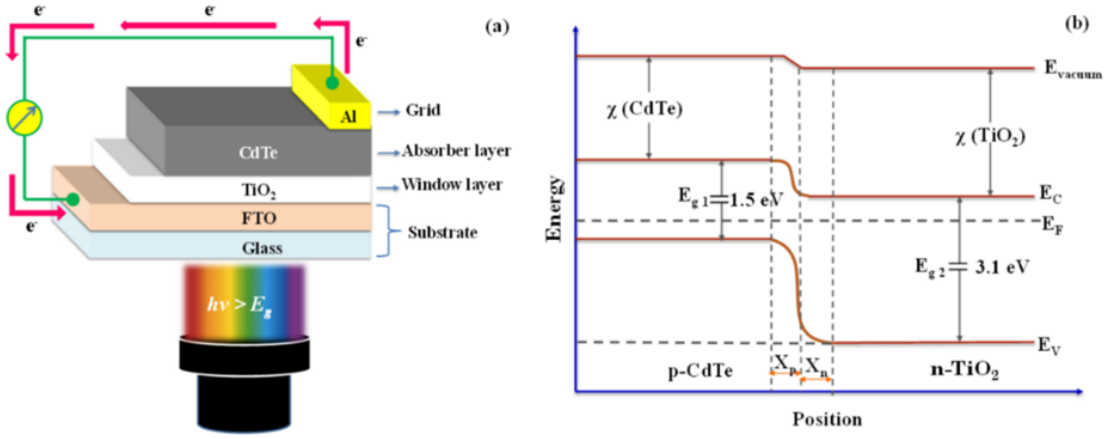

Figure 1: **(a)** Schematic diagram of the n-TiO_2/p-CdTe heterojunction solar cell and **(b)** schematic band energy diagram of the n-TiO_2/p-CdTe heterojunction.

Table 2: Parameters of the front and back contact used in the simulation of the (n-TiO_2/p-CdTe) solar cell.

Parameter	**Back contact electrical properties**	**Front contact electrical properties**
Surface recombination velocity of electrons (cm/s)	10^5	10^2
Surface recombination velocity of holes (cm/s)	10^7	10^5
Work function (eV)	4.98	4.09
Working temperature (K)	300K	

3 Results and Discussion

3.1 Effect of variation in the thickness of the absorber layer (p-CdTe) on cell performance

In a p-CdTe/n-TiO_2 heterojunction, the window layer typically has a lower thickness than the absorber layer to support fast exciton transport with a low recombination rate, resulting in a high current generation and maximum absorption at high voltages. In this study, the thickness variation effect of the p-CdTe layer on the heterojunction performance was investigated by varying the thickness of the p-CdTe layer from 1 to 5 μm with an interval of 1 μm while keeping the thickness of the n-TiO_2 layer fixed at 0.5 μm. The input parameters of the heterojunction are reported in Table 1. The impact of the p-CdTe thickness variation on the J-V curve, quantum efficiency, V_{OC}, J_{SC}, FF, and PCE were studied. As shown in Table 3, V_{OC} slightly increased from 0.751 to 0.773 V, and J_{SC} increased from 26.35 to 28.13 mA/cm^2 with the increase in p-CdTe thickness. The PCE also increased from 16.81 to 18.28 %, while FF decreased from 84.91 to 84.28 %. The optimal thickness for the p-CdTe absorber layer was found to be 3 μm, where the efficiency increased by 0.57 %. After 3 μm the increase in efficiency is just by value of 0.2 %, indicating that a thickness greater than 3 μm was unnecessary for device fabrication. The increase in thickness of the p-CdTe layer led to the absorption of more photons, resulting in an increase in current [4], [15].

Table 3: Effect of the thickness of the absorber layer (CdTe) on the cell efficiency parameters.

Thickness (μm)	**J_{SC} (mA/cm^2)**	**V_{OC} (V)**	**JMMP (mA/cm^2)**	**VMM (V)**	**FF%**	**η%**
1.0	26.35	0.751	25.39	0.662	84.91	16.81
2.0	27.39	0.760	26.33	0.668	84.51	17.60
3.0	27.75	0.766	26.72	0.671	84.39	17.95
4.0	27.97	0.770	26.94	0.673	84.18	18.15
5.0	28.13	0.773	27.10	0.674	84.28	18.28

Furthermore, the higher thickness of p-CdTe resulted in a lower recombination rate of excitons, allowing them more time to move before recombination. This, in turn, resulted in combined excitons that did not drop their energy as proximately upon hitting the absorber layer, leading to the observed increase in PCE. However, at higher thicknesses, excitons in the p-CdTe layer can undergo Auger recombination, transferring their energy to existing electrons and holes and reducing efficiency [16], [17], [18].

The band energy diagram of the optimized heterojunction n-TiO_2/p-CdTe indicates that hole recombination is more probable in the valence band of CdTe, while electron recombination is more probable in the conduction band of TiO_2. Increasing the thickness of the p-CdTe layer leads to an enhancement in quantum efficiency up to 3 μm, beyond which the quantum efficiency saturates. The numerical simulation results suggest that 3.0 μm is the optimal thickness for the p-CdTe layer. Figure 2 (a-f) illustrates the J-V, QE%, V_{OC}, J_{SC}, FF, and PCE curves for variations in the thickness of the given heterojunction solar cell.

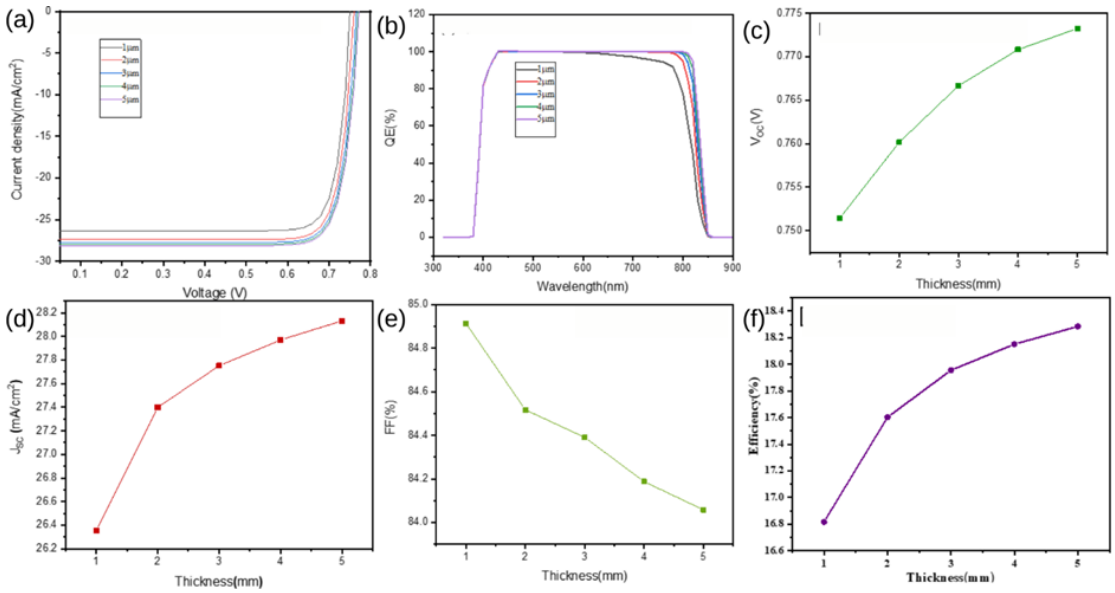

Figure 2: (a) Current-voltage (J-V) curves; (b) quantum efficiency (QE) as a function of wavelength; (c) open-circuit voltage (V_{OC}); (d) short-circuit current (J_{SC}); (e) fill factor (FF); (f) efficiency curves of the TiO_2/CdTe heterojunction at various thicknesses

3.2 Effect of variation of temperature on cell performance

The study of the temperature-dependence behavior of solar cells is crucial since the temperature has a contrary effect on the performance of heterojunctions. Different types of solar cells exhibit varying responses to temperature, with thin film solar cells being less sensitive to temperature than crystalline silicon solar cells. Additionally, the aging of the active layer affects the temperature coefficient of polymer solar cells, and the substrate temperature, reaction processing temperature, and annealing temperature can affect solar cell performance. As solar cells are exposed to various temperature ranges in different applications, monitoring the solar cell performance by varying the temperature range is important. In this work, we varied the temperature between 300 and 400 K and monitored the solar cell performance under optimized conditions. The results obtained under the optimized conditions are shown in Table 4, and the J-V curve for the effect of temperature variation on J-V, QE %, V_{OC}, J_{SC}, FF, and PCE was studied and reported in Figure 3 (a-f). An increase in temperature is beneficial for solar cell outcomes as it causes an increase in charge carriers; however, it limits to a certain extent because increased temperature affects the transport of charge carriers [19], [20]. As the temperature increases, the V_{OC} of the solar cell decreases, resulting in a decrease in cell efficiency.

Table 4: Effect of the thickness of the absorber layer (CdTe) on the cell efficiency parameters.

Temperature (K)	**J_{SC} (mA/cm^2)**	**V_{OC} (V)**	**JMMP (mA/cm^2)**	**VMM (V)**	**FF%**	**η%**
300	27.75	0.766	26.72	0.671	84.39	17.95
320	28.10	0.740	26.94	0.643	83.21	17.33
340	28.10	0.713	26.85	0.614	82.29	16.51
360	28.10	0.686	26.66	0.587	81.15	15.65
380	28.14	0.571	26.34	0.474	77.61	12.49
400	28.15	0.544	26.08	0.447	76.67	11.67

At the same time, an increase in temperature causes a slight increase in J_{SC}, which reduces the band gap energy with an increase in operating temperature. Thus, overall efficiency depends on the cooperation between a reduction in V_{OC} and an increase in J_{SC}. The results show that by varying the temperature from 300 to 400 K with an increment of 20 K for each interval, there was a significant decrease in V_{OC} from 0.766 to 0.544 V, FF from 84.39 to 76.07 %, and PCE from 17.95 to 11.67 %, but the J_{SC} value showed a slight increase from 27.75 to 28.15 mA/cm^2. The highest efficiency of 17.95 % was obtained at 300 K, and the efficiency decreased as the temperature increased. Therefore, 300 K is the optimized temperature for the n-TiO_2/p-CdTe heterojunction. When the operating temperature of heterojunction solar cells increases, the carrier concentration also increases, causing an increase in the rate of internal exciton recombination [21], [22]. This leads to an increase in the reverse saturation current, ultimately resulting in a decrease in V_{OC} (0.766 to 0.544) V.

At the same time, increased temperature causes a decrease in the band gap, which is responsible for a small increase in J_{SC} (27.75 to 28.15) mA/cm^2. However, as the temperature increases, thermally active photons cause the scattering of charge carriers, affecting material conduction and decreasing heterojunction efficiency [23].

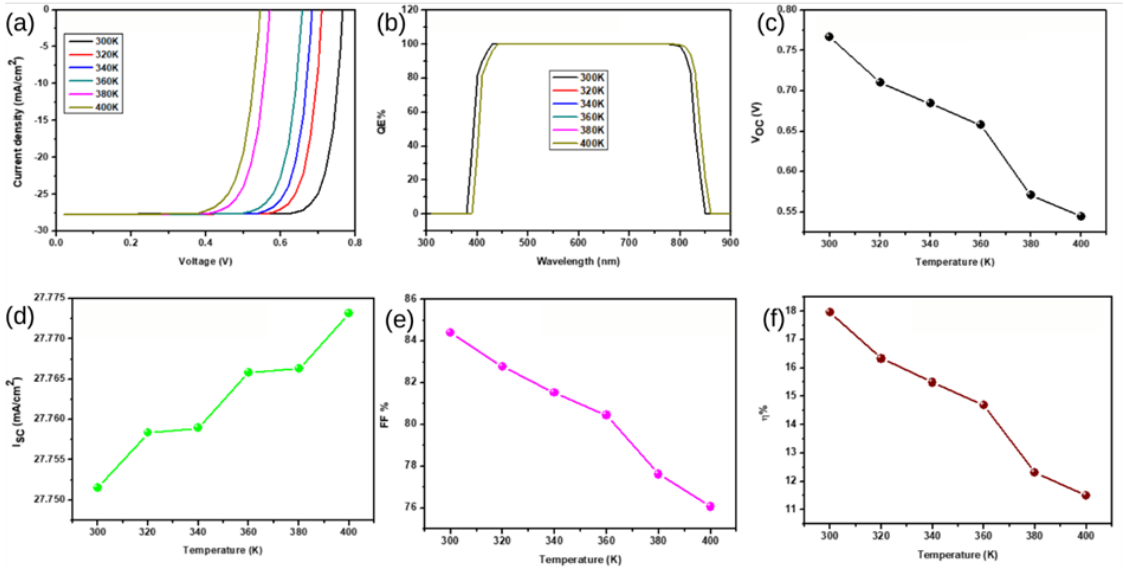

Figure 3: **(a)** Current-voltage (J-V) curves; **(b)** quantum efficiency (QE) as a function of wavelength; (c) open-circuit voltage (V_{OC}); **(d)** short-circuit current (J_{SC}); **(e)** fill factor (FF); **(f)** efficiency curves of the TiO_2/CdTe heterojunction at various temperatures.

3.3 Effect of band gap variation of absorber layer (p-CdTe) solar cell performance

The band gap is a crucial factor that affects the conversion performance of solar cells. Photons with energy nearly equal to the band gap energy participate in the photovoltaic effect [24], [25]. While each material has a fixed band gap, it can change when the semiconductor device is disturbed by external energy such as photons, electrical and magnetic fields, temperature, and pressure. The band gap is temperature-dependent; as the band gap of the material increases, its temperature dependency decreases. The band gap reflects the bond energy of the atom, and as the temperature increases, atomic vibrations increase, causing electrons to travel from the VB to the CB. Consequently, the band gap of the material decreases with increasing temperature [26]. When light falls on the window layer of the heterojunction, only those photons having energy nearly equal to the band gap energy show a transition from the VB to CB [27]. This determines the limit of the maximum wavelength of the solar spectrum, and absorption of this wavelength results in power production.

Table 5: Effect of the thickness of the absorber layer (CdTe) on the cell efficiency parameters.

Band gap (eV)	**J_{SC} (mA/cm^2)**	**V_{OC} (V)**	**JMMP (mA/cm^2)**	**VMM (V)**	**FF%**	**η%**
1.40	27.758	0.666	25.59	0.575	82.64	15.29
1.45	27.757	0.716	26.64	0.623	83.43	16.60
1.50	27.751	0.766	26.72	0.671	84.39	17.95
1.55	27.750	0.829	26.80	0.718	84.70	19.26

The photovoltaic effect will not occur when the band gap is too high. For low band gap materials, excess photonic energy is wasted after partial utilization to excite electrons to overcome the bandgap [28]. In this study, the band gap of p-CdTe was varied between 1.40 and 1.55 eV while keeping the window layer band gap constant. The simulation results are shown in Figure 4 (a-f), and the corresponding values of V_{OC}, J_{SC}, FF, and efficiency are listed in Table 5. The band gap of a material has a direct impact on the ejection and absorption of photons, and it varies with the material. The band gap of the material is also correlated with the thickness of the p-CdTe layer, which decreases with increasing thickness. The band gap of the p-CdTe material plays a vital role in enhancing the photovoltaic properties, absorption ability, and lifetime of carriers [29], [30], [31]. The impact of band gap alteration on the PCE of modulated heterojunctions was investigated in this work. The results showed that increasing the band gap of the absorber layer between 1.40 and 1.55 eV led to an increase in PCE from 15.29 to 19.26 % with a slight decrease in current density. The highest efficiency of 17.95 % was achieved at a band gap of 1.5 eV. After conversion failure occurred at a band gap of 1.55 eV, the optimized band gap for the n-TiO_2/p-CdTe solar cell was determined to be 1.5 eV.

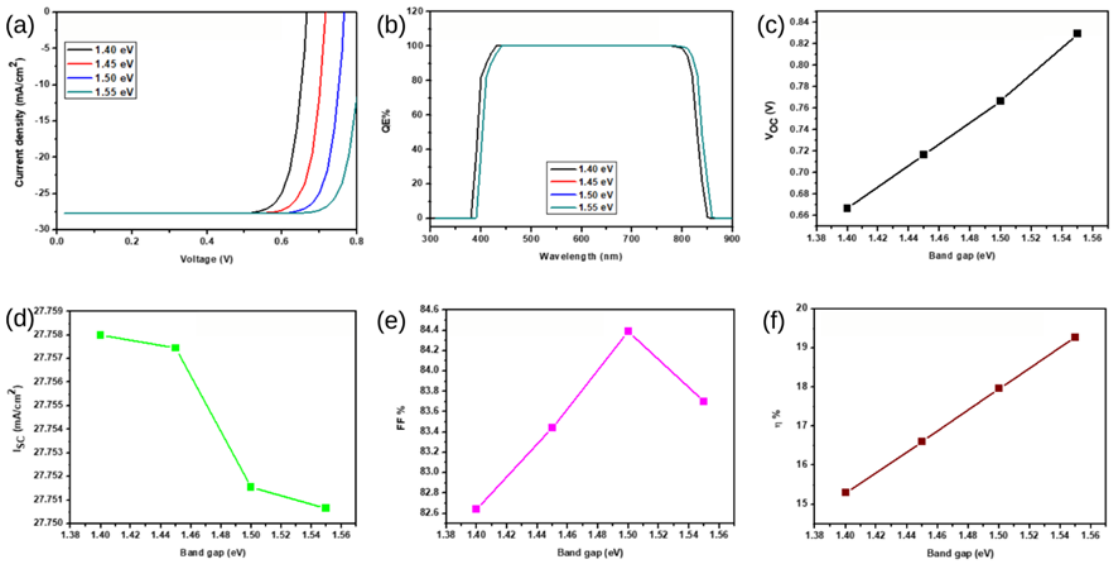

Figure 4: **(a)** Current-voltage (J-V) curves; (b) quantum efficiency (QE) as a function of wavelength; **(c)** open-circuit voltage (V_{OC}); **(d)** short-circuit current (J_{SC}); **(e)** fill factor (FF); **(f)** efficiency curves of the TiO_2/CdTe heterojunction concerning band gap variations.

3.4 Simulation at optimized parameters

To optimize the performance of the p-CdTe/n-TiO_2 heterojunction solar cell, a series of simulations were conducted to determine the optimal values of temperature, thickness, and band gap. Temperature significantly affects the performance of a solar cell by influencing carrier mobility, diffusion length, and carrier recombination rates. After conducting simulations at different temperatures, it was found that the optimal temperature for this solar cell was 300 K, which is approximately room temperature. The thickness of the absorber layer, p-CdTe, also affects the performance of the solar cell. If the layer is too thin, it may not absorb sufficient photons, while a layer that is too thick may result in more carrier recombination. After conducting several simulations, an optimal thickness of 3 µm was determined for this solar cell. The band gap of the absorber layer was varied between 1.40 eV and 1.55 eV, while the band gap of the window layer was kept constant. The simulations revealed that the optimal band gap for this solar cell was 1.5 eV. A band gap that is too high can result in insufficient photon absorption, while a band gap that is too low can lead to excessive recombination and a reduced open-circuit voltage. After determining the optimal values for temperature, thickness, and band gap, a simulation was carried out under these conditions to evaluate the performance of the solar cell. The simulation yielded a power conversion efficiency (PCE) of 17.95 %, which is the highest achieved for this solar cell. This was accompanied by a V_{OC} of 0.766 V, a J_{SC} of 27.75 mA/cm^2, and a fill factor (FF) of 84.39 %.

Table 6: Simulation results of the p-CdTe/n-TiO_2 heterojunction solar cell under optimized conditions.

Optimized parameters	J_{SC} (mA/cm^2)	V_{OC} (V)	JMMP (mA/cm^2)	VMM (V)	FF%	η%
Temperature 300K Thickness 3 µm Band gap 1.5eV	27.75	0.766	26.72	0.671	84.39	17.95

These values indicate efficient conversion of incoming photons to electrical energy and transport of carriers through the device. The results of this simulation are illustrated in Figure 5 (a) and Figure 5 (b), and the corresponding values are presented in Table 6.

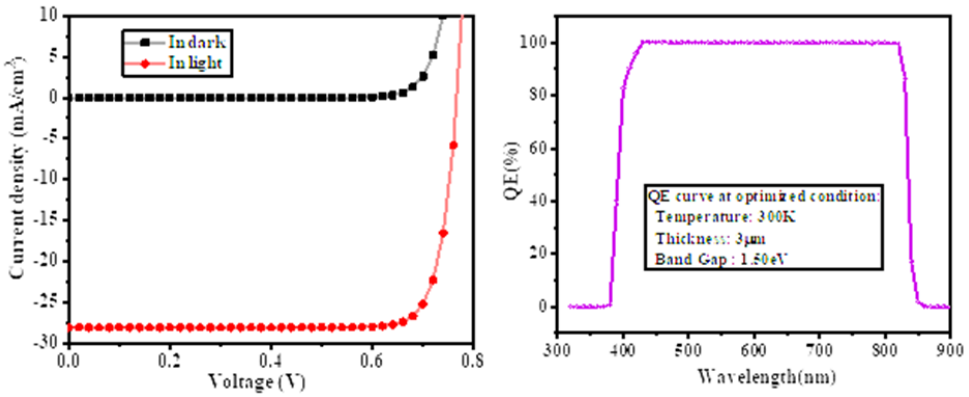

Figure 5: **(a)** Current-voltage (J-V) in the dark and in light and **(b)** quantum efficiency (QE) of the optimized solar cell simulation.

4 Conclusion

The present study utilized a simulation approach to examine the electrical and physical properties of a p-CdTe/n-TiO_2 heterojunction using SCAPS-1D software. The proposed p-CdTe/n-TiO_2 heterojunction solar cell was studied by varying the band gap, thickness, and temperature while keeping all electrical parameters constant. The simulation results showed that the optimized values of temperature, thickness, and band gap are 300 K, 3.0 µm, and 1.50 eV, respectively. Under these conditions, the highest power conversion efficiency (PCE) of 17.95 % was achieved with a V_{OC} of 0.766 V, J_{SC} of 27.75 mA/cm^2, and FF of 84.39 %. The obtained results indicate that the proposed p-CdTe/n-TiO_2 heterojunction solar cell exhibits the best performance under the optimized conditions. This theoretical modeling approach provides important guidelines for the fabrication of cost-effective thin-film solar cells. The findings of this study contribute to the development of efficient and sustainable photovoltaic devices with potential applications in the field of renewable energy.

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Declaration of Competing Interests

The author declares that she has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Author Contribution

Akanksha S. Chougale: Conceptualization, Methodology, Writing - Original draft preparation, Writing - Reviewing; **Harshad D. Shelke**: Conceptualization, Visualization, Investigation, Methodology, Data curation; Bikram Prasad: Conceptualization, Visualization, Investigation, Methodology, Data curation; **Sandesh R. Jadkar**: Investigation, Methodology, Data curation; **Nithesh Naik**: Investigation, Methodology, Data curation; **Habib M. Pathan**: Supervision, Methodology, Writing - Reviewing; Dnyaneshwar R. Shinde: Supervision, Methodology, Writing - Reviewing.

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Reviewing Software Testing Models and Optimization Techniques: An Analysis of Efficiency and Advancement Needs

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Abstract

Software testing is a crucial component of software engineering that aims to confirm the intended functionality of software modules and minimize the likelihood of future failures. This paper provides a comprehensive review of various software testing models and optimization techniques available in the literature, emphasizing their performance analysis and related research papers. The paper analyzes and discusses the most commonly used software testing models, including waterfall, incremental, V-model, agile, and spiral models, and identifies several areas for improvement to increase their effectiveness. These areas include using machine learning techniques to automate and optimize testing processes, reducing the number of test cases required, and introducing new metrics to gauge the success of testing. Moreover, the paper suggests developing entirely novel methods to deal with the challenges of contemporary software programs, such as the Internet of Things and artificial intelligence. This paper aims to analyze various software testing models and optimization techniques thoroughly, highlight their advantages and disadvantages, and suggest improvements to increase their efficiency and effectiveness. By continuously improving and optimizing software testing processes, software modules can function as intended, minimizing the likelihood of future failures.

Keywords: Software Testing; Optimization Techniques; Test Cases; Performance Analysis

1 Introduction

Testing is a validation and verification process determining whether a specific system meets its originally specified requirements. It aims to identify bugs, errors, or missing requirements in a developed system or software. The process provides stakeholders with precise information about the product's quality [1–4]. Software testing is essential for various reasons, such as saving money by identifying and fixing bugs early in the development process, ensuring the security of users' personal information, improving the quality of the product, enhancing customer satisfaction, and facilitating the development process [5]. Software testing must be thoroughly executed throughout the software development lifecycle to ensure that software modules meet the desired quality standards. Software testing can be divided into two types: static and dynamic. Static testing involves examining the code passively, including code reviews, syntax checks, and walkthroughs. On the other hand, dynamic testing examines the code as it runs, allowing security checks to be performed while the code or application executes. Both approaches are suitable and complement each other [6–8]. Despite decades of research and advancements in software testing, it remains a challenging aspect of continuous software development. The complexity of software systems and their environments contributes to this challenge, as software systems run on various platforms and environments. Although there have been efforts to automate the testing process, achieving 100% automation is still not feasible [2]. Additionally, long-standing issues remain when qualifying and evaluating testing criteria and reducing retesting after software changes.

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Researchers' interest in this topic has grown with numerous specialized events and workshops and an increasing percentage of testing papers in software engineering conferences and journal periodicals [9]. This review paper aims to provide a comprehensive analysis of commonly used software testing models and optimization techniques. The paper examines the effectiveness of selected testing models and optimization techniques and discusses their strengths and limitations. Additionally, the paper identifies areas where improvements and advancements are needed to increase the efficiency and effectiveness of software testing. The review paper is structured in the following way: the first section provides an overview of software testing and its importance in software engineering, the second section reviews various software testing models and evaluates their effectiveness in identifying flaws and reducing testing time and effort, the third section discusses optimization techniques such as test case reduction, fault localization, mutation testing, and combinatorial testing, the fourth section analyzes the efficiency and need for advancement of these models and techniques, and finally, the paper concludes by summarizing the findings and suggesting future research areas.

2 Software Testing Models

Software testing models serve as the foundation for systematically testing software applications. Testing is an essential aspect of the software development life cycle. Various models or approaches can be utilized throughout the development process, each with advantages and disadvantages [10]. This section discusses commonly used software testing models, providing an overview of their strengths and limitations.

2.1 Waterfall model

The waterfall model is an early and straightforward software development process involving a linear phase sequence. The model is named after the flow of one phase into the next, resembling a cascade. In the waterfall approach, user research is conducted at the beginning and end of the project to inform the requirements and evaluate a working prototype or finished product. The methodology requires completing phases in a specific order, each with formal exit criteria. The approach involves a detailed list of tasks, supporting documentation with exit criteria, and larger companies often mandate the use of SDLC methodology products [11–13]. Advantages of the waterfall methodology include early completion of requirements, better resource utilization, superior application design, and easier measurement of project status. However, there are also drawbacks to the approach, including difficulties in obtaining comprehensive business requirements upfront, the need for a highly detailed breakdown of tasks and deliverables, and projects that frequently span months or quarters, resulting in being behind schedule, exceeding budget, and not meeting expectations [14]. Despite its limitations, researchers and practitioners still widely use the waterfall model to solve problems that require a structured and sequential approach to software development. For instance, Swara et al. [15] presented a study on developing an Android-based information system for business travel to improve marketing, ordering, payment, and departure processes. The authors utilized the waterfall model as a development methodology and conducted observations to evaluate the system's success. The study concluded that the system achieved 100% functionality after black box testing, and users were highly satisfied with the system, as indicated by the average satisfaction score of 4.44 on a Likert scale.

This article provides insights into the practical application of the waterfall model in developing an information system and demonstrates its effectiveness in achieving project goals. Researchers have applied the waterfall model in various contexts, such as developing a coffee shop website in Malang by Ardhiansyah et al. [16], developing a Job Training Management Information System at Trunojoyo University Madura by Herawati et al. [17], developing an application for processing report evaluation of Islamic junior high schools based on boarding Pesantren by Rahayu et al. [18], developing a prototype application for finding and ordering boarding houses in Telang by Negara et al. [19], building a web-based conference registration system by Badri et al. [20], and creating a monitoring system for pregnant women and newborns by Purba and Sondang [21].Figure 1 depicts the waterfall model approach in its general form.

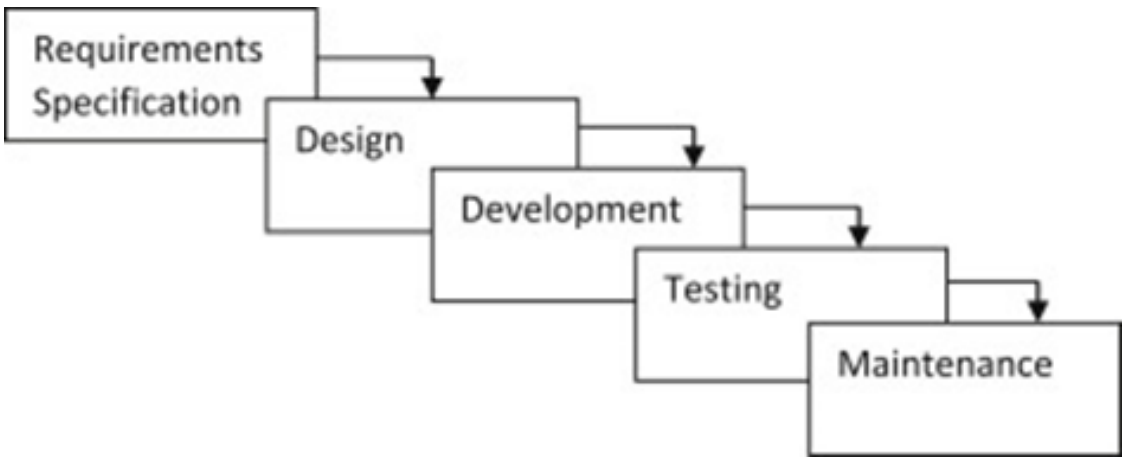

Figure 1: Waterfall model approach of software testing [22].

2.2 Incremental model

The incremental model is a software development methodology that involves multiple iterations of smaller cycles, including requirements, design, development, and testing. Each iteration produces a prototype of the software that builds on the previous prototype, making testing and managing easier with early error detection. This approach allows the user to plan the system's use and determine its requirements, and it also supports changing user requirements. However, frequent user feedback can lead to scope creep, and a never-ending development loop may occur. Since the requirements for the entire system are not gathered at the start of the project, the system architecture may be affected in later iterations. Additionally, a build-and-patch approach can lead to poor code design. Despite these drawbacks, the incremental model remains an effective approach, particularly for novel systems with unclear constraints or requirements [22–26]. Figure 2 represents the incremental model approach.

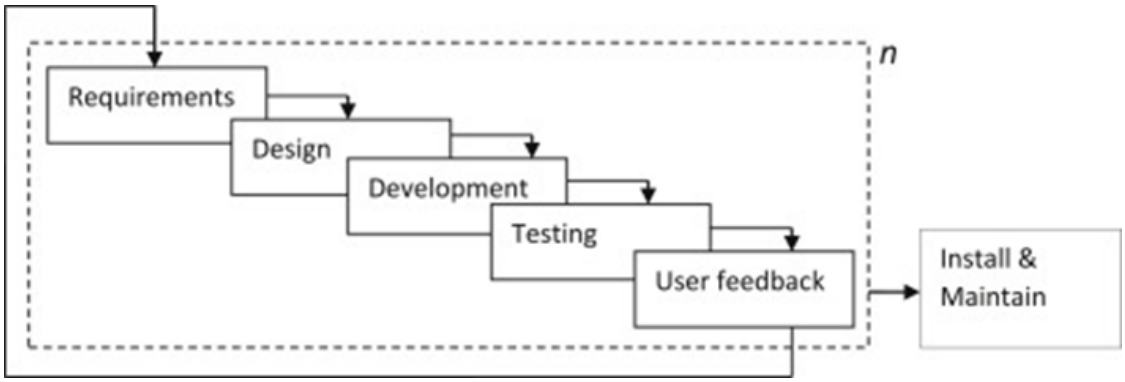

Figure 2: Incremental model approach [22].

Several recent studies have demonstrated the importance and effectiveness of incremental models in software development and testing, and the proposed strategies and models provide useful insights into the application of incremental models in various domains. For example, Shahzad et al. [27] proposed a strategy for identifying and mitigating software risks in the incremental software development model. The authors identified risk factors that may exist in other software development processes but are particularly relevant to the incremental model. Qiu and Riesbeck [28] described an incremental model for developing educational critiquing systems that integrated manual critiquing with critique authoring to facilitate the development of educational critiquing systems with the less upfront development effort.

Andreansyah et al. [29] described the implementation of incremental models in the development of web-based loan cooperative applications. The authors developed a web-based application to overcome the problems of a particular cooperative and tested it with 31 respondents from the company. The application received high ratings in terms of usability and usefulness. Lity et al. [30] proposed an automated change impact analysis based on incremental model slicing for incremental software product line (SPL) testing. The authors applied incremental slicing to determine the impact of applied model changes and to explain their potential retest. The effectiveness and applicability of the proposed approach were evaluated using four SPLs. Lochau et al. [31] also proposed an automated change impact analysis based on incremental model slicing for incremental SPL testing. The authors applied incremental slicing to determine the impact of applied model changes and to explain their potential retest. The proposed approach was evaluated using four SPLs, and the authors demonstrated its applicability and effectiveness.

2.3 V-model

The V-Model is an approach to system development projects that the State of Germany commissioned. It considers the entire lifecycle of a system and is nicely fitting for the line of thinking in systems engineering [32]. The V-model is regarded as an extension of the waterfall model, and in this methodology, software development processes occur in a sequential approach with a V shape that involves a sequence of processes. It is also referred to as the verification and validation model. The V-model is considered a high-level design of Test Driven Development (TDD), where each software development phase is directly associated with a corresponding testing phase. Each corresponding testing phase is planned in parallel with the development phase. Test cases are developed in the development phase to be implemented in the corresponding testing phase, but typically, testing is conducted once the software is completed [33]. The V-model is best suited for projects with clear and well-defined requirements. The model is unsuited for projects with frequently changing requirements because it does not allow much iteration or adaptation [34]. Figure 3 represents the simple V-model. The V-model integrates testing into every stage of the development process, making it highly effective for projects with a clear set of requirements. Defects can be detected and resolved early on in the process, reducing the overall cost and time required for testing. Furthermore, the high level of traceability between requirements, design, and testing ensures that every aspect of the product is thoroughly tested and meets the specified requirements. The V-model also encourages better collaboration between development and testing teams, as each stage has a corresponding testing stage executed in parallel. This ensures regular communication and coordination between team members, essential for producing high-quality software. Despite its many advantages, the V-model does have some limitations. One of the main drawbacks of this model is its limited scope for iteration and adaptation. Once a stage is completed, it can be challenging to make changes or adjustments without disrupting the entire process. Additionally, the cost and time required for testing can be higher than other models, as testing is integrated into each stage of the development process.

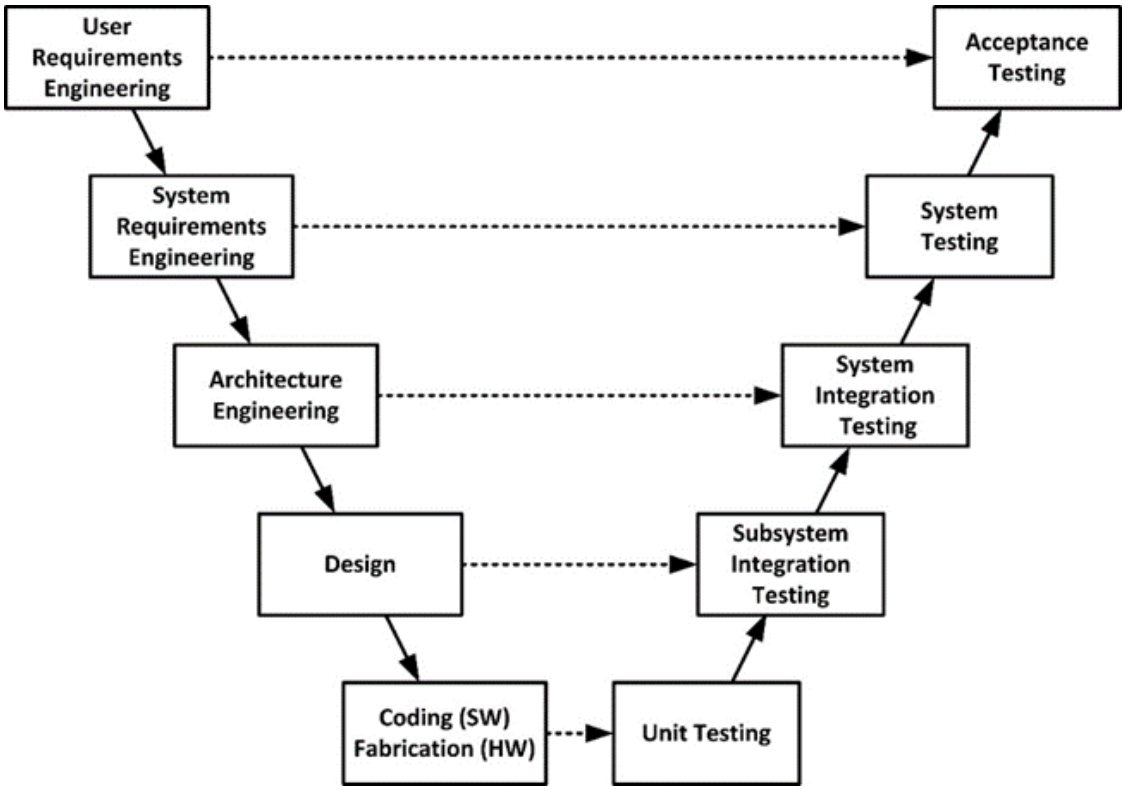

Figure 3: Representation of a simple V-model [35].

This can make the V-model less suitable for projects with limited resources. Finally, the V-model is unsuited for projects with frequently changing requirements, as it is designed to work best with a clear and well-defined set of requirements. If requirements are constantly changing, it cannot be easy to maintain the level of traceability needed for effective testing [35–37]. Despite its limitations, the V-model remains a popular and effective software development model for projects with clear and well-defined requirements. At present times, several researchers are using improved versions of the V-model. For example, Liu et al. [38] proposed an improved V-model process for automotive development. This process introduced early and continuous integrated verification enabled by simulation-based development to address the increasing complexity of modern vehicle systems. In another study, Lim and Chin [39] presented a V-model mobile app development technique incorporating two fuzzy quality function deployment (FQFD) phases. The study demonstrated the development of an online statistical process control app.

FQFD was used to structurally relate user requirements, system requirements, and design strategies in the V-model's verification phases. Integrating FQFD and the V-model in developing mobile apps is a novel contribution of this study. Hynninen et al. [40] addressed the gap between software engineering process terminology in formal education and the practical skills relevant to testing-related work. The authors proposed an approach to map the V-model development phases and testing levels with corresponding actual testing techniques. The approach was evaluated by designing the weekly topics, learning goals, and testing activities for a 7-week introductory course on the basics of software testing and quality assurance. Based on the course outcomes and recent literature, the strengths and weaknesses of the proposed curriculum were discussed. The study aimed to solve the problem of students having little knowledge about what is done during the V-model's development phases and testing levels, as the V-model is mainly conceptual and tied to the steps in the Waterfall model.

Khan et al. [41] proposed an enhanced V-model for developing complex medical devices in their study. They noted that with technological advancement, medical devices have evolved from simple hardware machines to integrated hardware and software systems. Regulatory bodies have imposed rules that medical devices must adhere to ensure the safety of both the hardware and software. However, the traditional Waterfall or Agile models may not be suitable for developing these devices. Therefore, the authors proposed an enhanced V-model and applied its recommendations to developing their wave therapeutic device. Febriyani et al. [42] proposed a verification and validation model of business processes to achieve business goals in implementing Enterprise Architecture designs based on the V-model. They emphasized the importance of testing and validating the design results of the Enterprise Architecture, specifically Business Architecture, to ensure their accuracy and suitability for the company's needs. The study suggests that using Enterprise Architecture designs based on the V-model in business process modeling is a good approach for error checking and achieving the company's business goals.

2.4 Agile model

The term "Agile Software Development" was coined by the Agile Manifesto. It is an iterative approach that emphasizes incremental specification, design, and implementation, while also requiring full integration of testing and development. The Agile development process was influenced by the Rapid Application Development (RAD) methodology [2].

Agile Software Development is well-established in the software industry and has been widely adopted by hundreds of large and small companies to reduce costs and increase their ability to handle changes in dynamic market conditions [43, 44]. The Agile approach prioritizes communication, continuous integration, rapid delivery of software modules, and an iterative and incremental approach. However, it also has limitations, such as a lack of upfront planning, insufficient documentation, and a lack of predictability [45]. Figures 4 (a) and 4 (b) illustrate the Agile Software Development cycle and the generalized process flow for the Agile model, respectively [46].

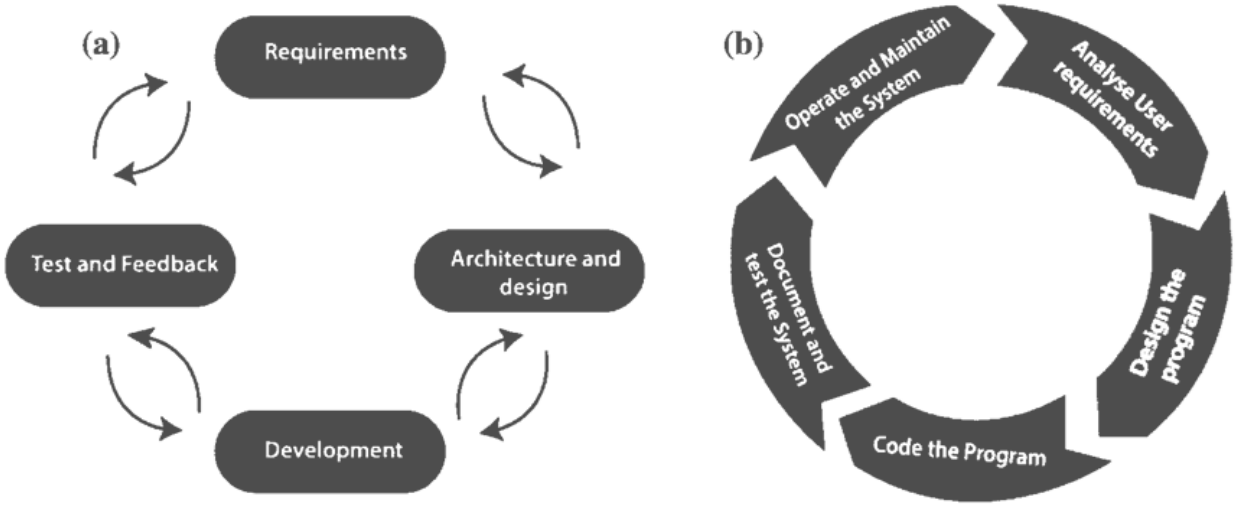

Figure 4: Agile model **(a)**software development cycle; **(b)**process flow [46]

Several researchers have been working on Agile testing models since its development. For example, Kahles et al. [47] presented a methodology for automating root cause analysis in Agile software testing environments using machine learning techniques. They extracted relevant features from raw log data, clustered them, and labeled them with ground-truth categories defined by testing engineers. Artificial neural networks were then trained on the labeled data to classify or pre-process it for clustering. In their study, Dhir and Kumar [48] discussed their approach to automating root cause analysis using machine learning techniques in Agile software testing environments. They proposed an Agile testing model that worked with the productization team in a planned and organized manner to deliver the products in the sprint. They conducted experimental work on a web application to evaluate the outcomes of their approach using the Agile testing model and compared it with traditional automated testing models. Elgrably and Oliveira [49] investigated the construction of a software testing syllabus using Agile practices to support its adherence to academic teaching skills. The research provided a set of skills considered favorable for teaching software testing, which academic program managers and teachers can use to facilitate the construction of syllabuses or subjects related to tests, learning objects, and academic syllabuses. Moreover, Kaur et al. [51] stressed the importance of the development team's continuous integration and deployment in Agile software development. They argued that automated testing could help improve software quality by allowing developers to identify and fix issues early in the development cycle. They also highlighted the importance of testing in real-world conditions and recommended combining manual and automated testing methods.

2.5 Spiral model

The Spiral model offers several advantages over other development models. It provides high flexibility and adaptability to the development process, allowing for continuous refinement and improvement throughout the project's lifecycle. It enables early identification and mitigation of potential risks and issues, as risk analysis is crucial to each spiral iteration. The model also allows for better stakeholder involvement and communication, as each spiral iteration allows stakeholders to review and provide feedback on the project's progress [52, 53]. Fig. 5 provides a general representation of the spiral model. The Spiral Model is a software development framework that uses the Waterfall Model for each version, with subsequent spirals adding functionality to the baseline spiral. It assumes hierarchical requirements and explicitly specifies risk analysis and management. While suitable for well-defined problems, it is not recommended for independent functions. The model provides a framework for designing processes based on project risk levels and can accommodate any development process model. It focuses on identifying and eliminating high-risk problems through careful process design guided by risk management principles [22], [54]. Nevertheless, researchers globally have been working on various applications of the Spiral model. For example, Sharma and Saha [55] proposed an improved Moth-Flame Optimization (MFO) algorithm for object-oriented testing. The paper explained that software testing had become a challenging task with the introduction of object-oriented technology due to its key concepts, such as polymorphism, encapsulation, and inheritance, which introduced various threats to testing. The paper stated that model-based testing was a cheaper and faster methodology, but optimal test path generation was still an open research area. The paper presented the use of the Fermat spiral instead of the logarithmic spiral to capture the spiral motion of moths and optimize the MFO algorithm. The improved algorithm was applied to State Transition Diagrams (STDs) of seven object-oriented software applications to produce test paths.

Aimicheva et al. [56] proposed a Spiral model for teaching mobile application development to bridge the programming knowledge gap between high school and higher education. The model covered all levels of programming education and aimed to effectively train highly qualified mobile developers in Kazakhstan's education system. Supiyandi et al. [57] developed a web-based Village Information System (SID) for Tomuan Holbung Village in North Sumatra, using the Spiral method for development. The system includes analysis, design, coding, testing, and entity relationship diagrams for the database. It facilitates effective and efficient processing of village information data and provides information about village government and activities. The web-based system can be adjusted by users, serving as a means of information in web development for the village. Khadapi [58] implemented the Spiral method to design and analyze a financial information system for the Cashier Financial Management Section (Cash Information Replacement) of PT Telekomunikasi Indonesia.Tbk cooperative. This research aimed to address the problems faced by employees, such as mixed financial data and poor data management. The Spiral method was used to develop a web-based application system that could enumerate financial arrangements, making it easier for employees to manage their finances.

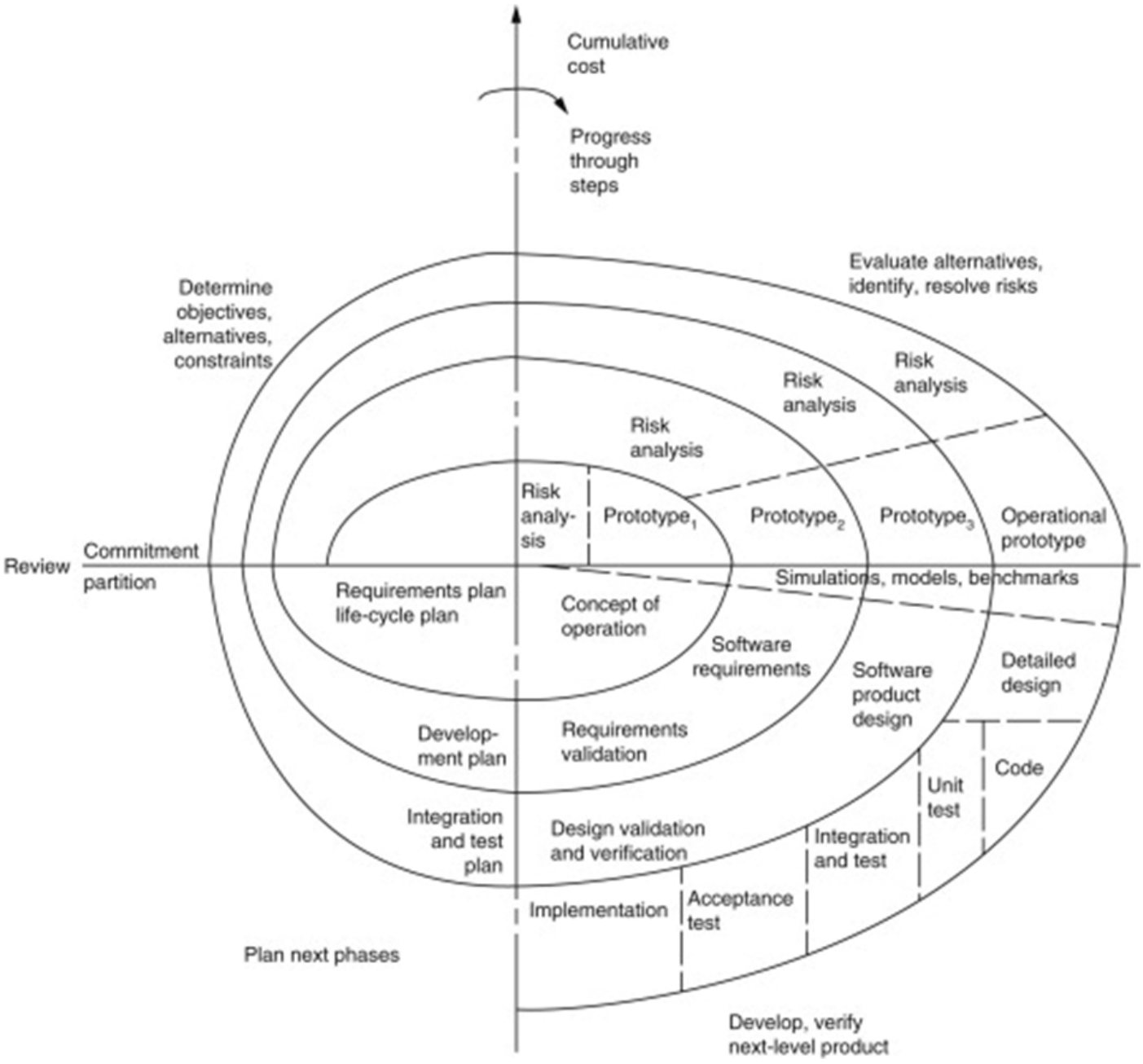

Figure 5: Spiral model of software testing [53].

3 Optimization Techniques

Software testing is a crucial aspect of software engineering, and it seeks to confirm that software modules function as intended and lower the likelihood of future failures [59]. Several optimization techniques have been developed to increase the efficiency and effectiveness of software testing [60]. In this section, we will review some of the most commonly used optimization techniques: test case reduction techniques, fault localization techniques, mutation testing, and combinatorial testing. We will also assess their advantages, disadvantages, and ability to improve software testing efficiency and effectiveness.

3.1 Test case reduction techniques

Test case reduction techniques minimize the number of test cases required to test software modules while maintaining adequate test coverage. These techniques reduce the testing effort and time required while ensuring the testing process effectively detects errors and defects [61, 62]. The first test case reduction technique is random testing, which involves randomly selecting a subset of test cases from the entire set of test cases based on a probability distribution function. This approach is useful in identifying errors or defects in the software module but cannot guarantee that all possible scenarios are tested, and it may be ineffective in detecting complex errors [63–66]. The second technique is prioritization, which involves ranking test cases based on their level of importance and executing them in order of priority. This approach ensures that high-priority test cases are executed first, which can help identify critical errors in the software module. However, lower-priority test cases may not be executed, which may miss identifying less critical errors [67–71]. The third technique is clustering, which involves grouping test cases with similar features and executing one representative test case from each group. This method can reduce the required test cases and may be more efficient than executing all test cases. However, this approach may miss identifying some errors that may only appear in specific test cases [66, 72–76]. While these test case reduction techniques can enhance software testing models by reducing the required test cases, they may not effectively identify all faults in the software module. Therefore, selecting an appropriate technique should be based on the specific characteristics of the software module under test.

3.2 Fault localization techniques

Fault localization is a crucial aspect of software testing that involves identifying the specific locations of faults or defects in the software module. Fault localization techniques are designed to reduce the time and effort required to identify and fix faults in the software, thereby improving the overall efficiency of the software testing process [77–79]. One of the commonly used fault localization techniques is spectrum-based or static techniques. This technique uses information such as statement or branch coverage to identify faulty statements in the software module. Spectrum-based techniques evaluate the coverage data collected during testing and calculate the suspiciousness score of each statement or code segment. The suspiciousness score indicates the likelihood of a faulty statement or code segment. The technique then prioritizes the statements or code segments based on their suspiciousness scores, and developers can investigate the highest-ranked statements or code segments to identify the fault [80–83]. However, while fault localization techniques have proven useful in enhancing software testing models, they may not be effective in identifying complex faults. Complex faults can occur when multiple defects or errors interact, making it challenging to identify the root cause of the fault. In such cases, fault localization techniques may not be sufficient to pinpoint the exact location of the fault.

3.3 Mutation test technique

Mutation testing is a technique used to evaluate the quality and adequacy of test suites. It involves creating artificial defects or mutations in the program under test by making small syntactic modifications, creating a modified version of the program called a mutant. The purpose of creating these mutants is to simulate common mistakes that programmers make while coding a program [84]. The goal of mutation testing is to ensure that the test cases effectively detect and identify defects in the program. By generating mutants and executing them with the same test suite, the adequacy of the test suite can be evaluated. Mutants that behave differently from the original program are considered dead, and equivalent mutants are identified when they exhibit the same behavior as the original program for all test cases. New test cases are then created to kill alive mutants, meaning mutants still exhibit different behavior than the original program [85]. Mutation testing has been applied at various levels of software development, including unit testing, integration testing, and specification testing. It has been used as a white-box unit testing technique for many programming languages, as well as for integration testing. Additionally, mutation testing has been applied at the design level to test program specifications or models [86]. Despite the benefits of mutation testing in terms of effectiveness in evaluating test cases, it also has some drawbacks. One of the major issues is the high number of mutants generated, which can be computationally expensive to execute. Additionally, identifying equivalent mutants can be a time-consuming and challenging task. However, despite these challenges, mutation testing has reached a maturity phase and is gradually gaining popularity in both academia and industry as a powerful tool for evaluating the quality of test suites [84–88].

3.4 Combinatorial test technique

Combinatorial testing (CT) is a dynamic testing technique that aims to detect interaction faults in software systems caused by the combined effect of multiple configurable parameters. It involves specifying test factors and their respective test settings based on requirements, system implementation, and other available information. Then, test cases are generated as combinations of one test set for each test factor. This technique detects failures triggered by parameter interactions in complex software systems with distributed environments [89]. CT is widely used to handle large test combination spaces in practical testing scenarios. However, the performance of existing constraint-handling methods can rapidly degrade when constraints are involved between parameters. Thus, more intelligent test data sampling mechanisms are needed to detect interaction faults in complex software systems [90]. The main goal of CT test generation is to generate covering arrays that cover all t-way parameter combinations. A covering array is a compact test suite that ensures that every t-tuple of parameter values occurs at least once in the test suite. The covering strength, t, determines the level of interaction between the parameters in the software system. CT is highly effective in detecting failures caused by interactions between parameters that are otherwise hard to detect using traditional testing methods [91].

In summary, combinatorial testing is a powerful dynamic technique that can detect complex interaction faults in software systems caused by multiple configurable parameters. It offers an effective testing mechanism to handle large test combination spaces and has been widely used for 20 years. However, more intelligent test data sampling mechanisms are needed to detect interaction faults in practical testing scenarios, especially when constraints exist between parameters [89–91].

4 Analysis of Efficiency and Advancement Needs

4.1 Comparison of software testing models and optimization techniques

This section will compare the software testing models and optimization techniques reviewed in the previous sections. The comparison of the four commonly used optimization techniques: test case reduction, fault localization, mutation testing, and combinatorial testing, is discussed based on their purpose, advantages, limitations, and applicability. This will help readers understand the differences between these techniques and choose the appropriate one for their specific testing needs. The information is summarized in Table 1. The comparison of the five commonly used software testing models: Waterfall, Incremental, V-Model, Agile, and Spiral, is discussed based on ten different important aspects of each technique to help readers understand their differences and choose the appropriate technique for their specific testing needs. The information is summarized in Table 2.

4.2 Identification of areas for improvement and advancement

Software testing is a crucial component of software engineering. There are various software testing models and optimization techniques available in the literature. Each model and technique have advantages and disadvantages, and their ability to identify flaws and reduce testing time and effort varies. Therefore, it is essential to assess and compare these models and techniques to identify areas for improvement and advancement. Based on the comparison of different testing models and optimization techniques, it is clear that there is no one-size-fits-all approach to software testing. The choice of model and optimization technique depends on the project requirements and context. However, several areas for improvement and advancement can increase the effectiveness and efficiency of software testing. One area for improvement is the integration of different software testing models and techniques. For example, it is possible to use the V-model for verification and validation and the Agile model for collaboration and feedback. Similarly, combining different optimization techniques to achieve better results is possible.

Table 1: Comparative analysis of optimizing techniques.

Aspects	**Test Case Reduction**	**Fault Localization**	**Mutation Testing**	**Combinatorial Testing**
Purpose	Minimize test cases while maintaining coverage	Identify specific fault locations	Evaluate the quality and adequacy of test suites	Detect interaction faults caused by parameter combinations
Advantages	Reduce overall testing time and effort	Improve the efficiency of the software testing process	Effective in evaluating the quality and adequacy of test suites	Highly effective in detecting failures triggered by parameter interactions
Limitations	May not identify all faults in the software module	It may not be effective in identifying complex faults	Computationally expensive to execute, challenging task of identifying equivalent mutants	Performance can rapidly degrade when constraints are involved between parameters
Applicability	When reducing the number of test cases is necessary	When identifying specific fault locations is critical	When evaluating the quality and adequacy of test suites	In complex software systems with distributed environments to detect interaction faults

Another area for improvement is the automation of software testing. Automation can reduce the time and effort required for testing and improve the accuracy and consistency of the results. Automation can also enable continuous testing, which is essential for Agile development. Machine learning techniques can be used to improve software testing in several ways. For example, machine learning can generate test cases automatically based on the software code analysis and its behavior. Machine learning can also prioritize test cases based on their likelihood of detecting faults. In addition, machine learning can be used for fault prediction and localization. Traditional metrics, such as code coverage and defect density, are useful but limited in their ability to gauge the success of software testing. New metrics are needed to capture the quality and effectiveness of software testing. In addition, it is important to measure the impact of software testing on the overall project, such as its effect on customer satisfaction and business value. Contemporary software programs, such as those used in the Internet of Things (IoT) and artificial intelligence (AI), pose unique challenges for software testing.

These programs are often distributed, heterogeneous, and complex, which makes testing more difficult. Thus, novel approaches are needed that consider the specific characteristics of these programs. One approach is to use model-based testing techniques that leverage formal models of the system under test to generate test cases automatically. This approach has shown promising results in testing IoT systems where many devices are connected, and the system's behavior is non-deterministic. Another approach is to use AI and machine learning techniques to improve the effectiveness and efficiency of software testing. For example, machine learning algorithms can be trained to automatically generate and prioritize test cases based on their likelihood of uncovering defects. This approach has shown promising results in reducing the number of test cases needed to achieve high test coverage.

Table 2: Comparison of software testing models.

Aspect	**Waterfall Model**	**Incremental Model**	**V-Model**	**Agile Model**	**Spiral Model**
Testing Approach	A sequential and linear approach	Iterative approach	A sequential and linear approach	An iterative and incremental approach	Iterative approach
Testing Phases	Testing is done after development is complete	Testing is done after each iteration or module is complete	Testing is done in parallel with development phases	Testing is done continuously throughout the project	Testing is done after each iteration
Documentation	Emphasis on documentation	Documentation is important but not emphasized as much as in the Waterfall model	Emphasis on documentation	Documentation is not the main focus, but agile methodologies have their own set of documentation practices	Emphasis on documentation
Communication	Communication is limited to predefined stages	Communication is ongoing and frequent	Communication is limited to predefined stages	Communication is ongoing and frequent	Communication is ongoing and frequent
Flexibility	Changes are difficult to implement	Changes are easier to implement	Changes are difficult to implement	Changes are easy to implement	Changes are easier to implement
Team Structure	Hierarchical structure with separate teams for each phase	Cross-functional teams with shared responsibilities	Hierarchical structure with separate teams for each phase	Self-organizing teams with shared responsibilities	Hierarchical structure with separate teams for each phase
Customer Involvement	Limited customer involvement	Moderate customer involvement	High customer involvement	Moderate customer involvement	Moderate customer involvement
Risk Management	Risk analysis is done before development starts	Risk analysis is done before each iteration	Risk analysis is done before development starts	Risk analysis is done continuously throughout the project	Risk analysis is done before each iteration
Testing Speed	Slower testing due to the sequential approach	Faster testing due to the iterative approach	Slower testing due to the sequential approach	Faster testing due to the continuous testing approach	Faster testing due to the iterative approach
Adaptability	Less adaptable to changes	Highly adaptable to changes	Less adaptable to changes	Highly adaptable to changes	Highly adaptable to changes

5 Conclusion

In conclusion, software testing is a critical aspect of software engineering that ensures software modules function as intended and minimizes the likelihood of future failures. The presented review paper comprehensively reviews various software testing models and optimization techniques, highlighting their advantages and disadvantages. The analysis showed no one-size-fits-all approach to software testing, and the choice of model and technique depends on the project's requirements, resources, and constraints. Additionally, the paper suggested areas for improvement and advancement to increase the effectiveness and efficiency of software testing, such as the use of machine learning techniques to automate and optimize testing processes, the introduction of new metrics to gauge the success of testing, and the development of novel approaches to deal with contemporary software programs. Ultimately, the software testing process should be continuously improved and optimized to ensure software modules function as intended and minimize the likelihood of future failures.

Declaration of Competing Interests

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Author Contribution

Sarvesh Kumar: Conceptualization, Methodology, Data curation, Writing - Original draft preparation, Writing – Reviewing

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Leveraging Hofstede's Cultural Dimensions for Devising COVID-19 Control Strategies

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Abstract

The COVID-19 Pandemic has caused unprecedented global challenges, including significant socioeconomic disruptions and the closure of schools and universities in almost all countries. Understanding the role of culture in shaping individual and societal responses to the Pandemic is crucial. This review article examines the applicability of Hofstede's cultural dimensions framework in devising effective COVID-19 control strategies. The article provides an overview of each dimension and its impact on the implementation of COVID-19 control strategies. It also includes a case analysis of four countries - India, the United Kingdom, the United States of America, and Poland - to illustrate the interplay between culture and COVID-19 control strategies. The insights provided by Hofstede's framework and the case analysis demonstrate that cultural differences can significantly impact the success of COVID-19 control strategies. By taking these differences into account, governments and public health authorities can improve the effectiveness of their COVID-19 control measures.

Keywords: COVID-19; Cultural Dimensions; Hofstede's Model; Cultural Backgrounds; Pandemic Handling

1 Introduction

The coronavirus disease, commonly known as COVID-19, has been making headlines every second since its emergence in Wuhan, China, and was declared a pandemic by the World Health Organization [1]. The COVID-19 Pandemic has forced employers to alter

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individual work styles to ensure good communication, work-life balance, and flexibility for employees and maintain optimal work productivity levels while also influencing economic decisions [2–4].

As of February 21, 2023, the number of infected people worldwide, including 6.8 million COVID-19-associated deaths, was approximately 757 million [5]. The manifestations of COVID-19 vary, and its severity is affected by age and preexisting medical conditions. Children and adolescents are usually asymptomatic or have mild symptoms, while older adults may experience severe illness and disproportionately elevated mortality. Among those who survive, some may experience enduring deficits. The viral load is particularly high in saliva and the oropharynx, which can be potential sources of infection. The diagnosis of the disease may be complicated by factors related to the virus's replicating cycle, viral load, and sensitivity of the diagnostic method used. Vaccines have been developed to prevent the spread of COVID-19 [6], with approximately 65.1 % of the total global population administered with the second dose and 71 % with the first dose [5]. The Pandemic has led to extreme socioeconomic disruptions and the cancellation or postponement of political, sports, cultural, and religious events worldwide [7]. It has also caused a shortage of essential goods due to panic buying among citizens [8]. The Pandemic is gradually leading the planet to one of its most significant recessions, with more than one-third of the global population in lockdown, limiting the scales of production [9, 10]. According to the United Nations Educational, Scientific and Cultural Organization (UNESCO), the education sector is sustaining significant losses as schools, colleges, and universities are closed in 197 countries, also affecting about 99 % of the global student population [11]. In these dire conditions, understanding individual behavior patterns and the cultures of different regions of the world would help analyze the virus's spread.

Culture can be defined as a set of traits shared by a group, where traits are characteristics of human societies potentially transmitted by non-genetic means and can be owned by an agent [12]. Humans are both cultural and biological entities, and as a pandemic sweeps through vast segments of the world, humans tend to cope both culturally and biologically. People of different social groups tend to reflect different cultural reactions. Such responses differ according to the nature of their societies, lifestyle, and the economic system of their country [13, 14]. Human behavior has influenced the spread of infectious diseases over the years. In 1918, during World War I, censorship of the media and demographic transitions due to war constraints adversely affected the influenza pandemic, causing a rise in the number of cases [15]. The rise of anti-vaccination movements in the United States and Western Europe caused many deaths during the measles outbreak [16]. Thus, one of the factors hindering the control of the pandemic disease is the behavior and actions of humans in a group or as an individual. It is essential to study cultural behaviors when analyzing the spread of infectious diseases like COVID-19 in humans. In this context, Hofstede's cultural dimensions framework, developed by Dutch social psychologist Geert Hofstede, is believed to provide a valuable lens for understanding how socio-cultural factors can influence the success of control strategies. The framework identifies five dimensions that can help explain cultural differences: power distance, individualism versus collectivism, masculinity versus femininity, uncertainty avoidance, and long-term versus short-term orientation. Based on the short theoretical discussion in this introductory section of the article, it is evident that these cultural dimensions play a crucial role in shaping individual behavior and societal responses during pandemics like COVID-19. The following section of this paper provides a brief overview of Hofstede's cultural dimensions and explains their impact on the implementation of COVID-19 strategies. Additionally, the article includes a small case analysis to help readers better understand the interrelationship between cultural dimensions and the success of control strategies.

2 Hofstede's Cultural Dimensions

Hofstede's cultural dimensions (HCD) framework is a tool that can help explain cultural differences between societies. The framework identifies five dimensions that can provide an understanding of how socio-cultural factors can influence the success of control strategies in tackling infectious diseases such as COVID-19. Understanding these cultural differences can help individuals navigate cross-cultural interactions and build effective relationships with people from different backgrounds [17]. This section explains the details of each of the five dimensions and how they influence COVID-19 control strategies.

2.1 Power Distance

The concept of power distance refers to the degree to which people in a culture or society accept and expect that power and status are distributed unequally among individuals and groups [18, 19]. In societies with high power distance, people tend to accept and even expect that some individuals or groups will have more power, wealth, or status than others. Conversely, in societies with low power distance, people tend to strive for an equal distribution of power and status. High power distance cultures often value respect for authority and hierarchy, and individuals are expected to defer to those in positions of power or authority [20–24]. For instance, in many Asian countries, elders and those in positions of authority are given great respect and deference [25]. This respect can also extend to workplace dynamics, where superiors are seen as having more authority and knowledge than their subordinates [26, 27]. In contrast, in low power distance cultures, individuals may question or challenge authority figures and may have a greater sense of personal agency and empowerment [28]. These cultures tend to emphasize the importance of individual rights, and the distribution of power and status is often more equalized. In such cultures, people may be more likely to engage in open discussions and debates with authority figures, and workplace hierarchies may be flatter [18]. It is important to note that power distance is not necessarily a value judgment about a culture but rather an observation of the way power and status are perceived and distributed within that culture [29]. Each culture has its own unique values and beliefs that influence its attitudes toward power distance.

2.2 Individualism vs. Collectivism

The concept of individualism versus collectivism refers to the extent to which people in a culture prioritize their personal interests versus the interests of the group or community [30, 31]. In individualistic cultures, individuals tend to prioritize personal goals, autonomy, and independence. They value individual achievement, success, and self-reliance [32, 33]. Conversely, in collectivistic cultures, people place greater emphasis on the goals and needs of the group or community over their own personal interests [34, 35]. Individualistic cultures typically place value on personal freedom, choice, and self-expression, and place a premium on competition and individual achievement. In such cultures, individuals may prioritize their own needs and desires over those of the community as a whole [36, 37]. For instance, in the United States, individualism is commonly emphasized, and people are encouraged to pursue their own dreams and goals [38]. In contrast, collectivistic cultures tend to stress social harmony, cooperation, and interdependence [39]. People in such cultures may prioritize the goals and needs of the group over their own individual interests. They may be more inclined to seek consensus and harmony and may prioritize maintaining social relationships and avoiding conflict [40]. For instance, in many Asian cultures, collectivism is emphasized, and people are encouraged to prioritize the needs of the family or community over their own personal desires [41]. It is important to note that individualism versus collectivism is not a value judgment about culture but rather an observation of how individuals in that culture prioritize their interests and relationships with others. Each culture has its own distinct values and beliefs that influence its attitudes toward individualism and collectivism.

2.3 Masculinity vs. Femininity

The cultural dimension of masculinity vs. femininity refers to how a society values and prioritizes traditional masculine or feminine traits [42]. Masculine traits typically include qualities such as competitiveness, assertiveness, and a focus on material success, while feminine traits tend to include values like cooperation, modesty, and quality of life. In societies that emphasize masculinity, men are typically expected to embody these traits, while women are often encouraged to adopt more traditional roles as caretakers and supporters of men's success [43, 44]. There is often a greater emphasis on achievement and material success and less importance placed on qualities like the quality of life or interpersonal relationships [45–47]. In contrast, in societies that prioritize femininity, there may be more emphasis on cooperative relationships and quality of life [45]. Both men and women may be expected to share caregiving and household responsibilities more equally, and traditional gender roles may be less strictly enforced. Success may be defined in terms of personal fulfillment and happiness rather than material wealth or status [48, 49]. It's important to note that these cultural dimensions are not fixed or absolute and can vary widely between different societies and even within the same society over time. Additionally, individuals may embody a mix of traditionally masculine and feminine traits, regardless of their gender identity.

2.4 Uncertainty Avoidance

The cultural dimension of uncertainty avoidance describes the extent to which individuals in a society feel uncomfortable with ambiguity and uncertainty [50]. In high uncertainty avoidance cultures, people tend to value structure, rules, and regulations and prefer to minimize ambiguity in their daily lives [51, 52]. They often have a strong preference for clear and explicit guidelines and rules, which they use to guide their behavior and decision-making. Such societies often have well-established legal systems, bureaucratic procedures, and standardized work practices designed to minimize risk and ensure stability [53]. In contrast, in low uncertainty avoidance cultures, individuals are more comfortable with ambiguity and uncertainty and are more open to change. They tend to be more accepting of risks and uncertainties and may be more willing to experiment with new ideas or ways of doing things. Such societies often value creativity, innovation, and entrepreneurship and may be less reliant on strict rules or regulations to guide behavior [54, 55]. The level of uncertainty avoidance can have a significant impact on many aspects of society, including education, work, and politics.

For instance, in high uncertainty avoidance cultures, education may emphasize memorization and rote learning, while in low uncertainty avoidance cultures, there may be more emphasis on critical thinking and problem-solving [56–59]. In the workplace, high uncertainty avoidance cultures may value seniority, experience, and adherence to established rules, while low uncertainty avoidance cultures may be more receptive to new ideas and approaches and may place greater value on creativity and innovation [60–63]. It's important to note that the level of uncertainty avoidance can vary widely between different societies and may be influenced by a variety of factors, including history, religion, and geography. Moreover, individuals within a given society may vary in their own level of uncertainty avoidance, depending on personal characteristics, experiences, and social context. Understanding the cultural dimension of uncertainty avoidance can help individuals navigate cultural differences and work effectively in diverse settings.

2.5 Long-term vs. Short-term Orientation

The cultural dimension of long-term orientation versus short-term orientation refers to how much emphasis individuals in a society place on long-term planning and investment, as opposed to focusing on short-term gains and immediate gratification [64, 65]. In long-term orientation cultures, individuals value traits such as perseverance, thrift, and respect for tradition and prioritize the achievement of long-term goals over immediate results [66, 67]. These cultures emphasize the importance of hard work and self-discipline and place greater emphasis on education, training, and personal development [65]. In contrast, in short-term orientation cultures, individuals prioritize quick results and immediate gratification over long-term planning and investment. They may be more likely to take risks and make impulsive decisions and prioritize personal enjoyment and satisfaction over long-term goals [68, 69].

Such cultures may place a greater emphasis on entertainment, leisure, and consumerism and may be less inclined to save or invest for the future [65, 70, 71].

The level of long-term orientation can significantly impact many aspects of society, including education, work, and politics. In long-term orientation cultures, education may be viewed as a long-term investment in personal development and future success, while in short-term orientation cultures, education may be seen as a means to obtain quick results, such as a job or promotion. Similarly, in the workplace, long-term orientation cultures may value loyalty, seniority, and hard work, while short-term orientation cultures may prioritize individual achievement and immediate results [65]. It's important to note that the level of long-term orientation can vary widely between different societies and may be influenced by a variety of factors, including history, religion, and geography. Moreover, individuals within a given society may differ in their own level of long-term orientation depending on personal characteristics, experiences, and social context. Understanding the cultural dimension of long-term orientation can help individuals navigate cultural differences and work effectively in diverse settings.

3 COVID-19 Control Strategies

3.1 An Overview

The COVID-19 Pandemic has presented unprecedented challenges and disrupted normal life globally. To mitigate the Pandemic's impact, governments and public health authorities have implemented various control strategies aimed at preventing the virus's spread. These strategies can be broadly classified into several categories [72–75].

The first category of COVID-19 control strategies is lockdowns, where the movement of people is restricted, and non-essential businesses are closed to reduce the virus's spread [76]. Lockdowns can be implemented at different levels, ranging from national to local [77, 78]. During lockdowns, individuals are required to stay at home unless carrying out essential activities, such as buying food or seeking medical care. In some cases, essential workers are allowed to continue working [79, 80].

The second category of COVID-19 control strategies is testing and tracing [81, 82]. Testing involves identifying individuals infected with COVID-19, while tracing involves identifying and monitoring individuals who have come into contact with infected individuals [83, 84]. Testing and tracing programs are crucial for identifying and isolating infected individuals before they spread the virus to others. These programs can also help to identify and break chains of transmission in the community [85, 86].

The third category of COVID-19 control strategies is quarantine measures [87–89]. Quarantine involves separating and restricting the movement of individuals who have been exposed to COVID-19 [90, 91]. Quarantine measures can be voluntary or mandatory and can be implemented at different levels, ranging from individual to national [92]. During quarantine, individuals are required to stay at home or in designated facilities for a specified period to prevent the spread of the virus [93, 94].

The fourth category of COVID-19 control strategies is mask mandates [95–97]. Wearing masks can help prevent the spread of COVID-19 by reducing the transmission of respiratory droplets from infected individuals [98–100]. Mask mandates refer to requirements that individuals wear masks in public places or in specific situations, such as public transport or crowded spaces [101].

The fifth and final category of COVID-19 control strategies is vaccination programs [102–104]. Vaccination is a crucial strategy for preventing the spread of COVID-19 and reducing its impact on public health [105]. Vaccines can help build immunity against the virus, preventing individuals from becoming infected or experiencing severe symptoms if they do become infected [106]. Vaccination programs have been implemented in many countries worldwide, with different approaches to distribution and prioritization [107, 108].

3.2 Successful Implementation in Various Countries

To minimize the impact of COVID-19, governments and public health authorities of various countries have implemented one or more types of control strategies, which were discussed in the article, aiming at preventing the spread of the virus. As seen from the literature comprising the data for 25 different countries, successful control strategies have varied across different cultural contexts, depending on the local context and circumstances.

Countries such as South Korea, Taiwan, Norway, Finland, and Denmark have successfully implemented testing and contact tracing programs, along with mandatory quarantine measures for infected individuals and their close contacts [109–115]. Countries such as Singapore, Iceland, Germany, Switzerland, and Austria have implemented contact tracing programs to identify and monitor individuals who have come into contact with infected individuals [116–121]. Countries such as Taiwan, Singapore, Austria, Israel, and India have implemented mandatory mask-wearing, which has been shown to reduce the transmission of respiratory droplets from infected individuals [123–129]. Additionally, countries such as Singapore, Japan, and Greece have promoted good hygiene practices and encouraged social distancing, which has helped to prevent the spread of the virus [130–132]. Countries such as Australia, Thailand, and Iceland have implemented strict border controls and quarantine measures for travelers, as well as imposing quarantine measures for infected individuals and their close contacts [133–135]. A total of 19 countries out of the selected 25 countries, including Israel, the United Arab Emirates, India, and Brazil, have implemented successful vaccination drives [136–139]. Countries such as India, the United Kingdom, the United States, and Canada have also successfully implemented a combination of lockdowns, contact tracing, and vaccination rollout to control the spread of COVID-19 [140–143].

It is noted from the studied literature that successful control strategies have varied across different cultural contexts, depending on

the local context and circumstances. Though some common elements of successful strategies included early detection and isolation of infected individuals, effective contact tracing, mandatory mask-wearing, quarantine measures, and rapid vaccination rollout, the implementation of these strategies, only when coupled with the cooperation of the public, has been crucial in controlling the spread of COVID-19 globally.

4 Influence of HCD on COVID-19 Control Strategies

Upon critical review of the literature, it is evident that Hofstede's cultural dimensions can offer valuable insights into how cultural differences may impact the development and effectiveness of COVID-19 control strategies.

Power distance, which refers to the acceptance of unequal distribution of power in a society, may influence the effectiveness of COVID-19 control strategies that rely on government authority and enforcement, such as lockdowns and mask mandates. In high power distance cultures, people may be more compliant with these measures, whereas, in low power distance cultures, people may be more resistant.

Individualism vs. collectivism refers to the focus on individual vs. group goals and interests in a society, which may affect the effectiveness of COVID-19 control strategies that require collective action, such as wearing masks and social distancing. In individualistic cultures, people may resist these measures as they may perceive them as infringing on personal freedoms, while in collectivist cultures, people may be more likely to comply as they prioritize the well-being of the group.

Masculinity vs. femininity refers to the degree of emphasis on traditional masculine vs. feminine values in a society, which may impact the effectiveness of COVID-19 control strategies that require sacrifice and cooperation for the greater good, such as lockdowns and social distancing. In cultures with high masculinity, people may be more resistant to these measures as they may perceive them as weak and uncompetitive, whereas in cultures with high femininity, people may be more likely to comply as they prioritize the well-being and safety of others.

Uncertainty avoidance refers to the comfort level with ambiguity and uncertainty in a society, which may influence the effectiveness of COVID-19 control strategies that require adaptation to changing circumstances, such as contact tracing and quarantine measures. In cultures with high uncertainty avoidance, people may be more likely to comply with these measures as they provide a sense of stability and predictability, whereas, in cultures with low uncertainty avoidance, people may be more resistant as they prioritize personal freedom and independence.

Finally, long-term vs. short-term orientation refers to the focus on long-term vs. short-term goals and planning in a society, which may impact the effectiveness of COVID-19 control strategies that require long-term planning and investment, such as vaccination programs. In cultures with a long-term orientation, people may prioritize long-term benefits over short-term costs, whereas in cultures with a short-term orientation, people may resist as they prioritize immediate gratification over long-term benefits.

5 Case Analysis

To minimize the impact of COVID-19, governments and public health authorities in various countries have implemented control strategies based on their unique cultural dimensions. In this analysis, four countries (India, the United Kingdom, the United States of America, and Poland) have been randomly selected to investigate the impact of Hofstede's cultural dimensions on these strategies. The authors have provided their collective discussion on each case based on their experience as residents of these countries. Table 1 summarizes the cultural dimensions of the selected countries [144], which can be correlated with the success rate of each control strategy.

Table 1: Hofstede's cultural dimensions for the selected four countries.

Country	Power distance	Individualism	Masculinity	Uncertainty avoidance	Long-term orientation
India	77	48	56	40	61
UK	35	89	66	35	51
USA	40	91	62	46	26
Poland	68	60	64	93	82

India has a high score in power distance, indicating the prevalence of hierarchical structures in society. This may have contributed to challenges in implementing social distancing measures during the nationwide lockdown. However, the collectivistic nature of Indian society may have facilitated the success of ramping up testing and contact tracing, as people prioritize the greater good. The high score in uncertainty avoidance also played a role in the success of using digital platforms to monitor and track the spread of the virus, as there is a preference for structure and clear rules. The UK has a low score in power distance, suggesting a more egalitarian society. This may have facilitated the implementation of control strategies such as social distancing measures and lockdowns, as individuals may be more willing to comply with guidelines from the government. The high score in individualism may have also contributed to the success of vaccination programs, as individuals prioritize their own health. However, the low score in uncertainty

avoidance may have made it challenging to enforce guidelines, as there is a preference for ambiguity and flexibility. The USA also has a low score in power distance, indicating an egalitarian society. This may have facilitated the implementation of control strategies such as social distancing measures and lockdowns, as individuals may be more willing to comply with guidelines from the government. However, the high score in individualism may have contributed to challenges in enforcing guidelines, as individuals prioritize personal freedoms over public health. The low score in uncertainty avoidance may have also contributed to the challenges in enforcing guidelines, as there is a preference for ambiguity and flexibility. Poland has a high score in power distance, suggesting a hierarchical society. This may have facilitated the implementation of strict measures such as lockdowns and social distancing guidelines. However, the low score in individualism may have contributed to challenges in implementing vaccination programs, as individuals may be less likely to prioritize their own health over the collective. The high score in uncertainty avoidance may have contributed to the success of contact tracing measures and the preference for clear rules and guidelines.

6 Conclusion

The COVID-19 Pandemic has challenged the global community in unprecedented ways, leading to the implementation of a variety of control strategies to curb its spread. However, the success of these strategies has varied across different cultural contexts, highlighting the importance of considering cultural dimensions in their development and implementation. Hofstede's cultural dimensions have been identified as a useful framework for understanding cultural differences and how they influence behavior, including the response to COVID-19. Through analysis of case studies from India, the UK, the US, and Poland, we have seen how power distance, individualism-collectivism, uncertainty avoidance, and long-term orientation dimensions have influenced the implementation of COVID-19 control strategies. India's case study highlighted the challenges of implementing social distancing measures effectively in a society with high power distance and collectivism and the potential reluctance to report COVID-19 symptoms due to the emphasis on family and community. The UK's case study demonstrated the importance of considering uncertainty avoidance in messaging and communication strategies, while the US case study highlighted the impact of individualism on compliance with control measures. Poland's case study showed the influence of long-term orientation on the acceptance of strict quarantine measures while also highlighting the challenges of implementing effective contact tracing in a society with low trust and high uncertainty avoidance. While Hofstede's cultural dimensions have provided valuable insights into the challenges and limitations of COVID-19 control strategies, they are not without their limitations. One of the main challenges is the potential for oversimplification and stereotyping of cultural differences, as cultural values and norms are not always fixed and can vary within and across cultures. Additionally, cultural dimensions may not fully capture the complexity and diversity of cultural contexts, and other factors such as socioeconomic status, age, and gender may also play a role in shaping behavior. To overcome these limitations, a more nuanced and context-specific approach is needed. This may involve engaging with local communities and stakeholders to understand their unique perspectives and needs, tailoring communication strategies to specific cultural contexts, and incorporating a range of cultural factors into the design and implementation of COVID-19 control strategies. In conclusion, the COVID-19 Pandemic has highlighted the importance of considering cultural dimensions in the development and implementation of control strategies. Hofstede's cultural dimensions have provided a useful framework for understanding cultural differences and their influence on behavior, and case studies from India, the UK, the US, and Poland have demonstrated their practical application. However, a more nuanced and context-specific approach is needed to address the challenges and limitations of using cultural dimensions in this context. Future research and policy-making should aim to incorporate a range of cultural factors and engage with local communities and stakeholders to develop effective and culturally sensitive COVID-19 control strategies.

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The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Author Contribution

Dasharathraj K Shetty: Conceptualization, Methodology, Writing - Reviewing; **Chetana Balakrishna Maddodi**: Methodology, Data curation, Writing - Reviewing; **BM Zeeshan Hameed**: Conceptualization, Methodology, Writing - Original draft preparation, Writing - Reviewing; **Milap Shah**: Writing - Reviewing; **Sufyan Ibrahim**: Writing - Conceptualization, Methodology, Original draft preparation, Writing - Reviewing; **Anshika Sharma**: Writing - Reviewing; **Rahul Paul**: Writing - Reviewing; Piotr Chłosta: Methodology, Data curation, Writing - Reviewing; **Bhaskar Somani**: Data curation, Writing - Reviewing.

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