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ICATI 2024: International Conference on Advances in Technology and Innovation

Forecasting Fraud Detection Using Data Science Methods

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Abstract: Fraud detection is critical in various domains, including finance, healthcare, and e-commerce, where fraudulent activities pose significant threats to organizational integrity and financial stability. Traditional fraud detection methods often fail to address the dynamic nature of fraudulent behavior. In response, data science methods have emerged as promising tools for forecasting fraudulent activities by leveraging advanced analytics techniques on large-scale datasets. This research will make significant contributions by focusing on predicting fraud detection through data science methods. The findings will guide on preventing customers from committing fraud. The research questions aimed to be answered in this study are as follows: What are the key factors affecting fraud detection? Which customer behaviors are the strongest predictors of fraud detection? This study will provide a valuable model to the industry, enabling financial institutions to strengthen their risk management strategies and translate innovations in AI into applications.

Keywords: Fraud detection, Logistic regression, XGBoost classifier, CatBoost classifier, Random forest

Introduction

The rapid digitalization of transactions has brought about a parallel increase in credit card fraud, a pressing issue that threatens financial institutions and consumers. The need to detect and prevent fraudulent activities in credit card transactions has thus become a critical area of research, urgently requiring innovative solutions to reduce financial losses and safeguard sensitive information. A key challenge in this field is the significant class imbalance in fraud detection datasets, where legitimate transactions far outnumber fraudulent instances. This imbalance poses a hurdle for traditional machine learning models, which often struggle to accurately identify the minority class (fraud transactions), leading to a high rate of false negatives and overall suboptimal model performance (Gupta et al., 2023; Tran & Dang, 2021).

Researchers have developed various strategies to address the limitations associated with imbalanced datasets, categorized broadly into data-level, algorithm-level, and ensemble-based approaches. Data-level techniques focus on modifying the dataset to achieve a more balanced class distribution. Commonly employed methods include oversampling the minority class (e.g., using the Synthetic Minority Over-sampling Technique (SMOTE) or Adaptive Synthetic Sampling (ADASYN)) and under-sampling the majority class to enhance the performance of the classification algorithms on skewed datasets (Makki et al., 2019; Tran & Dang, 2021). On the other hand, algorithm-level strategies involve adapting the learning process by incorporating cost-sensitive learning mechanisms, which assign a higher penalty to misclassifications of minority class instances. This helps to reduce the bias toward the majority class during training. Additionally, ensemble-based methods such as Random Forest, Boost, and AdaBoost have shown considerable promise by aggregating the results of multiple base classifiers, thus improving the overall accuracy and robustness of fraud detection systems (Awoyemi et al., 2017; Singh et al., 2022).

Despite these advancements, significant challenges remain. Even after employing data-level balancing techniques, achieving high precision and recall in fraud detection remains difficult due to the dynamic nature of fraud patterns. Fraud behaviors evolve rapidly, necessitating adaptive models that accommodate new patterns. Consequently, recent research has increasingly focused on integrating multiple techniques to develop comprehensive and robust frameworks for fraud detection. For example, combining data-level balancing with advanced machine learning algorithms, such as deep learning networks or ensemble approaches, has significantly improved classification performance on highly imbalanced datasets (Isangediok & Gajamannage, 2022; Makki et al., 2019).

Moreover, the advent of hybrid approaches, which simultaneously apply multiple strategies (e.g., combining oversampling, cost-sensitive learning, and ensemble techniques), has shown potential to address the limitations of existing methods, such hybrid models improve detection rates and reduce the computational burden of processing large datasets, making them suitable for real-time fraud detection applications. This paper aims to delve into these issues by systematically evaluating the effectiveness of various data science methodologies in forecasting credit card fraud. It will propose an integrated approach that leverages the strengths of different techniques to develop an adaptive, high-performance fraud detection framework capable of operating in a dynamic and data-intensive environment.

This study focuses on fraud detection using machine learning techniques, specifically CatBoost, LightGBM, XGBoost, Logistic Regression, AdaBoost, and Random Forest. First, the performance differences among these methods and their impact on the dataset were analyzed. Then, various hyperparameter tuning and model enhancement strategies were applied to improve the techniques' effectiveness. Finally, the results were compared to determine the most suitable approach for fraud detection.

Literature Review

Recent advancements in credit card fraud detection have explored various strategies to overcome challenges associated with data imbalance, dynamic fraud patterns, and the need for computational efficiency. One promising area is hybrid techniques for balancing datasets and feature selection. Researchers have increasingly employed a combination of under-sampling and oversampling methods to achieve better class distribution. A notable approach is SMOTE-ENN (SMOTE combined with Edited Nearest Neighbors), where synthetic samples are first generated to oversample the minority class, followed by an under-sampling process to remove noisy data points, thus enhancing model robustness (Makki et al., 2019; Warghade et al., 2020). Additionally, feature selection methods such as recursive feature elimination, principal component analysis (PCA), and information gain have been effective in identifying the most relevant features, leading to reduced model complexity and improved generalization performance (Awoyemi et al., 2017; Tyagi & Mittal, 2020).

Deep learning methods, especially Convolutional Neural Networks (CNNs) and Long Short-Term Memory (LSTM) networks, have emerged as powerful tools for detecting complex fraud patterns. LSTM networks, in particular, are well-suited for handling sequential data and capturing temporal dependencies in transaction records, making them effective for identifying subtle changes that could indicate fraudulent behavior. Moreover, autoencoders and Generative Adversarial Networks (GANs) have been utilized for anomaly detection, where the model learns normal behavior patterns and flags deviations as potential fraud instances (Singh et al., 2022; Tran & Dang, 2021).

Due to fraudulent activities' dynamic nature, adaptive and incremental learning models have gained attention. These models can update themselves continuously with new data, enabling them to detect evolving fraud patterns without requiring frequent retraining from scratch. Techniques such as AdaBoost and Streaming Random Forest have demonstrated effectiveness for real-time fraud detection, balancing accuracy and computational efficiency (Isangediok & Gajamannage, 2022; Tyagi & Mittal, 2020)

Traditional metrics like accuracy are often inadequate to evaluate models effectively in imbalanced data. Alternative metrics such as the Area Under the Precision-Recall Curve (PR-AUC), Matthews Correlation Coefficient (MCC), and F-measure have been recommended for better assessment (Makki et al., 2019; Warghade et al., 2020). Cost-sensitive learning approaches have also been adopted to address the imbalanced nature of the data by assigning different costs to misclassifications, which significantly enhances the model's ability to detect minority class instances (Singh et al., 2022).

Comparative studies on different machine learning algorithms have highlighted the superior performance of ensemble techniques, such as Random Forest and Gradient Boosting, compared to individual classifiers like Decision Trees, Support Vector Machines (SVM), and K-nearest Neighbors (KNN). These ensemble models reduce bias and variance, improving the robustness of fraud detection systems (Awoyemi et al., 2017; Gupta et al., 2023; Warghade et al., 2020).

In addition, transfer learning and domain adaptation approaches have been employed to improve fraud detection by leveraging knowledge from related tasks or domains. With labeled fraud data being scarce, transfer learning allows models trained on large datasets from one domain to be adapted for use in another with minimal labeled data, thus enhancing model generalization capabilities. Techniques such as fine-tuning pre-trained models and using domain-specific regularization have shown promise in this area (Singh et al., 2022; Varmedja et al., 2019).

Lastly, explainability and interpretability become crucial as fraud detection models become more complex. Techniques like Gradient Boosting Decision Trees (GBDT) and SHAP (SHapley Additive exPlanations) provide insights into the contribution of each feature to the final prediction, making the decision-making process more transparent. This transparency is essential for regulatory compliance and building trust in automated fraud detection systems (Isangediok & Gajamannage, 2022; Tran & Dang, 2021).

The existing literature indicates that integrating diverse data preprocessing techniques, sophisticated machine learning algorithms, and interpretability methods can markedly improve the efficacy and robustness of credit card fraud detection systems. This study seeks to consolidate these advancements by developing a comprehensive framework incorporating deep learning approaches, ensemble techniques, and adaptive strategies, thereby addressing the multifaceted challenges of forecasting fraud detection.

Method

Dataset and Preprocessing

The dataset used in this study comprises 284,807, with 31 and a highly imbalanced class distribution. Most data represent non-fraudulent transactions, while a small fraction constitutes fraudulent cases. Due to this imbalance, initial preprocessing steps were necessary to ensure a more balanced dataset and to mitigate the risk of model overfitting. These steps included checking missing values. No null values were detected. Robust scale algorithms were used for the two off-scale variables. The data was divided into training, validation, and test sets with a 20% ratio. FeatureWiz was used as the feature selection method. FeatureWiz is an automated feature engineering and selection tool designed to enhance model accuracy by identifying the most relevant features within a dataset. It employs sophisticated statistical techniques and machine learning algorithms to evaluate the contribution of each feature to the target variable. The process encompasses several key steps: data cleaning and preprocessing to address issues such as missing values and outliers; feature engineering, which involves generating new features through transformations, interactions, and polynomial functions; and feature selection, using methods, LightGBM's feature importance. Additionally, FeatureWiz addresses multicollinearity by detecting and removing highly correlated features, thereby improving the model's interpretability and reducing overfitting. It is particularly effective in handling large and imbalanced datasets, streamlining the feature selection process while maintaining or enhancing predictive performance.

A "Random Under-Sampling" technique was implemented to address the class imbalance, which involved reducing the number of majority class instances to match the minority class. Specifically, the non-fraudulent transactions were down-sampled to 492 cases, equaling the fraudulent cases to achieve a 50/50 ratio. This approach resulted in a balanced sub-sample of the original dataset, with an equal representation of fraud and non-fraud transactions. Following the under-sampling, the data was shuffled to eliminate any potential ordering biases and ensure that the models' performance remained consistent across multiple runs. While random Under-Sampling can effectively address class imbalance, it also carries the drawback of potential information loss.

Machine Learning Models

This study used six machine learning algorithms to detect fraud: CatBoost, LightGBM, XGBoost, Logistic Regression, AdaBoost, and Random Forest. These algorithms were chosen for their demonstrated effectiveness in handling classification tasks, particularly in imbalanced datasets. Each model brings unique strengths to the

problem. CatBoost, a gradient-boosting algorithm based on decision trees, excels in handling categorical data through its native feature encoding and is known for its fast-training speed. LightGBM, another gradient-boosting framework, employs a leaf-wise tree growth strategy, which enhances speed and memory efficiency, particularly with large datasets. XGBoost, also a gradient boosting method, is distinguished by its regularization capabilities and level-wise tree growth, often yielding superior performance in predictive modeling competitions. Logistic Regression, a linear model, was included for its simplicity and utility as a baseline approach for binary classification tasks. AdaBoost, an ensemble learning technique, constructs a strong classifier by iteratively combining multiple weak classifiers, focusing on correcting misclassified samples. Lastly, Random Forest, an ensemble of decision trees, enhances classification performance by aggregating the predictions from numerous trees, thus reducing the likelihood of overfitting. To optimize the performance of each algorithm, hyperparameter tuning was conducted using techniques such as random search to determine the most suitable parameter configurations for the task.

Threshold Optimization, Model Training and Evaluation

In addition to training the models, threshold optimization was applied to enhance the classification performance, especially given the imbalanced nature of the data. The default decision threshold of 0.5 was adjusted to optimize precision, recall, and F1-score metrics. The optimal threshold was determined by evaluating the trade-offs using metrics like the Precision-Recall curve and Area Under the Receiver Operating Characteristic Curve (ROC-AUC), selecting the threshold that provided the best balance for fraud detection.

The models were trained using the training set, with hyperparameter tuning performed on the validation set to identify the optimal configurations for each algorithm. The final evaluation of the models was carried out on the test set, employing various performance metrics to assess their effectiveness. The metrics included accuracy, which measures the overall correctness of the model's predictions, and precision, representing the proportion of true positive predictions out of all predicted positive instances, indicating the accuracy of fraud detection among the predicted cases. Recall, or sensitivity, was used to evaluate the model's ability to identify fraudulent cases, calculated as the ratio of true positive predictions to the total number of fraud cases. The F1-Score, which is the harmonic mean of precision and recall, was considered to provide a balance between these two metrics. Additionally, the ROC-AUC metric was utilized to assess the model's capability to distinguish between fraudulent and non-fraudulent cases, with higher values indicating better discrimination.

Hyperparameter Optimization

To ensure optimal performance for all models, hyperparameter tuning was conducted using techniques such as random search. These methods allowed for an extensive search across various hyperparameter combinations to identify the configurations that yielded the best results for each algorithm. These optimized settings were intended to maximize the predictive capabilities of the models in detecting fraudulent transactions.

Following hyperparameter tuning, a comprehensive comparison and analysis of the models were performed to identify the most effective technique for fraud detection. The evaluation considered the impact of threshold optimization, alongside the influence of hyperparameter tuning, on the models' overall performance. The models were assessed using various metrics, including accuracy, precision, recall, F1-score, and ROC-AUC, to understand their strengths and weaknesses in different scenarios thoroughly. The results were then analyzed to determine which model achieved the best performance, highlighting the conditions under which each algorithm excelled.

Results and Discussion

This study aimed to identify the best methods for achieving accurate results in detecting fraud within highly imbalanced datasets. Various techniques were applied to Kaggle-Credit Card Fraud Detection datasets (https://www.kaggle.com/datasets/mlg-ulb/creditcardfraud), including under-sampling, which incorporates machine learning algorithms such as CatBoost, LightGBM, XGBoost, Logistic Regression, AdaBoost, and Random Forest. These datasets, characterized by a significant class imbalance between fraud and non-fraud instances, necessitate specialized methods to enhance model performance. Examining the distributions provides insight into the degree of skewness in the features, allowing us to assess the balance of the dataset. Additional

distributions of other features offer further insights into potential patterns. In the future, techniques to reduce skewness in these distributions will be applied within this notebook.

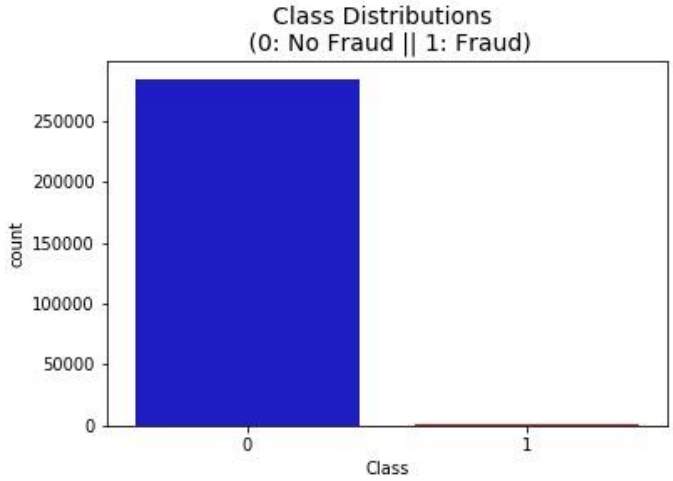

Figure 1. Distribution of Kaggle dataset

Figure 1 shows the distribution of classes in a fraud detection dataset, specifically indicating the imbalance between non-fraud (class 0) and fraud (class 1) transactions. The non-fraud class (0) has a significantly higher count, represented by the large blue bar on the left, while the fraud class (1) has a minimal count, shown as a nearly invisible red bar on the right. This extreme imbalance (where most cases are non-fraud) highlights the challenge in fraud detection, as standard models may struggle to identify the minority (fraud) cases accurately. To address this, methods like resampling or algorithmic adjustments will likely be needed to improve model performance on the minority class.

The variables Amount and Time were scaled using the robust scaling algorithm. The robust scaler algorithm scales data based on the median and interquartile range, specifically to reduce the impact of outliers. This adjustment ensures that outliers in the data distribution do not negatively impact model performance. Next, we balanced the imbalanced data using random under-sampling. This technique reduces the number of instances in the majority class to match the minority class, creating a more balanced dataset for improved model performance on both classes. Figure 2 shows the distribution of classes balanced dataset.

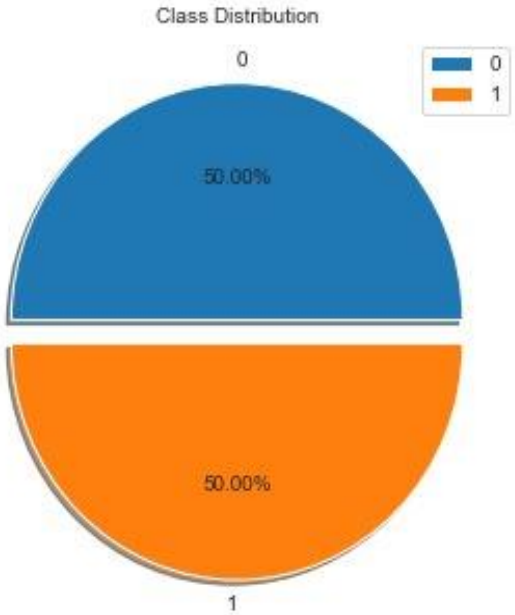

Figure 2. Distribution of balanced dataset

Figure 2 displays a balanced class distribution in the dataset, with both classes (0 for non-fraud and 1 for fraud) representing 50% each. This balanced distribution is likely the result of applying a technique like random under-

sampling to address the initial imbalance. By equalizing the number of instances for both classes, the model is expected to have improved performance in identifying fraud cases without being biased toward the majority (non-fraud) class.

Table 1. Model performance metrics

	Accuracy	Precision	Recall	f1	Roc_Auc
Logistic Regression	0.959391	0.989247	0.929293	0.958333	0.977118
Random Forest	0.944162	0.988889	0.898990	0.941799	0.985003
ADA	0.939086	0.939394	0.939394	0.939394	0.983509
XGBoost	0.923858	0.946809	0.898990	0.922280	0.981653
LightGBM	0.934010	0.957447	0.909091	0.932642	0.987838
CatBoost	0.949239	0.978495	0.919192	0.947917	0.989487

Table 1 presents the performance metrics for six machine learning modelsLogistic Regression, Random Forest, AdaBoost, XGBoost, LightGBM, and CatBoost—evaluated on a fraud detection dataset. Each model's effectiveness is assessed using accuracy, precision, recall, F1-score, and ROC-AUC metrics. These metrics offer a comprehensive view of each model's ability to correctly identify instances of fraud while maintaining a low false positive rate. Using F1-score as the main metric, CatBoost and Logistic Regression stand out as the top-performing models for fraud detection, with F1-scores of 0.947 and 0.953, respectively. These scores indicate their strong balance between precision and recall, making them reliable for identifying fraud without excessive misclassification. Random Forest, AdaBoost, and LightGBM also perform well, though slightly lower, while XGBoost shows a lower F1-score, suggesting it may prioritize precision over recall. Overall, CatBoost and Logistic Regression are this dataset's most effective models for balanced fraud detection.

Since the F1-score was highest for Logistic Regression, threshold optimization was performed on this model. This approach allows for fine-tuning the decision threshold to achieve an optimal balance between precision and recall, further enhancing the model's performance in fraud detection by adjusting it to best capture fraud cases without excessively misclassifying non-fraud instances.

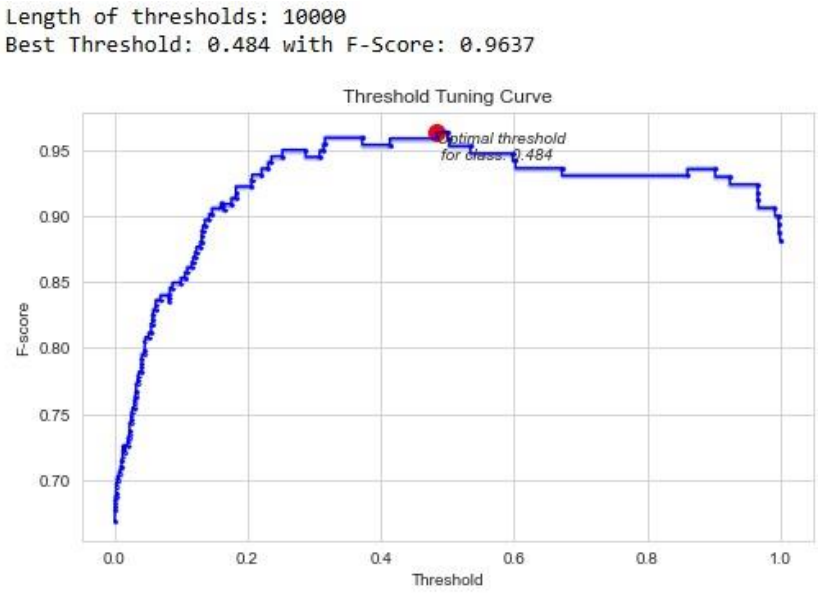

Figure 3. Threshold tunning curve

Figure 3 shows the F1-score for different threshold values, helping identify the optimal threshold for balancing precision and recall in fraud detection. In this case, a threshold of 0.484 achieves the highest F1-score of 0.9637, indicated by the red marker on the curve. This threshold represents the point at which the model best captures fraud cases without over-penalizing non-fraud instances. Lowering or raising the threshold from this optimal point would decrease the F1-score, highlighting the importance of fine-tuning to achieve balanced and effective performance.

Next, feature selection was performed using FeatureWiz, resulting in the selection of 10 variables: ['V14', 'V4', 'V10', 'scaled_amount', 'V19', 'V13', 'V20', 'V21', 'V25', 'V2']. The primary goal of feature selection is to improve the model's score by identifying the most relevant variables; however, in some cases, an increase in

score may not be observed, which is considered normal. This outcome can occur when the removed variables have minimal impact on performance, indicating that the model is already optimized with a smaller, more relevant subset of features.

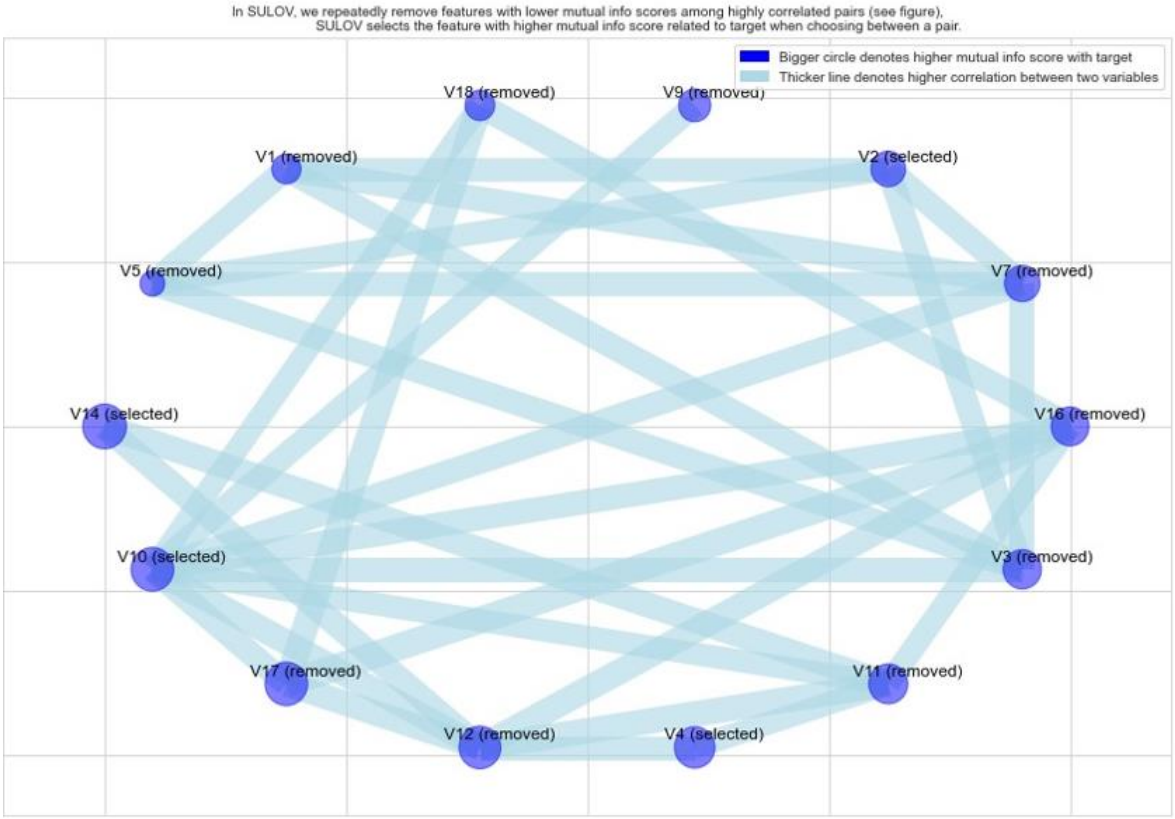

Figure 4. SULOV method for removing highly correlated features

Figure 4 illustrates how the Search for Uncorrelated List of Variables (SULOV) method works by removing highly correlated features. In SULOV, pairs of highly correlated features are compared, and the feature with the lower mutual information score related to the target variable is removed, while the one with the higher score is retained. The larger circles represent features with higher mutual information scores with the target variable, indicating higher relevance. Thicker lines denote stronger correlations between feature pairs, guiding the removal of redundant features. This method helps retain the most informative features and reduce multicollinearity, improving model performance. In this example, features like V4 and V10 are selected, while others like V1, V5, and V18 are removed due to high correlation with selected features.

Table 2. Model performance metrics after feature selection

	Accuracy	**Precision**	**Recall**	**f1**	**Roc_Auc**
Logistic Regression	0.939086	0.978022	0.898990	0.936842	0.985261
Random Forest	0.944162	0.958333	0.929293	0.943590	0.983766
ADA	0.908629	0.926316	0.888889	0.907216	0.974232
XGBoost	0.939086	0.957895	0.919192	0.938144	0.977840
LightGBM	0.923858	0.928571	0.919192	0.923858	0.981550
CatBoost	0.949239	0.958763	0.939394	0.948980	0.989384

After applying feature selection, Table 2 shows the performance metrics for six machine learning models: Logistic Regression, Random Forest, ADA, XGBoost, LightGBM, and CatBoost. The models are evaluated on accuracy, precision, recall, F1-score, and ROC-AUC. Feature selection led to varying impacts on the models' F1-scores. XGBoost and CatBoost showed improved F1 scores, indicating a better balance between precision and recall after reducing features. Random Forest also saw a slight improvement, suggesting it benefitted marginally from feature selection. However, Logistic Regression and ADA experienced a drop in F1-score, indicating that these models may rely on a broader set of features for optimal performance. LightGBM's F1-score slightly decreased, showing a minor impact. Overall, feature selection helped optimize some models,

particularly tree-based methods like XGBoost and CatBoost, but was less beneficial for simpler models like Logistic Regression and ADA.

Threshold optimization was performed again. This step allows further fine-tuning of the decision threshold for each model to enhance the balance between precision and recall after feature selection. Re-optimizing the threshold can help adjust the models to the updated feature set, ensuring optimal performance in detecting fraud cases while minimizing misclassification.

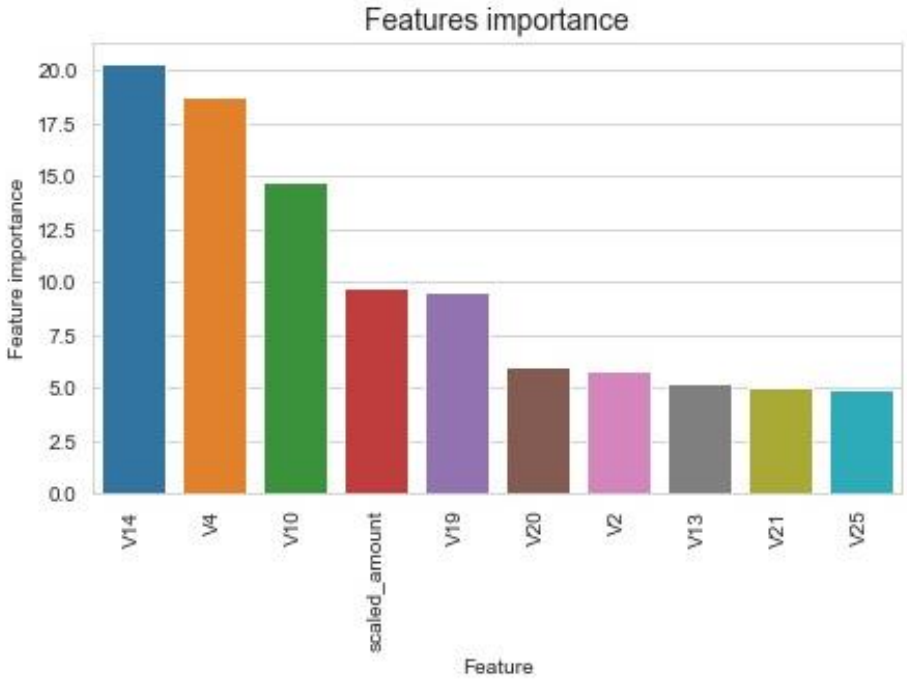

Figure 5. Feature importance

Figure 5 illustrates the relative contribution of each selected variable in predicting fraud cases. The analysis identifies V14, V4, and V10 as the most influential features, with V14 contributing the highest importance, followed closely by V4. These top features are critical in enhancing the model's predictive capacity and distinguishing between fraud and non-fraud cases. scaled_amount and V19 also demonstrate moderate importance, suggesting they provide substantial, though less critical, information for the model. In contrast, features such as V2, V13, V21, and V25 display relatively lower importance, indicating they contribute minimally to the model's performance. This distribution of feature importance suggests that a select group of variables, particularly V14, V4, and V10, serve as the primary predictors in the model, significantly influencing its ability to accurately detect fraud within the dataset.

Table 3. Model performance metrics after hyper parameter

	f1	**Roc_Auc**	**CV Score Mean Before Optimization**	**CV Score Mean After Optimization**
Logistic Regression	0.958333	0.979180	0.9397	0.9409
Random Forest	0.918033	0.983509	0.9309	0.9239
ADA	0.936170	0.988868	0.9207	0.9302
XGBoost	0.938144	0.984642	0.9349	0.9449
LightGBM	0.938776	0.986601	0.9306	0.9402
CatBoost	0.947917	0.987941	0.9374	0.9377

Further hyperparameter optimization was conducted; however, the results indicate no significant improvement compared to the previous table. The F1-score, ROC-AUC, and cross-validation (CV) score remains largely unchanged across models, suggesting that the initial settings were already close to optimal for this dataset. This outcome implies that additional tuning of hyperparameters did not yield substantial performance gains, and the models may have reached their maximum efficiency given the current feature set and data characteristics.

Conclusion

This study evaluated various machine learning techniques for fraud detection within a highly imbalanced dataset. Logistic Regression, Random Forest, AdaBoost, XGBoost, LightGBM, and CatBoost were analyzed through feature selection, hyperparameter tuning, and threshold optimization to enhance performance. CatBoost and Logistic Regression emerged as the top-performing models, exhibiting strong F1-scores, indicative of their effective balance between precision and recall. However, further hyperparameter tuning yielded minimal improvements, suggesting that the initial configurations were near-optimal. The study underscores the importance of tailored feature selection and threshold tuning in handling class imbalances, though certain models may reach performance limits even with optimization.

Recommendations

Future research should explore hybrid models combining multiple techniques, such as ensemble and deep learning, to adapt to evolving fraud patterns. Additionally, incorporating real-time incremental learning could enhance the models' adaptability to dynamic fraud behaviors. Investigating advanced data augmentation methods, such as synthetic sample generation, may improve the models' ability to handle imbalanced datasets. Finally, explainability tools like SHAP could be integrated to enhance model interpretability, allowing for better regulatory compliance and trust in automated fraud detection systems.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

Acknowledgements or Notes

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An Analysis Comparing the Performance of Wind Energy Conversion Systems Utilising FLC Controllers

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Abstract: This research gives a comparative analysis of Proportional-Integral (PI) and Fuzzy Logic Control (FLC) controllers for control systems of wind energy conversion systems (WECS). The PI controller is a conventional control technique that is extensively employed due to its simplicity and efficacy in regulating system behaviour through the adjustment of proportional and integral gains. FLC, on the other hand, utilises language rules and fuzzy logic reasoning to imitate human decision-making processes, providing a flexible and adaptable control strategy. The selection between PI and fuzzy controllers is dependent on the particular demands and limitations of the control application. The comparison study evaluates the performance of PI and Fuzzy controllers in various control scenarios, specifically in the scenario of speed control of cascaded doubly fed induction generator (CDFIG). Wind energy conversion systems consist of CDFIG connected to the grid via a matrix converter or rectifier and inverter. This study will present numerical simulation results conducted using the MATLAB/Simulink program to demonstrate the feasibility and efficacy of the proposed control technique

Keywords: Fuzzy logic control, Wind energy, Cascaded doubly fed induction generator, Power converter

Introduction

The employment of approaches that are based on artificial intelligence in the management of the energy that is produced by wind turbines is becoming more than essential in today's world due to the complexity of the control of these turbines and the intermittent nature of the wind. Fuzzy logic is one of these new methods that we have discovered. The use of fuzzy logic allows for more accurate regulation of wind turbine power by taking into account variables that are uncertain or imprecise, such as the speed and direction of the wind and the changing weather conditions. In comparison to conventional controls, it enables adjustments to be made to the rotation speeds or blade angles in a more smooth and effective manner (Nasrullo, et al., 2022; Aghaloo et al., 2023)

Pitch angle control and dynamic vibration absorbers are incorporated into (Jiawei et al., 2024), in order to enhance the performance of wind turbines in environments that are challenging. For the purpose of controlling a variable-speed wind energy conversion system (WECS), the primary focus of this study in (Dendouga & Essounbouli, 2022) is on the research and design of a type-2 fuzzy logic controller (T2-FLC). Under these circumstances, the maximum power point tracking (MPPT) method has been implemented in order to collect the maximum amount of power that is available from the wind system, despite the fact that the wind conditions

have been changing (Maafa, 2024). Significant research has been done about fuzzy controllers, but, a noticeable absence of comparison with other controllers to derive conclusions is evident. Therefore, this work aims to address this gap.

Comparing a conventional controller (PI) with an intelligent controller (FLC) is the objective of this work. The purpose of this comparison is to identify the most suitable control method for more effectively managing the generation of wind energy. The majority of wind turbines are equipped with a double fed induction generator (DFIG), which enables the generation of electrical energy at varying speeds. However, the existence of the ring-brush system diminishes the dependability of the machine. In order to address this issue, our proposal includes the electrical and mechanical coupling of two DFIGs through their rotors. The entire system is referred to as a cascade of asynchronous machines, often known as CDFIG (Maafa, 2016, 2022, 2024).

Description and Modelling of the CDFIG

The cascaded doubly fed induction machine (CDFIM) is a system that comprises two induction machines, each with a different number of pole-pairs (p1 and p2), coupled in a cascade configuration (Maafa et al,. 2023), (Hossain et al., 2023; Dauksha et al., 2020). The technology utilises two successive induction machines to avoid the need for brushes and copper rings in the conventional Doubly Fed Induction Machine (DFIM). The coupling is illustrated in Figure 1. There are two potential configurations for the rotor connections of both DFIMs. The connection of the same phases results in a direct connection, while the reverse order of two phases results in an opposite connection. Each coupling type of the CDFIM has distinct advantages. For direct connection, these include the elimination of copper contacts and brushes, power segmentation, and improved reliability. For a reverse connection, there is a represented rise in the number of paired poles, resulting in the elimination of the copper rings and brushes that make contact. For the rest of our study, we will focus on the inverse relationship.

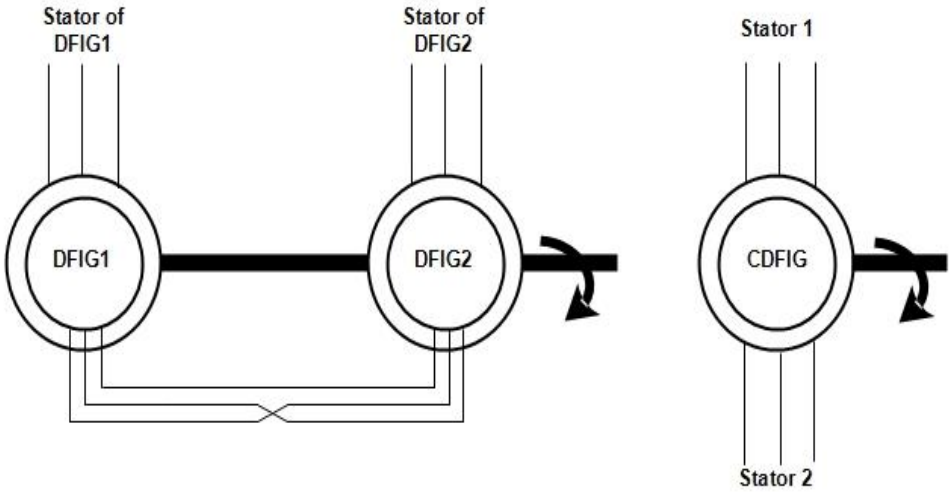


Figure 1. The mechanical and electrical coupling of two (DFIGs)

In the Park frame, all equations are written in a frame of reference that is related to the rotating field. The following equations can be used to determine the voltage and flux of the two DFIGs:

- The DFIG 1:

$$\begin{cases} v_{ds1} = R_{s1} i_{ds1} + \dfrac{d}{dt}\varphi_{ds1} - \omega_s \varphi_{qs1} \\ v_{qs1} = R_{s1} i_{qs1} + \dfrac{d}{dt}\varphi_{qs1} + \omega_s \varphi_{ds1} \\ v_{dr1} = R_{r1} i_{dr1} + \dfrac{d}{dt}\varphi_{dr1} - (\omega_s - \omega_{r1})\varphi_{qr1} \\ v_{qr1} = R_{r1} i_{qr1} + \dfrac{d}{dt}\varphi_{qr1} + (\omega_s - \omega_{r1})\varphi_{dr1} \end{cases} \quad (1)$$

-The DFIG 2:

$$\begin{cases} v_{dr2} = R_{r2} i_{dr2} + \dfrac{d}{dt}\varphi_{dr2} - (\omega_s - \omega_{r1})\varphi_{qr2} \\ v_{qr2} = R_{r2} i_{qr2} + \dfrac{d}{dt}\varphi_{qr2} + (\omega_s - \omega_{r1})\varphi_{dr2} \\ v_{ds2} = R_{s2} i_{ds2} + \dfrac{d}{dt}\varphi_{ds2} - (\omega_s - \omega_{r1} - \omega_{r2})\varphi_{qs2} \\ v_{qs2} = R_{s2} i_{qs2} + \dfrac{d}{dt}\varphi_{qs2} + (\omega_s - \omega_{r1} - \omega_{r2})\varphi_{ds2} \end{cases} \quad (2)$$

The flux of stators and rotors in a CDFIG may be mathematically represented as:

$$\begin{cases} \Phi_{ds1} = L_{s1} i_{ds1} + L_{m1} i_{dr} \\ \Phi_{qs1} = L_{s1} i_{qs1} + L_{m1} i_{qr} \\ \Phi_{dr1} = L_{r1} i_{dr} + L_{m1} i_{ds1} \\ \Phi_{qr1} = L_{r1} i_{qr} + L_{m1} i_{qs1} \end{cases} \quad (3) \text{ and } \begin{cases} \Phi_{ds2} = L_{s2} i_{ds2} - L_{m2} i_{dr} \\ \Phi_{qs2} = L_{s2} i_{qs2} - L_{m2} i_{qr} \\ \Phi_{dr2} = -L_{r2} i_{dr} + L_{m2} i_{ds2} \\ \Phi_{qr2} = -L_{r2} i_{qr} + L_{m2} i_{qs2} \end{cases} \quad (4)$$

Electric coupling between the two rotors is represented by the following model:

$$\begin{cases} v_{dr1} = v_{dr2} = v_{dr} \\ v_{qr1} = v_{qr2} = v_{qr} \end{cases} \quad (5) \text{ and } \begin{cases} i_{dr1} = -i_{dr2} = i_{dr} \\ i_{qr1} = -i_{qr2} = i_{qr} \end{cases} \quad (6)$$

The structure of the interconnections between the rotor circuits is designed in such a way that it is possible to add up the torques of each machines:

$$T_e = p_1 . L_{m1} \left(i_{dr} . i_{qs1} - i_{ds1} . i_{qr} \right) + p_2 . L_{m2} \left(i_{dr} . i_{qs2} - i_{ds2} . i_{qr} \right) \quad (7)$$

Through the process of aligning the axis d of the mark (dq) with the flux of the first stator ϕs1, the model that is obtained from CDFIG is achieved through simplification.

$$\begin{cases} \varphi_{ds1} = \varphi_{s1} \\ \varphi_{qs1} = 0 \end{cases} \quad (8)$$

The voltages can be automatically represented by the rotor currents in the following manner:

$$\begin{cases} v_{ds2} = R_{s2} i_{ds2} + (L_{s2} - C.L_{m2}) \dfrac{di_{ds2}}{dt} - s.\omega_s (L_{s2} - C.L_{m2}) i_{qs2} \\ v_{qs2} = R_{s2} i_{qs2} + (L_{s2} - C.L_{m2}) \dfrac{di_{qs2}}{dt} + s.\omega_s (L_{s2} - C.L_{m2}) i_{ds2} + s. \dfrac{L_{m1} V_s}{L_{s1}} \end{cases} \quad (9)$$

The two-phase components of the voltages of the second stator that are to be forced on the machine in order to generate the ids2 and iqs2 currents that are needed are expressed as vds2 and vqs2, respectively.

It is possible to regulate the powers of stator 1 by manipulating the currents of stator 2 using the following equation system:

$$\begin{cases} P_{s1} = -C.V_s \dfrac{L_{m1}}{L_{s1}} i_{qs2} \\ Q_{s1} = \dfrac{V_s^2}{\omega_s . L_{s1}} \left(1 + \dfrac{C.L_{m1}^2}{L_{s1} . L_{m2}} \right) - C.V_s \dfrac{L_{m1}}{L_{s1}} i_{ds2} \end{cases} \quad (10)$$

$$\text{With: } s = \frac{\omega_s - (p_1 + p_2)\Omega_r}{\omega_s} \quad \text{and} \quad C = \frac{L_{m2}}{L_{r1} + L_{r2} - \frac{L_{m1}^2}{L_{s1}}}$$

Control Method of the CDFIG

PI Controller

Regulation of wind power systems using proportional-integral has been the subject of a significant number of papers that have been published in the academic literature (Yessef et al, 2024; Preeti et al, 2024; Ramirez-Cabrera et al., 2024). Figure 2 depicts the closed loop system, which is then rectified by a PI controller. The form of the transfer function of the PI controller is as follows:

$$G_{PI}(S) = k_p + \frac{k_i}{S}$$

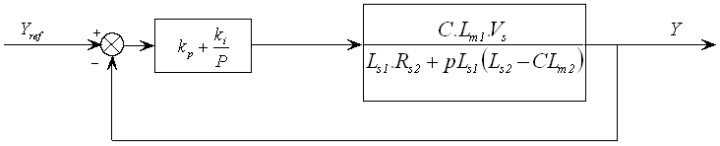


Figure 2. Design of PI controller

The response time of the system is around ten milliseconds, which is a sufficient amount of time for its application on wind turbines, which are characterized by moderate wind fluctuations and considerable mechanical time constants. Lowering the value may not boost overall performance, but it could potentially produce in disturbances during transient scenarios, resulting in undesirable exceeds its and instabilities. It is evident that the pole compensation approach is not the only appropriate way for the synthesis of the PI controller; however, we chose to utilize it because of its speed in this particular instance.

FLC Controller

In control systems when it is difficult or impossible to develop exact mathematical models, fuzzy controllers are employed. Their foundation is in fuzzy logic, a methodology capable of managing uncertainty and imprecision by employing truth values that are not binary "true" or "false", but rather degrees of truth. A significant number of academic papers have been published on the FLC controller (Kumbasar, 2016; Rubaai & Jerry, 2014; Nethaji & Kathirvelan, 2024; Majid, et al., 2023; Mukesh & Pradipta, 2024).

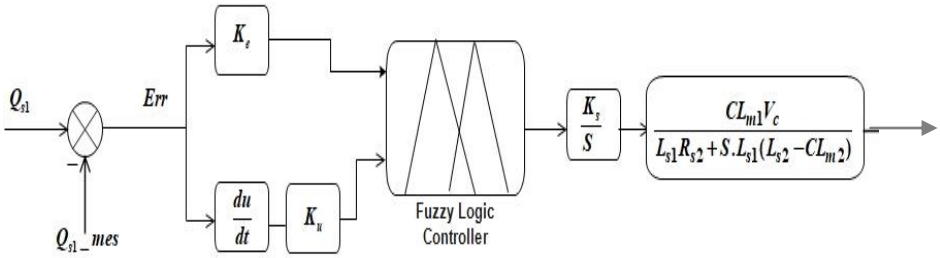
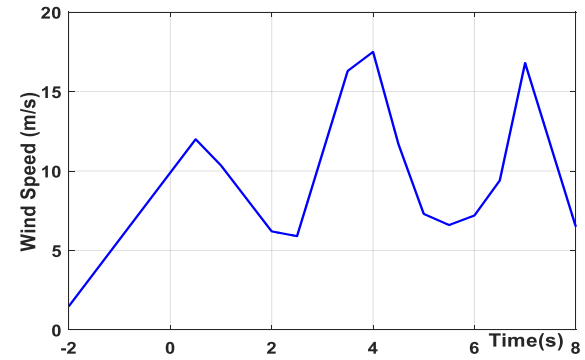


Figure 3. Design of fuzzy logic controller

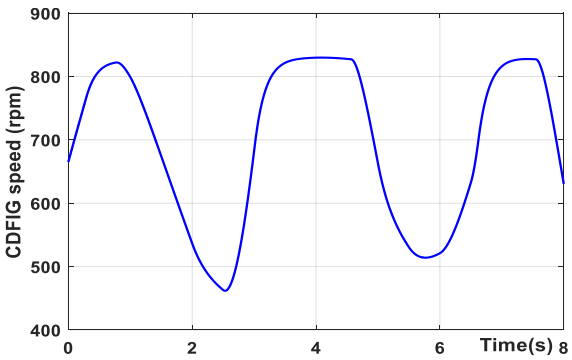
In order for a fuzzy controller to produce accurate results, it must undergo four stages: input fuzzying, rule base application, inference to integrate rule results, and defuzzification.

Results and Discussion

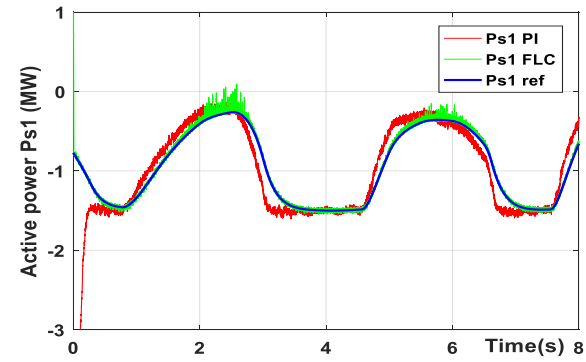
The goal of this part is to look at how the regulators (PI and FLC) responds to changes in the wind speed. We will use active power reference steps to compare the answers from the controls. Figure 4 shows how this test turned out.



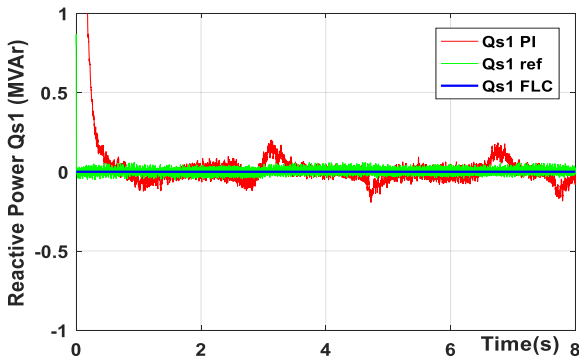
(a)



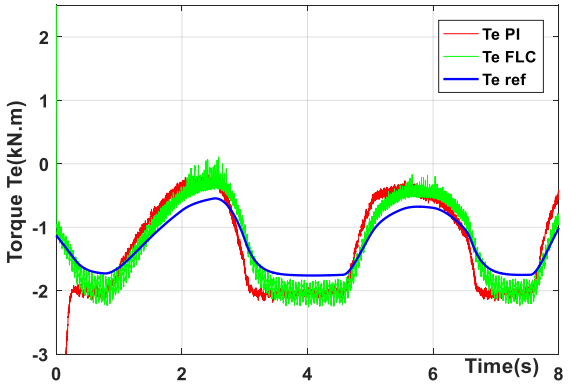
(b)



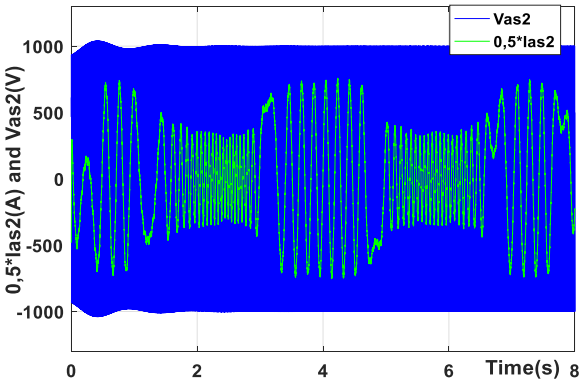
(c)



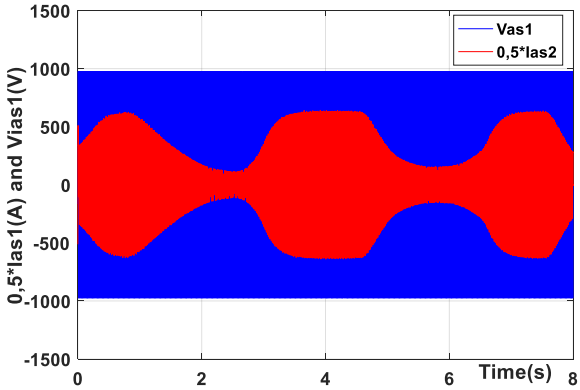
(d)



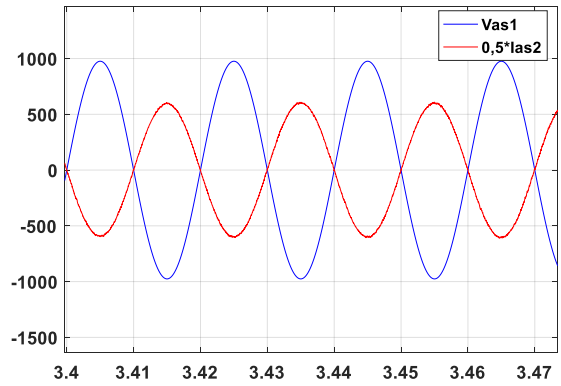
(e)



(f)



(g)



(h)

In Figure 4.a, the wind speed that was applied to the CDFIG is displayed. The speed of the wind is selected at random. The speed obtained by the CDFIG is depicted in Figure 4.b. We have observed that it is limited to a particular variation in wind speeds. The active power, reference, PI controller, and fuzzy controller of the first stator are each displayed in Figure 4.c, respectively.

The results show that the active power using the FLC controller is better compared to those of the PI controller in terms of tracking and disturbance rejection. When compared to the results obtained by the PI controller, the reactive power of stator 2 as shown in Figure 4.d for the FLC controller is in perfect accordance with its reference. A representation of the torque of the CDFIG is shown in Figure 4.e, together with the torque of reference, the torque of the PI controller, and the torque of the FLC controller. When compared to its reference, the torque of the FLC controller is the best.

An illustration of the voltage and current that are produced by the second stator may be found in Figure 4.f. Both the current and voltage of the first stator are depicted in Figures 4g and 4.h, respectively, along with their zoom. In order to demonstrate that the first stator is always the source of supply for the electrical network, it is important to take note that the current and the voltage are in phase opposition.

Conclusion

The management of power generated by wind turbines is increasingly utilizing approaches derived from artificial intelligence. The use of fuzzy controllers is a technique that may be utilized to solve problems that emerge during the process of injecting energy into the electrical network. One of the challenges that is discussed in this article is the process of selecting a controller that will satisfy the requirements that have been put by the electrical network management.

Through an analysis of the simulation data, it is evident that the performance of a fuzzy controller in terms of tracking and disturbance rejection is significantly better to that of a PI controller. Based on this, we can ultimately deduce the following conclusion: The introduction of a fuzzy controller enhances the efficiency of the system. By eliminating sliding ring-brush contacts, CDFIG offers a viable alternative for wind energy generation.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

Acknowledgements or Notes

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Diagnosis of the Effect of Steel Fiber on the Mechanical Properties of Cement Mortars

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Abstract: The reinforcement of cement-based materials by fibers has currently become an interesting solution in order to improve their qualities and their structural resistance. In fact, there are several types of fibers, differing according to their origins, such as polymer, metallic or ceramics. This study aims to examine in particular, the effect of the addition of steel (metallic) fibers on the mechanical properties of cement-based mortars. For this, an experimental approach described in this work was followed in order to achieve this objective. The fibers were introduced into the mixture during mixing with varying percentages from 0.4 to 3% of the cement mass, and the mechanical strengths (Tensile and compressive) were measured. The results showed that the introduction of steel fibers into a mortar gives compressive and tensile strength results higher than those of control mortars, and that the best percentages in terms of resistance and economy are between 0, 7 and 1.9% of the mass of cement. Indeed, we recorded an increase in compressive strength ranging from 15% to 54% (up to approximately 70 MPa) and an increase in tensile strength ranging from 29 to 57% (up to approximately 10 MPa). The addition of fiber therefore makes it possible to increase the resistance of the mortar specimens and the appearance of cracks without rupture or destruction in the case of the bending test in comparison with ordinary mortars specimens

Keywords: Concrete, Mortar, Steel fibers, Tension, Compression.

Introduction

Concrete is widely used in construction, however, we known to have low tensile strength, low stiffness, low ductility, low energy of absorption of deformation, combined with brittle behavior which results in sudden rupture by pulling without warning (Altun et al.,2007; Pesaran et al.,2011; Kiranbala et al.,2013; Joshi et al.,2016; Saand et al.,2016; Saqib et al.,2020), moreover, when the concrete is hardened, shrinkage cracks appear on its surface, which limit its applications (Frazão et al.,2013; Saand et al., 2016).

The concrete then requires some form of tensile reinforcement to compensate for its brittle behavior and improve its tensile strength and deformability (Belmahi et al., 2018a; Belmahi et al., 2019), therefore, to improve these deficiencies in concrete, a daily variety of fibrous materials such as straw, long wood fibers, steel fibers, plastic, glass and other natural materials are now used in concrete for better structural and service applications (Katzer, 2006; Pesaran et al., 2011; Frazão et al., 2013; Saand et al., 2016).

Unlike conventional rebars, which are specifically designed and placed in the tensile zone of the concrete member, the fibers are thin, short and randomly distributed throughout the concrete member (Pesaran et al., 2011). Their role is to fill the cracks that develop, provide a certain "ductility" post-cracking, allow the FRC to withstand significant stresses on a relatively large deformation capacity translated by a considerable increase in the total energy absorbed, an increase fatigue strength, flexural strength, shear strength and impact strength, improved durability and increased concrete toughness, it also increases the workability of concrete (Altun et al., 2007; Frazão et al., 2013; Kiranbala et al., 2013; Velayutham et al., 2014; Bazgir, 2016; Joshi et al., 2016; Saqib et al., 2020; Muhammad et al., 2022).

The work developed in this study consists in diagnosis the effect of the addition of steel fibers on the mechanical properties of the mortars in particular the tensile strength and the compressive strength as well as determining the ideal fiber dosages. For this, an experimental approach described below was followed in order to achieve this objective

Method

Materials

Cement: The cement used is a CEM II / A-L composite cement with a resistance of 42.5 N, manufactured at the AMOUDA factory in "EL BAYDHA" Laghouat, Algeria. It is gray cement in accordance with the Algerian standard NA 442 as well as the European standard EN 197 -1 (Table1). It is used for reinforced concrete works, self-compacting concrete, paving, industrial floors, screeds, foundations, underground works and concrete roads and pavements.

Table 1. Chemical and physico-mechanical properties of cement.

Chemical properties AN 5042 (EN 196-2)	Physico-mechanical properties AN 230 (en 196-3) / AN 234 (EN 196-1)	
S03 ≤ 3.5% chloride ≤ 0.1%	Setting time > 60 min	Compressive strength 2 jours>10 Mpa 28 jours > 42.5 Mpa

Sand: The sand used is natural sand, from the quarry of El Galta Laghouat, its characteristics are as follows: Apparent density (1450 Kg/m3), absolute (2500 Kg/m3), particle size class 0/3 and the sand equivalent equal to 78% (it is a clean sand with a low proportion of fine clay which is perfectly suitable for high quality concrete) The results are in line with the work of Belmahi et al. (2018b, 2021).

Adjuvant: the adjuvant used is MEDAFLOW 145. It is a high water-reducing super plasticizer from the new generation of adjuvants. It is designed based on modified polyether carboxylates and it makes it possible to obtain very high quality concretes and mortars. Its recommended dosage range is 0.3 to 2.0% of the weight of cement, i.e. 0.33L to 1.8L per 100 kg of cement. It is accordance with the Algerian standard NA 774 as well as the European standard EN 934-2 (Table 2).

Table 2. Characteristics of the adjuvant used EN 934-2 & AN 774

stat	Color	PH	Density	chloride content
liquid	brown	5-6	1.065	<1g/l

Steel fibers: the steel fibers used are from the FIBERTEK brand of the Hassnaoui GSH group which are obtained by cold drawing high-strength steel wire with special shaping to obtain the best anchorage over their entire length. FIBERTEK-A fibers are intended for structural reinforcement. It makes it possible to obtain concrete and mortar with high resistance to shocks and vibrations and to concentrated loads. The uniform distribution of fibers in the mixture makes it possible to use FIBERTEK to replace secondary reinforcement and containment of crack propagation.The characteristics of the steel fibers are summarized in the table 3.

Table 3. Characteristics of the steel fibers used (FIBERTEK A).

Longueur (mm)[1]	Diamètre fil (mm)[2]	Rapport d'aspect (1/2)	Format	Section transversale	Tension à la rupture à la traction (N/mm²):	Allongement à la rupture
50 ± 10 %	1 ± 10 %	(L/de) 50	à crochet	circulaire	1100-2700	< 4 %

Procedure

The mortars made are of the 1/2 type (the mass of the sand is equal to twice the mass of the CEM II /A-L cement with a resistance of 42.5 N) mixed with water and an admixture. The specimens produced are prismatic specimens of dimension (4×4×16) cm3. To achieve the objective of the study, we made in the first step a reference mortar (without additions) whose quantity of water and admixture were adjusted experimentally in order to obtain a normal consistency (table 1). Subsequently, we introduced the quantity of steel fibers weighed directly into the mixer (at the time of mixing with the other ingredients). The problem may lie in the formation of sea urchins (or fiber balls), due to the fact that the fibers naturally tend to agglomerate during mixing as a result of reciprocal friction. So, this phenomenon to be avoided during this step. The compositions selected are summarized in Table 4.

Table 4. Mortars compositions.

Mortars	Cement (g)	Sand (g)	E/C	adjuvant %	Steel Fiber %
Witness	675	1350	0,35	0,7	**0,00**
1	675	1350	0,35	0,7	**0,40**
2	675	1350	0,35	0,7	**0,70**
3	675	1350	0,35	0,7	**1,10**
4	675	1350	0,35	0,7	**1,50**
5	675	1350	0,35	0,7	**1,90**
6	675	1350	0,35	0,7	**2,20**
7	675	1350	0,35	0,7	**2,60**
8	675	1350	0,35	0,7	**3,00**

The mortars are made according to the requirements of the Algerian standard NA442 and the European standard EN 197-1 (mixing, filling and packaging).

Results and Discussion

After 28 days of storage and hardening of the specimens, they were subjected to mechanical bending and compression tests using machines according to the standards (NA 234, EN 12615 and EN 1015-11). The results obtained are summarized in Table 5.

Table 5. Results of mechanical tests

Steel fiber		Tensile strength (MPa)	Compressive strength (MPa)
(g)	**%**		
0	0	6,32	44,23
2,5	0,4	9,36	55,78
5	0,7	9,48	65,00
7,5	1,1	9,95	68,17
10	1,5	9,83	68,32
12,5	1,9	9,13	61,56
15	2,2	8,93	59,42
17,5	2,6	8,78	55,61
20	3,0	8,19	51,10

According to the results above, we have generally observed good mechanical strength, all the values are higher than that of the control mortar: Compressive strengths between 51 and 68 MPa (Figure 1), which corresponds to an increase of approximately 15 to 54% compared to the control mortar and tensile strengths of between 8.18 and 9.95 MPa (Figure 2), which corresponds to an increase of 29 to 57% compared to the control mortar. It should be noted that all the results obtained in this study are good. compared to the results of the standard or ordinary mortar. Thus, the best steel fiber dosages taking into account the resistance and the manufacturing costs are between 0.7 and 1.9% of the cement mass. We have observed through experience that the steel fibers reinforce the cohesion of the mortar. Thus, after applying a tensile force to a sample of ordinary mortar, it splits into two parts as shown in Figure 3 while the steel fiber reinforced mortar breaks and the two parts remain

connected and bound together by the steel fibers as shown in Figure 4, which improves stability and safety during the post-crack phase.

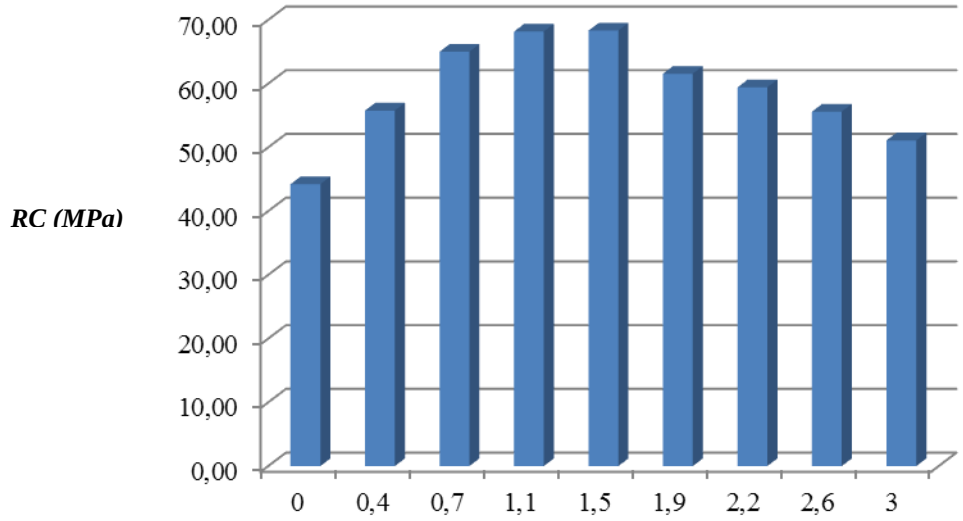

Figure 1. Compressive strength (MPa).

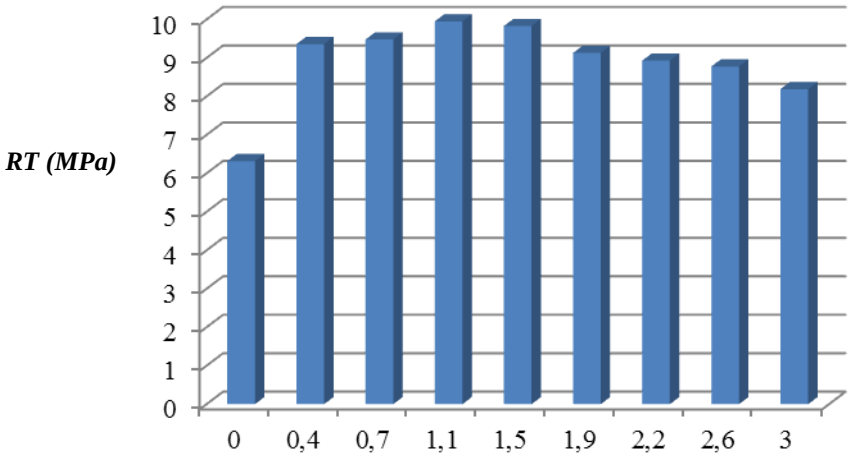

Figure 2. Tensile strength (MPa).

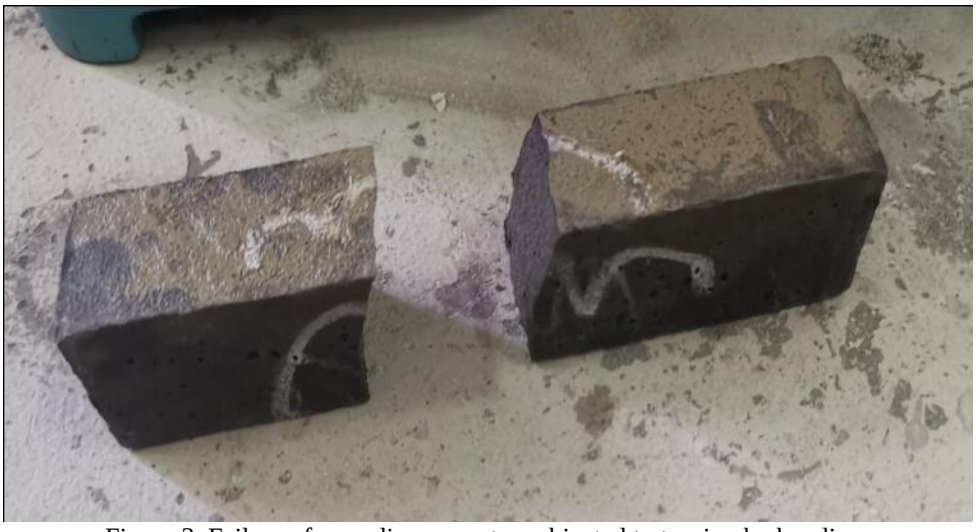

Figure 3. Failure of an ordinary mortar subjected to tension by bending.

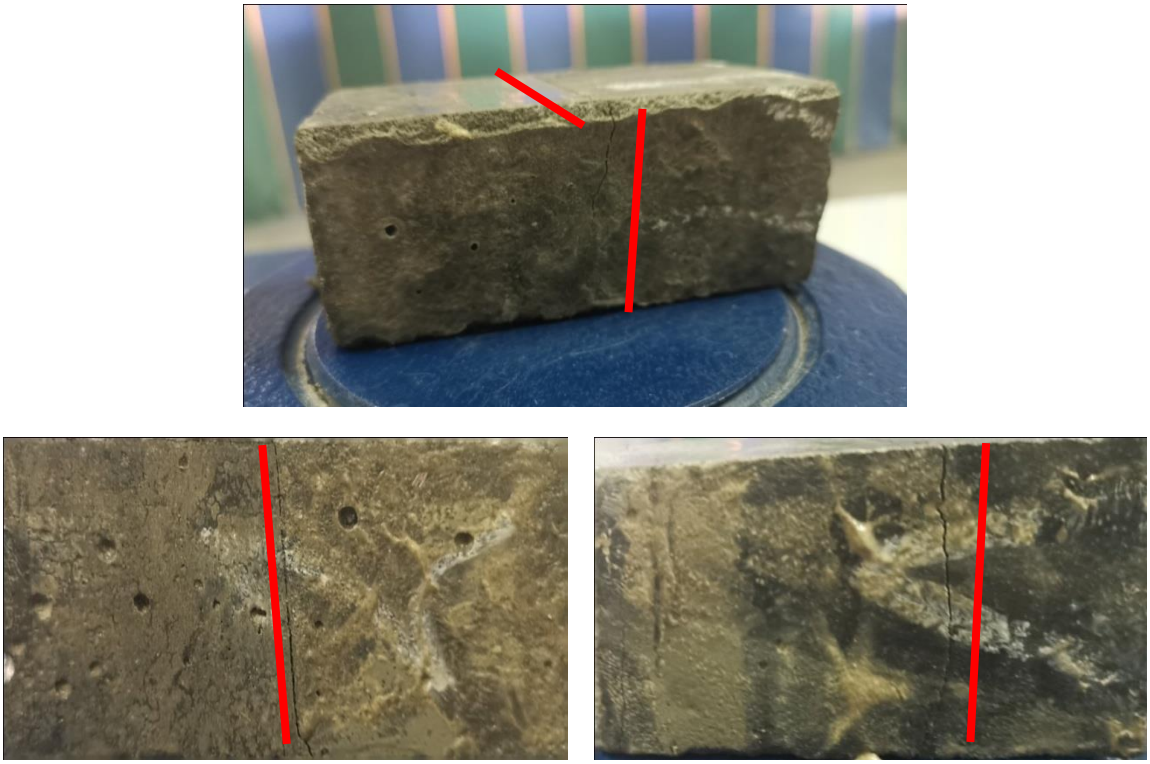

Figure 4. Failure of a mortar reinforced with steel fibers subjected to tension by bending.

Conclusion

The mechanical properties were improved during the post-crack phase translated by an increase in ductility and will be generated on the durability of the mortar following the absorption of the applied stresses. We can also say that fibers help reduce or eliminate the need in traditional reinforcing steels. Also in terms of dosage we conclude that an excessive dosage of fiber is not always the right choice. The fractions proposed in this work have proven that the latter must be between 0.7 and 1.9% of the mass of cement, therefore the methods of introducing metal fibers into the mixture are very important and depend on the volume of the concrete. , implementation and expected objectives. A study can be carried out and compared to this work; the fibers are introduced manually and in layers when filling the concrete or mortar into the molds or into the formwork instead of putting them directly into the mixer. This method can give better homogeneity and completely avoid the formation of sea urchins (or fiber balls).

Recommendations

The results of this work are highly recommended for reinforcement and repair work on elements of reinforced concrete structures.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

Acknowledgements or Notes

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Determination of Battery Capacity and Type in Electric Wheel Loader Machines Considering Variable Operating Conditions

Mustafa Karahan
Hidromek

Abstract: In recent years, the development and production of fully electric battery vehicles have become increasingly common in the construction equipment sector. Conventional construction machines with diesel internal combustion engines are losing popularity in city centers with high human density due to the harmful gases and high noise levels emitted into the environment. In some developed countries, the use of conventional machines has already been prohibited in some areas, and it is reflected in the media that other administrations have been concentrating on similar activities. In addition to easy access to charging stations in city centers, charging systems that can provide high power, especially in construction sites where machines operate, and charging the machines within a particular area makes charging more practical than passenger vehicles. The machines have multiple consumers, such as the powertrain and hydraulic systems, and have various operating conditions. Therefore, the power demand and energy consumption should be definite correctly. The requirement analysis for the battery package of the fully electric wheel loader has been made according to various operating scenarios, and the capacity of the battery package is investigated. Different battery types are compared, and their pros and cons are explained. Several field tests, measurements, and engineering calculations have provided data. The overall schematic plan of the fully electric machine has been created, and technical details have been explained.

Keywords: Battery electric wheel loader, Battery requirement analysis, Battery types, Energy requirement analysis, Electrification of construction machinery.

Introduction

The electrification of earth-moving and material-handling machines is one of the most significant and effective ways of reducing carbon emissions without compromising performance. The experience from electric commercial vehicles like buses and trucks can be utilized to develop electric construction machines. Determining battery capacity and type is one of the most crucial steps of an electrification project in the construction machinery sector. Power demand and energy consumption are variable in construction machines and vehicles, which are different from on-road vehicles. In machines, such as wheel loaders, the power is transferred from the diesel engine to the transmission with torque converters, 70% of the energy taken from the engine flywheel is converted into useful work, and the remaining part is thrown into the atmosphere as heat. There is no need for low-efficient powertrain elements such as torque converters for construction machinery driven by electric motors. Electric motors can connect to powertrains directly without any hydro-dynamic clutch. Besides, the regenerative energy recovered from the brake system can be stored in the battery package, which is a remarkable benefit for wheel loaders.

Wheel Loaders as Construction Machinery

Wheel loaders are machines that load gravel, earth, sand, rock, etc., and carry from one place to another or a truck by a front bucket in construction fields or industrial facilities. They are called according to the bucket

- Selection and peer-review under responsibility of the Organizing Committee of the Conference

volume and the working weight. Engines or electric motors drive the powertrain and the pumps of hydraulic systems. The most common operation conditions are V/Y cycle, stockpiling, grading, load and carry, etc.

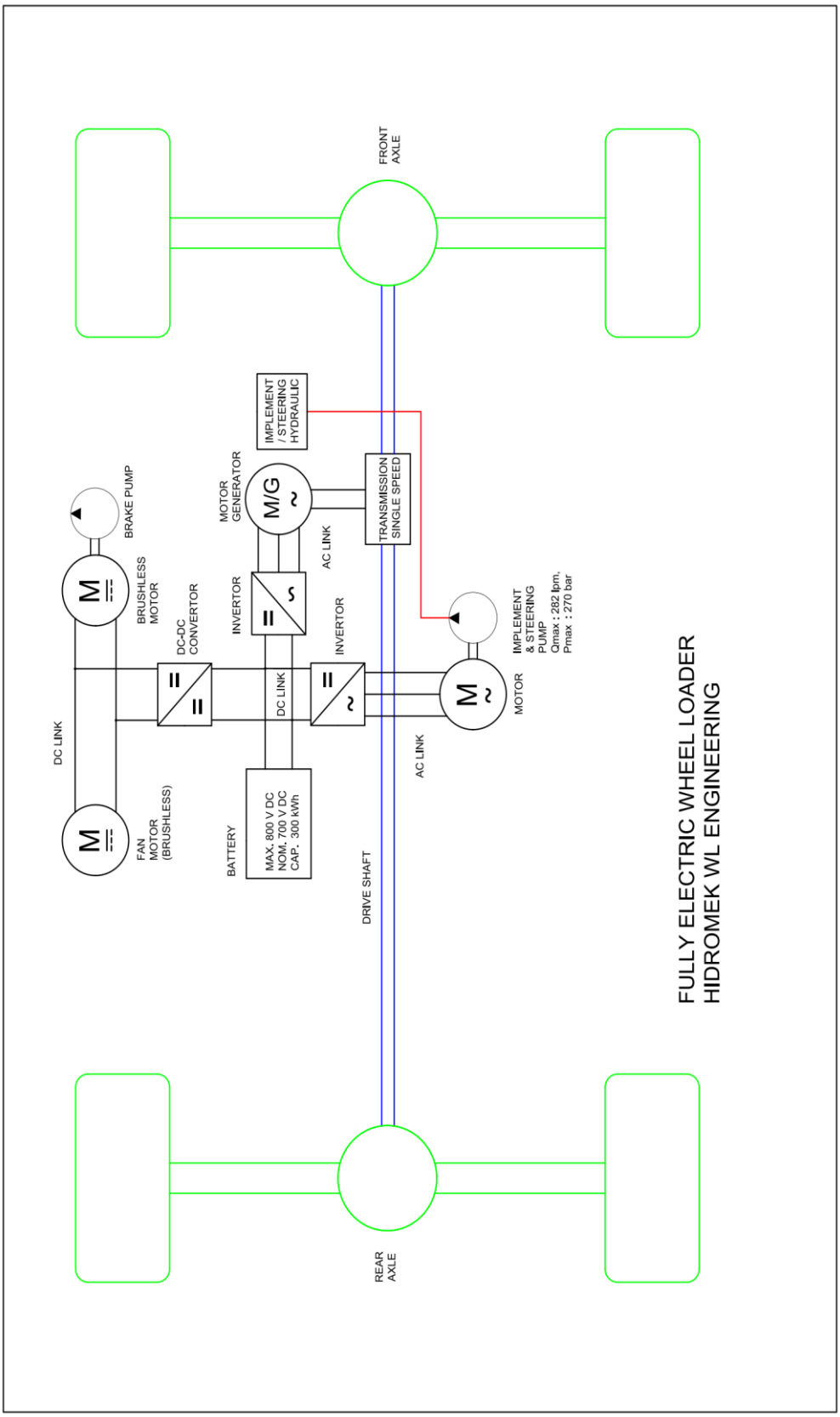

Figure 1. The overall layout of the electric wheel loader

Overall Layout of the Electric Wheel Loader

The electric wheel loader mentioned in this study consists of a powertrain, hydraulic systems, work equipment, cooling system, battery packages, power distribution unit, etc. The powertrain and hydraulic systems have separate electric motors. This provides several advantages, such as high efficiency and performance, better controllability, etc. The electric motors of the powertrain drive the single-speed transmission. The hydraulic systems, including the implement and steering hydraulics, are powered by a separate electric motor. The inverters of the electric motors convert D.C. to A.C. and control the motors. The battery package stores the electric energy and provides it to all the systems. The overall layout of the machine is shown in Figure 1.

Determination of Battery Capacity

Several parameters determine the battery capacity of wheel loaders. These are average energy consumption, power demand, required minimum working hours per shift and between breaks, working environment, ambient temperature, room for batteries, etc. First, it is necessary to define the operating conditions by considering the average energy consumption and power demand.

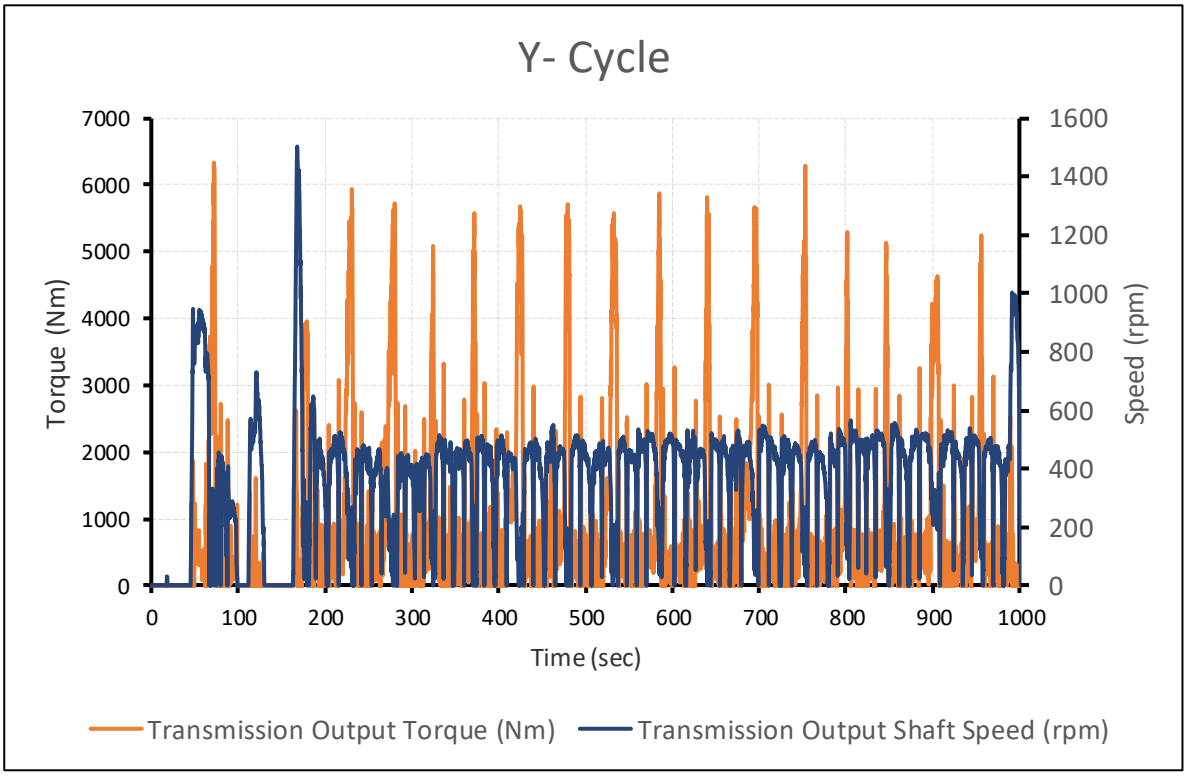

Figure 2. Y-cycle test data of the traction

The main approach to determining the battery capacity is taking into account the working hours of a shift and the duration between breaks. Wheel loaders generally run 8-9 hours a shift. After operators work 4,5-5 hours, they have a one-hour break like a lunch break. The wheel loader tested for this study has a 19-ton working weight and 3.2 m^3 bucket volume. Y-cycle test data of the traction is shown in Figure 2. The power has been calculated by the torque and speed values. The flow rate and pressure values of the Y-cycle are shown in Figure 3. The power of the hydraulic system was calculated using the flow rate and pressure values (7) (8). The energy value was calculated based on the power and time.

According to the test data, including Y-cycle, stockpiling, grading, and load & carry, the machine consumes an average of 40 kWh of energy under various operating conditions per hour. However, when heavy-duty conditions and very cold or high ambient temperatures are taken into account, the average energy consumption rises to 48 kWh. The better assumption is to consider the machine's high energy consumption conditions. For a 5-hour working duration, the total consumption equals 240 kWh, which defines the energy consumption from the beginning of the shift to the break. For high performance and long battery life, it is recommended not to

discharge batteries not less than 20% of the whole capacity. Therefore, the total capacity of the battery package is determined to be 300 kWh. The total capacity can be higher than 300 kWh. However, one of the critical parameters is the overall cost of the machine. The initial investment cost is quite significant when we look at the customer demands. Meanwhile, one challenging point for this kind of mobile machine is placing the battery packages in the machine. From the point of maneuverability, extending the machine length to create more space for the batteries is not a perfect idea. Not only the battery energy capacity but also the D.C. voltage level of the battery package is quite essential. Maximum and nominal voltage levels must be compatible with other electric components, such as motors, inverters, etc., fed by the batteries.

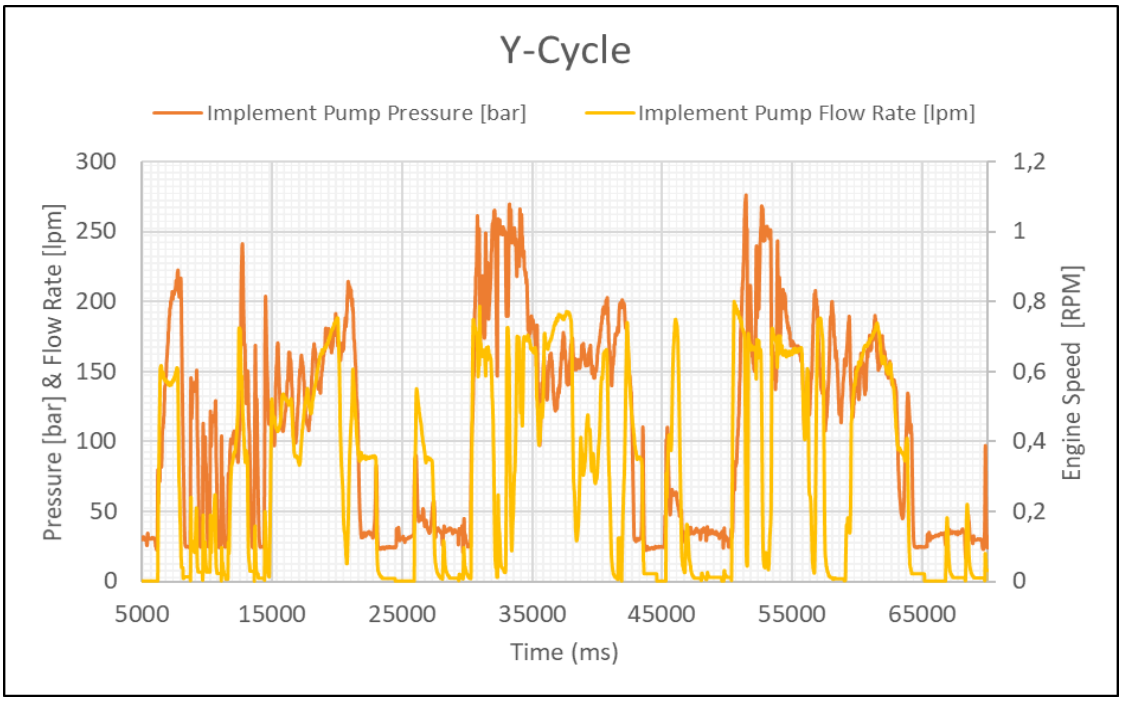

Figure 3. Y-cycle test data of the hydraulic system

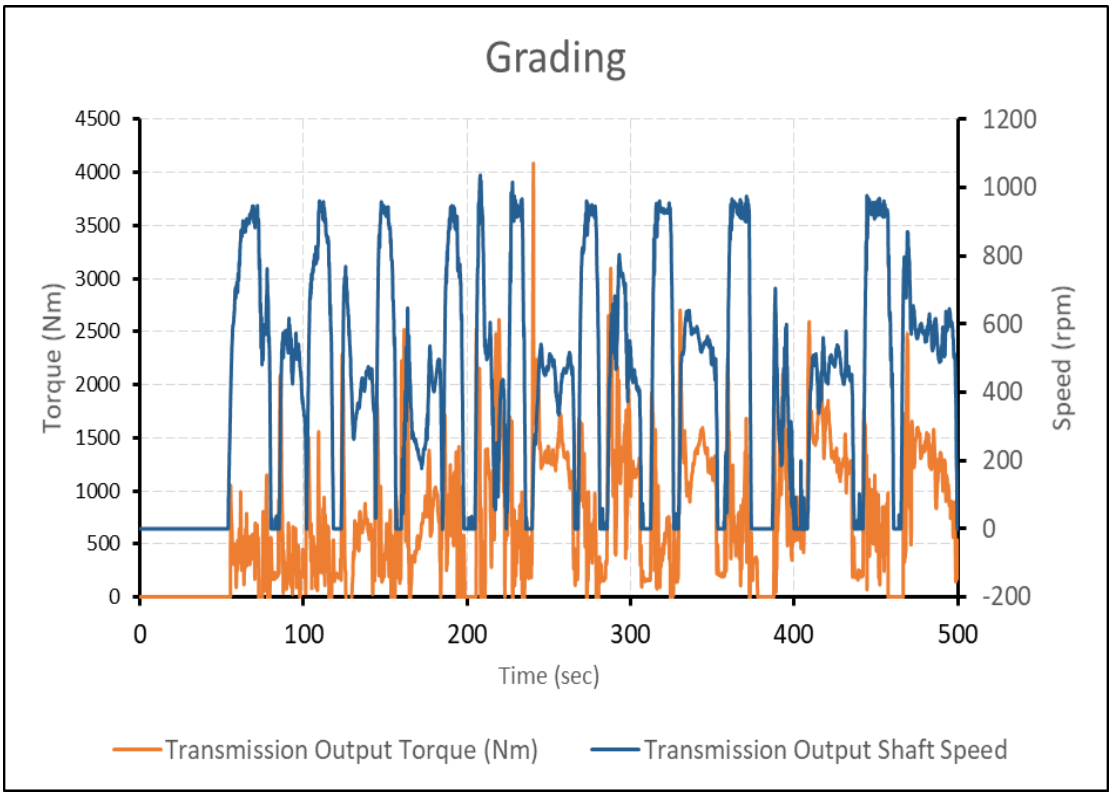

Figure 4. Grading test data of the traction

Calculation of Powertrain Traction Force and Power

When the machine travels, the traction electric motors work against the friction between the tire and the ground (rolling), gravity, and air resistance. The motors' torque and power are determined by considering the total resistance. In the calculations, it is seen that air friction resistance (4) can be neglected in construction equipment and similar vehicles due to low speed. The total resistance $R_{.T.}$ (1) is calculated as follows:

$$R_{.T.} = R_g + R_r + R_a \quad [N] \tag{1}$$

$$R_g = W_{.T.} \times g \times \sin \Theta \quad [N] \tag{2}$$

$$R_r = W_T \times g \times \cos \Theta \times F_r \quad [N] \tag{3}$$

$$R_a = \frac{1}{2} \times \rho \times C_D \times A_f \times V^2 \quad [N] \tag{4}$$

R_T : Total Resistance [N]
R_g : Gradient resistance [N]
R_r : Rolling resistance [N]
F_r : Rolling resistance coefficient
R_a : Aerodynamic resistance [N]
$W_{.T.}$: Vehicle gross weight [kg]
g : Gravity [m/sn^2]
ρ : Air density 1,225 kg/m^3 (at sea level and 15°)
C_D : Air drag coefficient
A_f : Projected area [m^2]
V : Vehicle speed [m/sn]
Θ : Ramp angle [degree]

The traction force (5) must be greater than the total resistance (1) for the vehicle to accelerate under definite driving conditions. The batteries must be capable of providing the power and current requirements. Battery discharge rate designates the power and current capacity. Calculating the traction force and power is quite significant in deciding the battery type and capacity, which designates the machine's climbing and excavation penetration ability.

$$F_t = \frac{T_M \times I_T \times I_A \times \eta_T \times \eta_A \times \eta_S}{R_W} \quad [N] \tag{5}$$

$$P_{TM} = \frac{F_t \times V}{1000 \times \eta_T \times \eta_A \times \eta_S} \quad [kW] \tag{6}$$

T_M : Motor torque [Nm]
F_t : Traction force [N]
η_T : Transmission efficiency
η_A : Axle efficiency
η_S : Drive shaft efficiency
$R_{.W.}$: Wheel radius [m]
$I_{.T.}$: Transmission gear ratio
I_A : Axle gear ratio
P_{TM} : Transmission motor power [kW]
V : Vehicle speed [m/sn]

Hydraulic Power and Torque Calculation

The power (7), (8), and torque calculation (9) must be carried out to determine the power demand and energy requirement of the hydraulic systems.

$$P_P = \frac{Q \times \Delta P}{600 \times \eta_{PT}} \quad [kW] \tag{7}$$

$$P_P = \frac{V\ x\ n\ x\ \eta_V\ x\ \Delta P}{1000\ x\ 600\ x\ \eta_{PT}} \quad [kW] \tag{8}$$

$$T_P = \frac{V\ x\ \Delta P}{20\ x\ \pi\ x\ \eta_{HM}} \quad [Nm] \tag{9}$$

$P_{.P.}$: Pump power [kW]
ΔP : Differential pressure [bar]
$Q_{.F.}$: Flow rate [lt/dk]
V : Displacement [cm^3]
$T_{.P.}$: Torque [Nm]
η_{HM} : Hydraulic-mechanical efficiency
η_{PT} : Total efficiency
η_V : Volumetric efficiency
n : Rotational speed

Determination of Battery Type

Battery type plays a crucial role in the Electrification of construction machinery. The factors determining the battery type are energy density, cycle life, cost-effectiveness, safety, charge and discharge C-Rate, thermal stability, temperature range, etc. In this study, the three most likely battery types have been inspected. These are NMC, LFP, and LTO. In the previous section, the battery capacity has been decided to be 300 kWh, which is one of the constraints. From the performance point of view, LTO batteries seem the best option, which also have the best cycle life. However, they cannot be applicable easily in terms of the energy density. Since the package size is 300 kWh, the LTO battery does not fit the room of the energy storage section in the machine.

Besides, the cost of the LTO battery option is too high for this fully electric wheel loader. When compared NMC to LFP, NMC batteries look like more advantageous with regards to energy density, temperature range, and discharge C-Rate. However, in terms of cost-effectiveness, thermal stability, cycle life, and safety, NMC batteries are not the best option. As for LFP batteries, they need more room and cannot run with high performance at low ambient temperatures. Inspection of the vehicle platform is required in detail. For example, the answer to how much room is available for the battery package is significant. The package size of the LFP option seems to fit the separate room. The ambient temperature range of the machine varies from -30° to 50° C, which is improper for LFP batteries. Thus, if the machine has a versatile thermal management system that includes heating up and cooling down the batteries, LPF can be the optimum battery type for this electric vehicle. Besides, in the market, these kinds of machines are expected to have at least 15.000 hours lifespan, ideally 20.000 hours. The LFP battery package with a 5-hour discharging time and an average 4.000-cycle life will meet customer expectations. The comparison of the Batteries is shown in Table 1.

Table 1. Comparison of the batteries

	NMC	**LPF**	**LTO**
Chemistry	Nickel Manganese Cobalt	Lithium Iron Phosphate	Lithium Titanium Oxide
Energy Density (Wh/L)	High	Moderate	low
Cycle Life	1.000-3.000	2.000-6.000	6.000-over 10.000
Cost Effectiveness	Moderate	High	Very Low
Safety	Moderate	High	Very High
Charge C-Rate	1C	1C	1C-5C
Discharge C-Rate	1C-2C	1C	10C
Thermal Stability	Moderate	High	Very High
Temperature Range	Good	Moderate	Very Good

Conclusions and Recommendations

It has been defined and investigated wheel loaders' working scenarios. The overall layout of the fully electric wheel loader has been created and described. Energy consumption and power requirements have been determined by evaluating the various cases like V-cycle, grading, stockpiling, and load & carry. The typical working hour and break duration for charging have been explained. Traction and hydraulic system calculations

have been described. The battery type and capacity of the machine are determined. The battery types, NMC, LPF, and LTO, have been compared, and their pros and cons and which battery type is ideal have been explained for this electrification case study, explained. Thermal management of battery packages significantly changes the performance and cycle life of batteries. Therefore, establishing a versatile thermal management system of battery packages is essential for this kind of construction machinery.

Due to some unfavorable aspects of LTO batteries, such as low energy density and high cost, it cannot be the best option for a fully electric wheel loader. However, for hybrid electric wheel loaders, LTO batteries are one of the best solutions. NCM batteries seem a good solution, but it may not meet the lifespan of the machine. Because of the high cost, it cannot satisfy the end-user when the replacement time comes. LFP batteries can be one of the optimal solutions for this platform with perfect thermal management.

Scientific Ethics Declaration

The author declares that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the author.

Acknowledgements or Notes

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Intelligent Traffic Lights Control System: Riyadh City

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Abstract: Traffic congestion is one of the main problems facing Riyadh city's growth, which results in significant environmental pollution and makes transportation difficult. These factors not only generate material losses but also make daily living difficult for people. The principal reasons of traffic congestion in Riyadh include, but are not limited to, the rapid growth of the population. By 2030, the Kingdom of Saudi Arabia aims to have a population of 50-60 million, which will make traffic congestion worse if preventive measures are not taken. The development of an intelligent traffic lights control system is one strategy to address traffic issues. The purpose of traffic lights is to efficiently control vehicle traffic at intersections. These traffic signals typically operate in a preset order based on a fixed cycle period. Due to this design, vehicles on one side of the road must wait even while there are no automobiles on the other, making them intrinsically unable to effectively regulate traffic flow during atypical conditions. As a result, it becomes necessary to simulate traffic control algorithms in order to reduce the amount of stops, vehicle delays, etc. There is a chance to create a system that will meet these needs with fuzzy logic. We use fuzzy logic toolbox in MATLAB to design the intelligent traffic lights control system for an isolated traffic junction.

Keywords: Traffic lights controller, Fuzzy logic, Extension time

Introduction

Fuzzy mathematics can be considered as an extension of classical logical systems. Fuzzy logic offers an effective conceptual framework for addressing the challenge of knowledge representation in an uncertain and imprecise context as it mimics human reasoning, this conceptual leap boosts mathematics' usefulness and expands its applications (Ande, 1996).

Around the world, one of the biggest issues with modern cities is traffic congestion. Traffic congestion is a major cause of many difficulties and obstacles. Traveling between locations becomes more challenging due to the abundance of cars in crowded cities. People waste time, miss chances, and get disappointed as a result of these traffic issues. Companies are directly impacted by overcrowding. As a result, employee productivity declines, opportunities are wasted, deliveries are delayed, and costs continue to climb (Chabchoub et al., 2021). Therefore, one of the most critical issues that must be fixed in order to boost any nation’s economy is traffic congestion. In Riyadh city, the principal reasons of traffic congestion include, but are not limited to the rapid growth of the population. By 2030, the Kingdom of Saudi Arabia aims to have a population of 50 - 60 million, with Riyadh’s maximum population of 25 million (SABQ, 2022), which will make traffic congestion worse if preventive measures are not taken.

The development of an intelligent traffic lights control system is one strategy to address traffic issues. Conventional methods for traffic light control based precise models failed to deal efficiently with the complex and varying traffic situations. They were modeled based on the fixed cycle time to change the signal without any

analysis of traffic situation. Due to this design, vehicles on one side of the road must wait even while there are no automobiles on the other, making them intrinsically unable to effectively regulate traffic flow during atypical conditions (Alam et al., 2013). Therefore, even with the advancement of technology, traffic police officers are still assigned to areas of congestion in order to boost flow rates by using their cognitive abilities. Due to its ability to translate traffic police officers' methods of managing traffic lights into mathematical models and algorithms, fuzzy logic based traffic light control algorithms are essential for improving traffic flow management in urban areas and enabling drivers to engage with their environment in a cooperative and intelligent manner. In light of these benefits, our goal is to use fuzzy logic technology to design an intelligent traffic light control system for isolated intersections that can adapt to the traffic demands of Riyadh city. Numerous scholars have tried to apply fuzzy logic to traffic control in the past. Pappis and Mamdani made an early attempt to use fuzzy logic to traffic control, showing that it could be applied to specific traffic intersections (Alam et al., 2013; Pappis et al., 1977).

Algorithms of Traffic Light Controller

The following are two common strategies employed for controlling traffic lights (Omina, 2015; Salehi et al., 2014; United States Department of Transportation, 2021):

1. Fixed-time signal control algorithm:

This kind of control does not analyze the traffic condition; instead, it changes the traffic lights based on a predetermined cycle period. Fixed-time control offers a number of benefits. Since the start and finish of green light are predictable, it can be utilized, for instance, to offer effective coordination with nearby fixed-timed signals. Its operation is also resistant to issues related to detector failure because it does not require detectors. Lastly, setting it up and keeping it running just takes a minimal bit of training. On the other hand, fixed-timed control is ineffective at isolated intersections where traffic arrivals are random and is unable to account for unplanned fluctuations in traffic flows.

2. Real-time signal control algorithm:

This control integrates proximity sensors, which have the ability to trigger a change in the cycle time or the lights, with a predefined cycle time. Proximity sensors will cause a change in light when cars are present on a roadway with less traffic, which may not require a regular cycle of green lights. Real-time signal control algorithm is more flexible to real-world traffic conditions because it utilizes data acquired by detectors. Based on a set of rules and the state of the traffic, a decision is taken about signal control.

We will concentrate on the use of fuzzy logic controllers in traffic light systems that use sensors that count vehicles, as opposed to proximity sensors, which simply detect the presence of vehicles. The number of cars waiting in each direction determines how the traffic lights should adjust their signaling patterns. This enables a better evaluation of shifting traffic patterns by giving the controller information about traffic concentrations in the lanes.

Fuzzy Logic Control System

Here, we may demonstrate a fundamental setup for fuzzy logic control. Figure 1 illustrates how the fuzzy logic control operations can be broken down into three main stages (Javatpoint, n.d.; Priy, 2023):

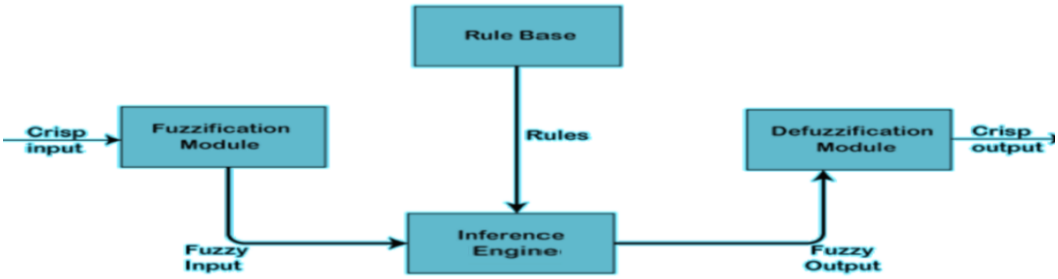

Figure 1. Process of a fuzzy logic control system

Fuzzification is a component for transforming the system inputs, i.e., it translates accurate crisp input values into linguistic variables. The crisp numbers are those exact inputs measured by sensors and then fuzzification passed them into the control systems for further processing.

Fuzzy Inference Engine is the key component of the fuzzy system. To accomplish the primary goal of issue solving, it uses fuzzy or approximate inference to mimic human thought processes and decision-making styles. It utilizes the "IF-THEN" rules as a basis to determine the optimal course of action for any given circumstance and infers the fuzzy outcome from fuzzified inputs. The fuzzy IF-THEN rules are the rule base that includes all relevant input-output combinations created by the user to suggest a mathematical link between them. The rule connects an output or conclusion to a condition given by fuzzy sets and linguistic variables. The "IF" section is mostly used to record knowledge using elastic conditions, and the "THEN" section can be used to deliver the conclusion or output in the form of a linguistic variable. Based on human knowledge or experience, the legislation to establish a set of fuzzy IF-THEN rules depends on each specific application.

Defuzzification is the final phase in the fuzzy logic controller process, which is simply the process of turning the conclusions produced by the fuzzy inference engine into crisp values. To make the conclusion or fuzzy output applicable to real-world applications, this procedure is necessary. A variety of defuzzification techniques exist, and the most appropriate one is employed in conjunction with a particular expert system to minimize error.

Fuzzy Logic Traffic Light Controller

For the isolated 4-lane traffic intersection (north, south, east, and west), a fuzzy logic controller will be constructed using fuzzy logic toolbox in MATLAB. The amount of traffic on the arrival side (Arrival), the amount of traffic on the queuing side (Queue) and the range of visibility during driving (visibility) are the traffic lights controller fuzzy input variables. In the event when both the north and south are green, they are regarded as the arrival side and the west and east as the queuing side, and vice versa. The length of time required for the arrival side green light (Extension) would be the fuzzy output variable, as seen in Figure 2. Therefore, fuzzy rules can be created based on the current traffic conditions to determine whether or not the fuzzy controller's output will extend the present green light time.

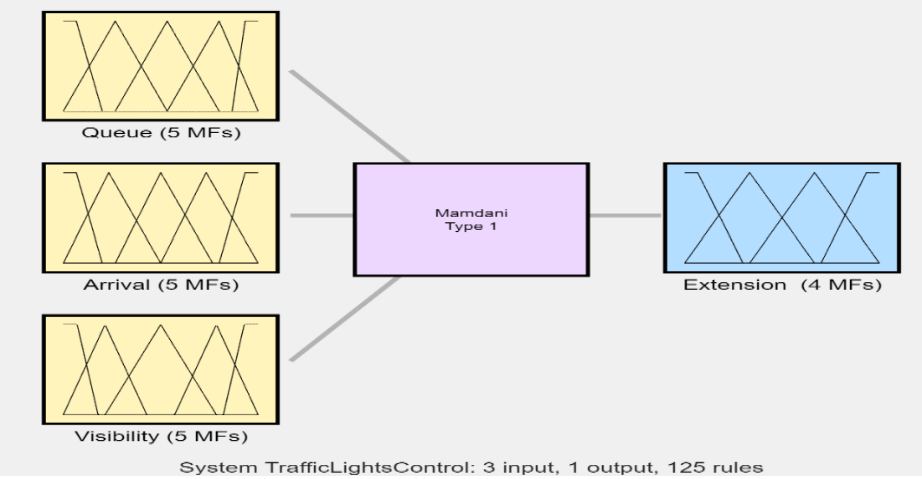

Figure 2. Fuzzy inference system

Membership Functions

Queue (Input)

The membership function of the linguistic variables of Queue is presented in Table 1. It can be observed that there are five linguistic variables: very short, short, medium, long, and very long. As seen in Figure 3, the y-axis of the graphical representation of the membership functions of the linguistic variables of Queue is the degree of its membership and the x-axis is the number of Queue of vehicles. The range of this input variable is selected from 0 to 15 vehicles.

Table 1. Queue membership function description

Fuzzy Set	Membership Function Type	Parameters
Very Short	Trapezoidal	[-1 0 1 3]
Short	Triangular	[0 4 8]
Medium	Triangular	[4 8 12]
Long	Triangular	[8 12 15]
Very Long	Trapezoidal	[13 14 15 20]

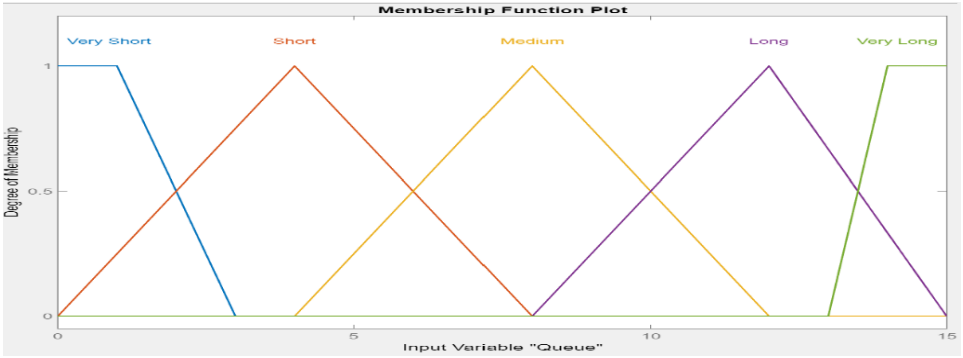

Figure 3. Queue membership function plot

Arrival (Input)

The linguistic variables of arrival input variable are very few, few, average, many and too many. Its values range from 0 to 30 vehicles, as seen in Figure 4.

Table 2. Arrival membership function description

Fuzzy Set	Membership Function Type	Parameters
Very Few	Trapezoidal	[-1 0 2 6]
Few	Triangular	[0 7 15]
Average	Triangular	[8 15 23]
Many	Triangular	[15 22 30]
Too Many	Trapezoidal	[24 28 30 35]

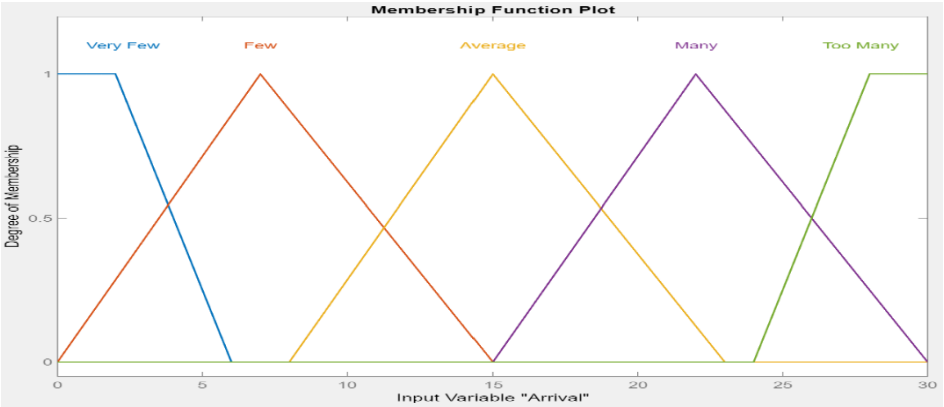

Figure 4. Arrival membership function plot

Visibility (Input)

Due to Saudi Arabia's arid geographical location, dust storm is meteorological phenomenon common in Riyadh, and it peak in the summertime in particular. It goes without saying that it is risky to drive during a sandstorm since the thick dust decreases visibility, which causes cars to be driven much more slowly and eventually causes a build-up of vehicles. For Visibility input variable the x-axis is the visibility range in meters that ranges from 100 to 1500 meters. Its linguistic variables are very high, high, medium, low, and very low.

Table 3. Visibility membership function description

Fuzzy Set	Membership Function Type	Parameters
Very Low	Trapezoidal	[0 100 200 350]
Low	Triangular	[100 400 700]
Medium	Triangular	[400 800 1200]
High	Triangular	[900 1200 1500]
Very High	Trapezoidal	[1250 1400 1500 1600]

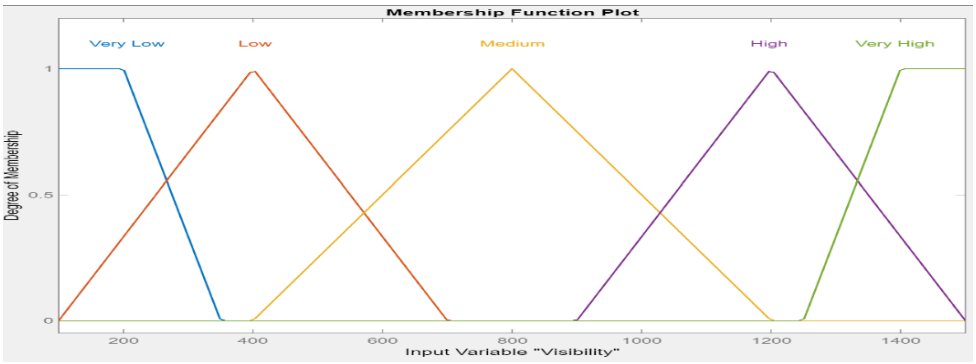

Figure 5. Visibility membership function plot

Extension (Output)

The extension time of the green light in seconds is the output variable of the proposed fuzzy controller, and it will be determined by four linguistic variables: zero, short, medium, and large. It ranges between 0 and 30 seconds.

Table 4. Extension membership function description

Fuzzy Set	Membership Function Type	Parameters
Zero	Trapezoidal	[0 0 2 9]
Short	Triangular	[0 10 20]
Medium	Triangular	[10 20 30]
Large	Trapezoidal	[21 28 30 30]

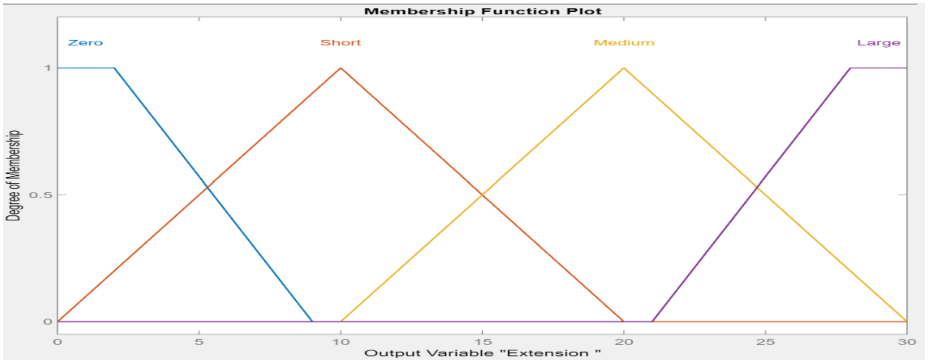

Figure 6. Extension membership function plot

Fuzzy Rules Analysis

Humans create rules to carry out whatever activity they undertake. For instance, if there were a traffic cop on duty at a junction, one from the north and one from the west, he would employ his professional judgment to essentially manage traffic in the following ways: Permit traffic from the north to flow through the city for a longer period of time if it is heavier than traffic from the west. The fuzzy logic controller's inference mechanism and this human cognitive process are comparable. In the development of the fuzzy logic controller, we use almost similar rules and below are some examples:

• If there are too many vehicles at the arrival side and the queue of vehicles is very short at the queuing side and the visibility is medium, then extend the green light longer.
• If there are very few of vehicles at the arrival side and the queue of vehicles is very short at the queuing side and the visibility is very high, then do not extend the green light.

The number of rules can be calculated by multiplying the number of membership functions per input. On the basis of three input variables there are 125 fuzzy rules. Some rules are indicated in Figure 7.

	Rule
1	If Queue is Very Short and Arrival is Very Few and Visibility is Very High then Extension is Zero
2	If Queue is Very Short and Arrival is Very Few and Visibility is High then Extension is Zero
3	If Queue is Very Short and Arrival is Very Few and Visibility is Medium then Extension is Zero
4	If Queue is Very Short and Arrival is Very Few and Visibility is Low then Extension is Short
5	If Queue is Very Short and Arrival is Very Few and Visibility is Very Low then Extension is Medium
6	If Queue is Very Short and Arrival is Few and Visibility is Very High then Extension is Zero
7	If Queue is Very Short and Arrival is Few and Visibility is High then Extension is Zero
8	If Queue is Very Short and Arrival is Few and Visibility is Medium then Extension is Short
9	If Queue is Very Short and Arrival is Few and Visibility is Low then Extension is Medium
10	If Queue is Very Short and Arrival is Few and Visibility is Very Low then Extension is Medium
11	If Queue is Very Short and Arrival is Average and Visibility is Very High then Extension is Short
12	If Queue is Very Short and Arrival is Average and Visibility is High then Extension is Short
13	If Queue is Very Short and Arrival is Average and Visibility is Medium then Extension is Medium
14	If Queue is Very Short and Arrival is Average and Visibility is Low then Extension is Medium
15	If Queue is Very Short and Arrival is Average and Visibility is Very Low then Extension is Large
16	If Queue is Very Short and Arrival is Many and Visibility is Very High then Extension is Medium
17	If Queue is Very Short and Arrival is Many and Visibility is High then Extension is Medium
18	If Queue is Very Short and Arrival is Many and Visibility is Medium then Extension is Large
19	If Queue is Very Short and Arrival is Many and Visibility is Low then Extension is Large

Figure 7. Rule base editor

According to Figure 8, as the Arrival (y axis) and Queue (x axis) decrease, so does the Extension (z axis). Additionally, Figure 9 shows that the Extension increases in response to a decrease in Visibility and an increase in Queue. Similarity can be seen in Figure 10.

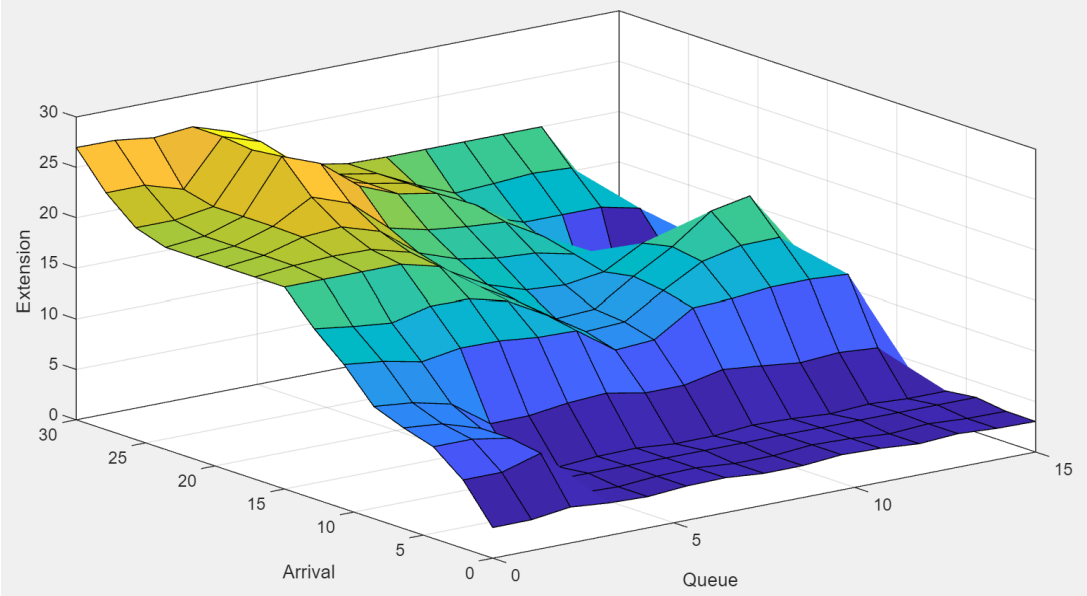

Figure 8. Surface graph of Queue and Arrival vs Extension

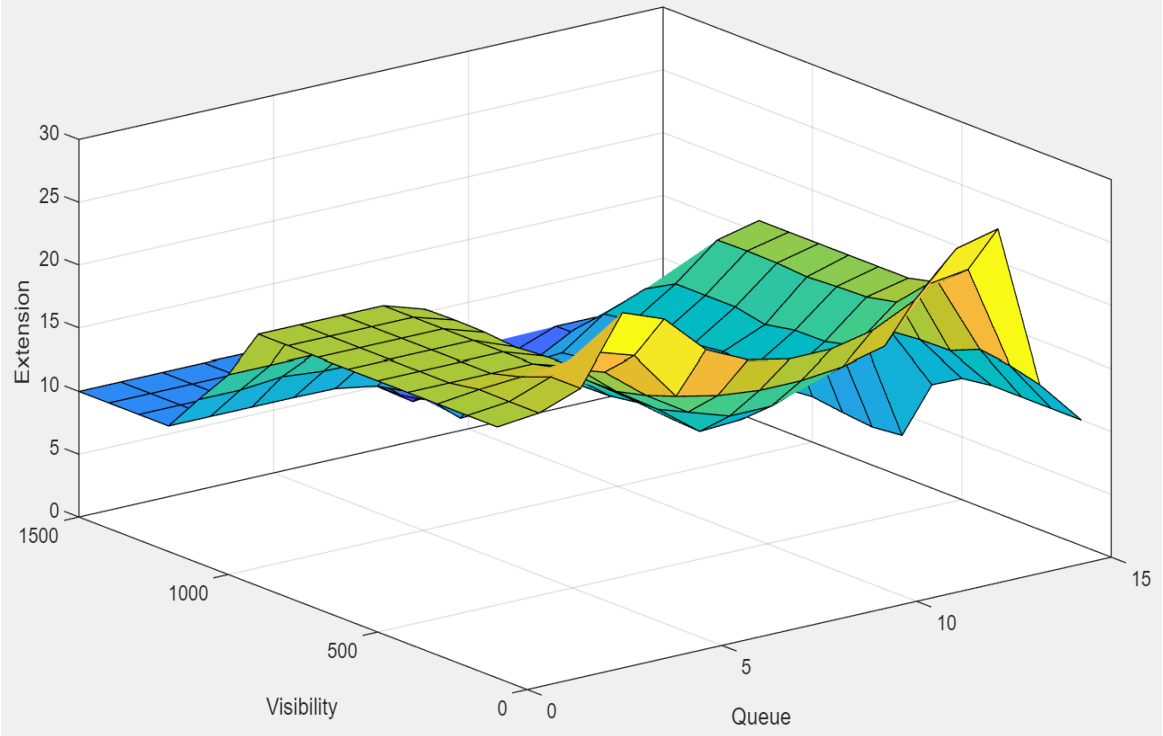

Figure 9. Surface graph of Queue and Visibility vs Extension

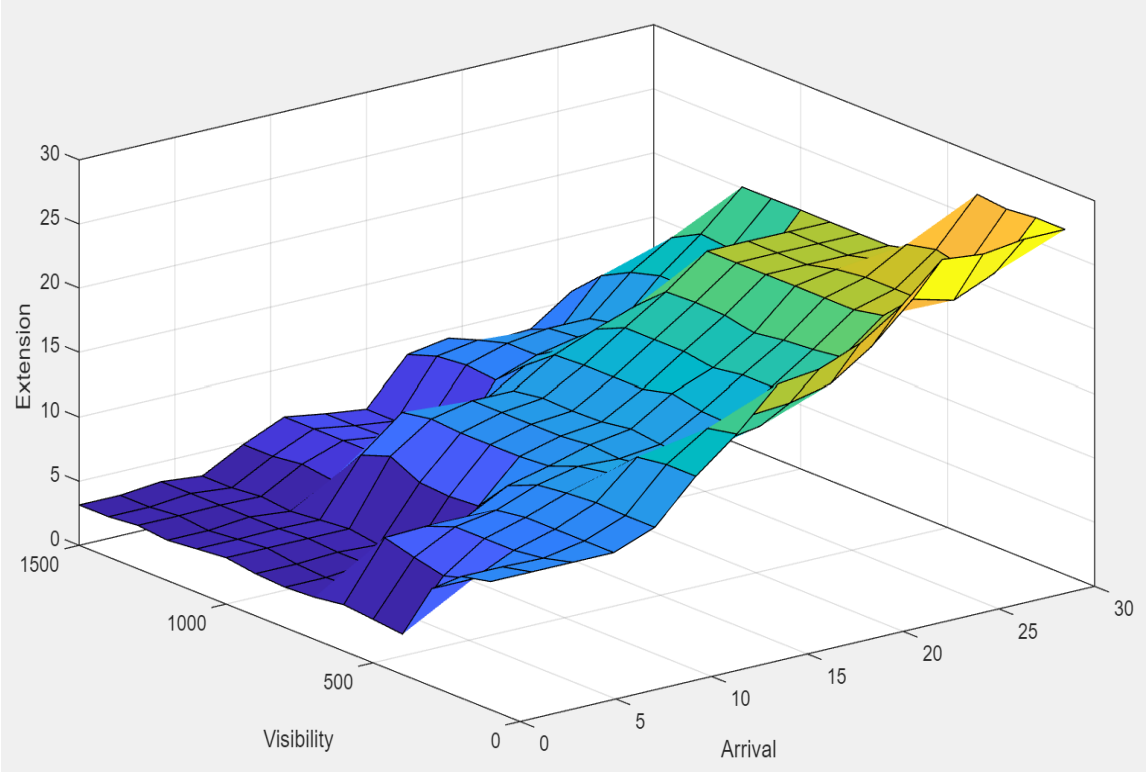

Figure 10. Surface graph of Arrival and Visibility vs Extension

Results and Discussion

A set of crisp values has been added to the fuzzy logic control system, as shown in Figure 11. The variables Queue, Arrival and Visibility have been assigned values of 7, 15 and 800, respectively. The corresponding crisp output is 12.9 seconds.

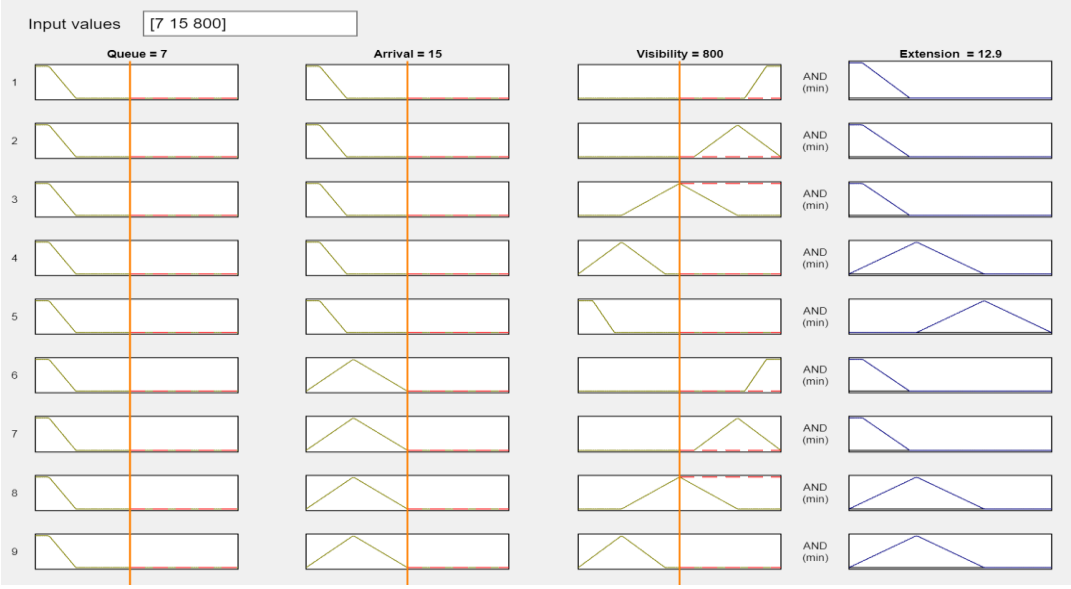

Figure 11. Rule viewer

Following a thorough design process, we test the intelligent traffic light control system and talk about how the input variables affect the output variable, as shown in Table 5. In the ninth and third rows, the Arrival and Visibility remain unchanged, but the Queue grew from 3 to 15, resulting in a drop in the Extension from 26.6 to 13.5. In addition, the Visibility increased from 500 to 1300, resulting in a decrease in the Extension, while the Queue and Arrival in the fifth and sixth rows stay constant.

Table 5. Extension time at different values of input variables

No.	Queue	Arrival	Visibility	Extension
1	3	6	350 m	10 sec
2	3	19	900 m	21.5 sec
3	3	27	500 m	26.6 sec
4	7	14	350 m	12.9 sec
5	10	19	500 m	14.6 sec
6	10	19	1300 m	8.74 sec
7	13	27	900 m	16 sec
8	13	6	350 m	3.39 sec
9	15	27	500 m	13.5 sec

Simulation

The MATLAB simulation (Simulink) was used to evaluate the effectiveness of the fuzzy controller in controlling traffic flow at an isolated intersection as shown in Figure 12.

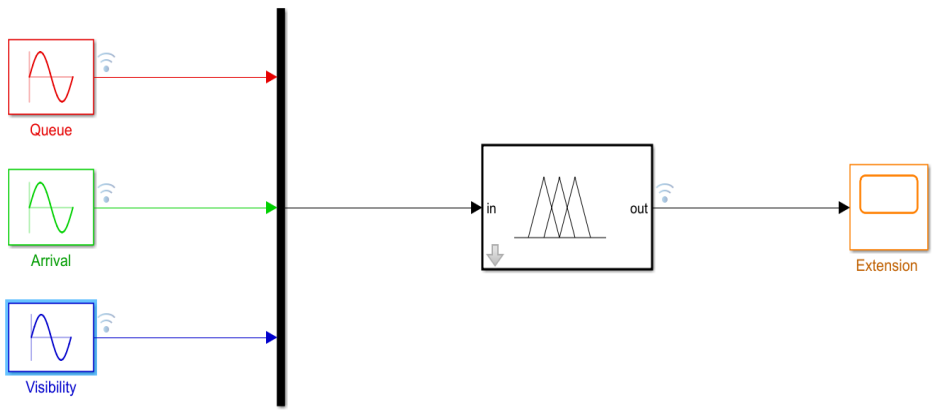

Figure 12. Simulink model

Figures 13, 14 and 15 show that the x-axis represents simulation time, and the y-axis represents the value of the corresponding variable relative to its unit of measurement. Every possibility as stated in the fuzzy rule base is permuted by subjecting each input variable to a sine wave function block with different parameters.

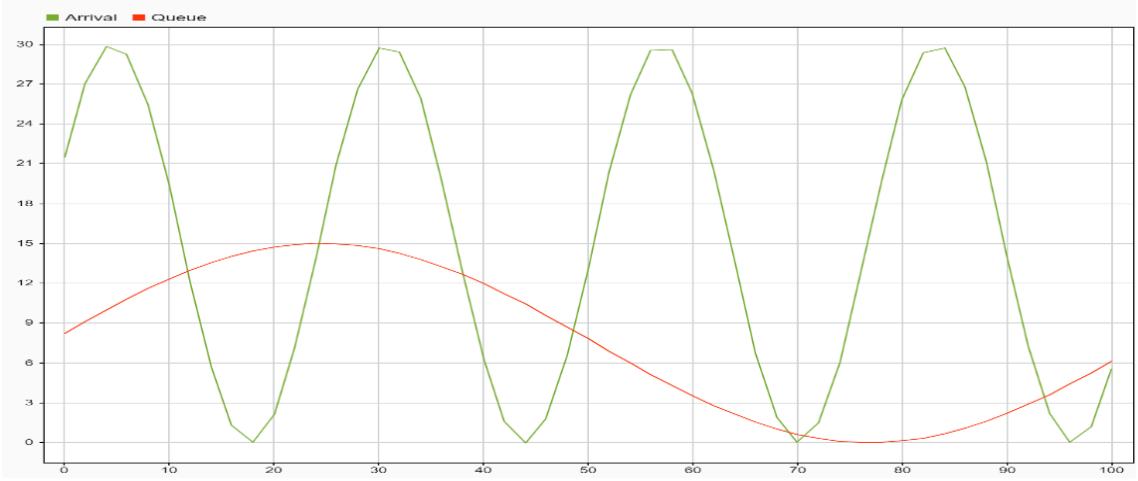

Figure 13. Arrival and Queue in simulink model

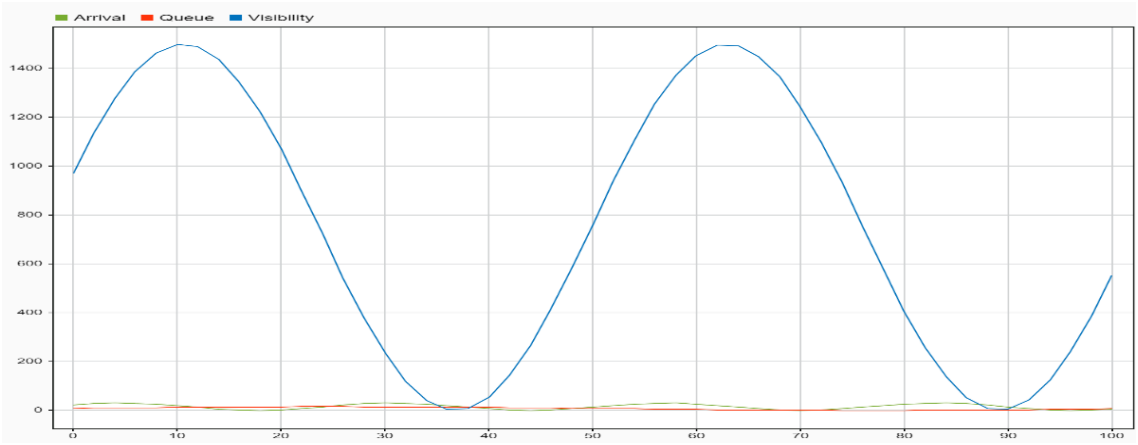

Figure 14. All inputs in simulink model

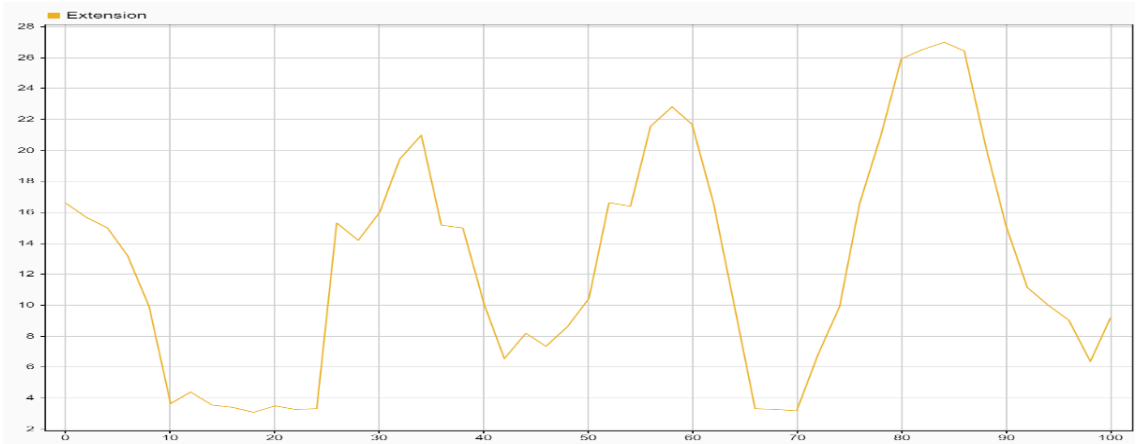

Figure 15. Output in simulink model

Figure 14 illustrates the changes in the values of the input variables throughout the simulation, and Figure 13 clearly depicts the changes in the inputs Queue and Arrival, while Figure 15 displays the output result. From 10 to 18 on the x-axis, we have noticed that when the Queue increased and Arrival reached its lowest point, the extension time dropped to the absolute minimum. On the other hand, the extension time peaked at 27 sec as we move from 78 to 84 on the x-axis, which coincides with an increase in Arrival to its peak, Visibility decreases, and there was a gradual increase in Queue.

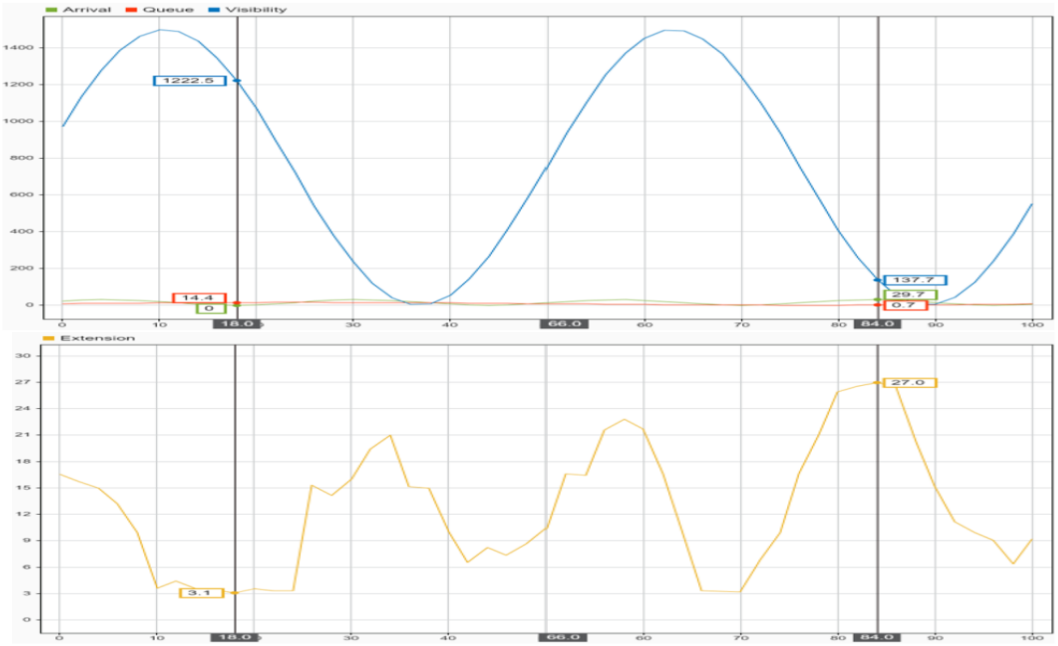

Figure 16. Simulink model with two cursors

Conclusion

In this paper, we gave a fuzzy logic controller to improve the performance of Riyadh's traffic lights controller. Using the suggested fuzzy logic controller, the number of arriving vehicles and queuing vehicles under various weather conditions have been taken into consideration when estimating the green light extension time.

Recommendations

The fuzzy controllers' design and programming are completed. However, to guarantee the accuracy of the rules and attain optimal system performance, expert's knowledge is required.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

Acknowledgements or Notes

* This article was presented as an oral presentation at the International Conference on Advances in Technology and Innovation (www.icati.net) held in Antalya/Turkey on November 14-17, 2024.

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Comparative Analysis of Digital Translation Tools

Alma Karasaliu
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Abstract: As technology progresses, educators become essential in effectively integrating and guiding the application of digital tools to enhance students' learning experience. This paper focuses on the dynamic use of three distinct digital tools—Google Translate, ChatGPT, and My AI on Snapchat—by Bachelor's Degree students while translating and comparing economy-related texts. The study employs a hands-on methodology, encouraging students to explore the functionalities of each tool and propose alternative translations in instances of any identified errors or any inappropriately translated version. Through detailed analysis of the students' contributions, it is sought to reveal patterns and preferences in the usage of the above-mentioned tools, providing a better understanding of their impact on English language learning. Beyond the immediate context, the study sheds light on the broader implications of technology integration in the field of education. Gaining insights into students' interactions with digital tools not only shapes pedagogical methods but also contributes to the ongoing dialogue on incorporating digital tools in foreign language acquisition in higher education. In conclusion, besides highlighting the transformative impact of digital translation tools in the field of education, further benefits such as enhanced contextual comprehension, immediate feedback, and personalized learning experiences will be pointed out.

Keywords: Artificial intelligence, Digital translation tools, Machine learning

Introduction

The multi-arrayed influence that technology exercises on students' performance is nowadays acknowledged and accepted by many educators from all over the world. While the hesitance of whether to embrace its use in their classes, to promote a conventional teaching practice, or to allow limited-technology use has come to an end, trying to find fruitful and engaging ways of purposely incorporating technology into practice seems to be the purpose of research for many educators. In particular, the relationship between artificial intelligence and education is becoming increasingly important (Genc & Kocak, 2024).

This study focuses on the use of digital translation tools in English for Special Purposes (ESP) classes with 1st year Bachelor's Degree students studying 'Finance' in "Fan S Noli" University. It aims to identify patterns and preferences in students' use of digital tools like: "Google Translate", and the translation services offered by Chatbots like: "ChatGPT", and "MY AI" (recently integrated in 'SnapChat') during their completion of tasks in the class or remotely. Even though the primary focus of the two later tools isn't text translation, they both offer such a service and are widely utilized for this purpose.

It is worth noting that despite the existence of a number of machine translation tools, the main reason for selecting these specific tools for student work are their free accessibility and user-friendly qualities. In addition, due to their frequent use in daily activities, students didn't require detailed instructions on how to use these tools, resulting in less ambiguous tasks and more involvement on students' behalf.

Another important point to be mentioned is the fact that a significant number of students in this group did full-time and/or part-time jobs, so the times they had to miss our onsite classes were considerable. Deciding to

implement a Blended-Learning approach was seen as appropriate due to its flexibility (Lin, 2018), high-engaging qualities (Halverson & Graham, 2019) and the positive impact it has on improving students' language acquisition (Mulyadi et.al., 2020; Kurucova et al., 2018) hence, allowing all of them to participate actively and express their views on thought-provoking issues regarding transition variances. As Meng (2022) notes, the incorporation of various forms of teaching greatly improves teachers' and students' experiences of knowledge acquisition. As such, it can be assumed that both parties will have better teaching and learning perspectives. However, implementing this teaching approach required careful planning and selection of materials, a point supported even by other researchers like Luo and Garner (2017).

The role of Machine Translation in ESP Teaching

Machine translation technologies are playing their constructive (and when left unsupervised) destructive role in foreign language acquisition. Offering immediate access to authentic texts, these technologies facilitate the process of practicing a foreign language in many aspects (Lee & Briggs, 2021). They provide their users (and in our case the students) with the possibility to choose from a number of synonyms and encounter relatively simple sentences thus, motivating them to explore more content-related material, fostering their critical thinking (Young, 2023), inspiring collaborative learning, and also enriching their vocabulary repertoire.

Several researchers (O'Neill, 2013; Clifford et al., 2013; Lee, 2023; Yang, 2024) have explored the benefits and drawbacks of utilizing machine translation in foreign language teaching, generally agreeing on its positive influence on the learning process. Sujarwo (2020) highlights that students' learning performance is highly boosted by the use of these tools.

However, Young (2023) stresses the importance for careful planning of appropriate writing tasks and other activities that employ these tools to enrich students' linguistic competence rather than purely avoiding engagement in expressing their own capacities. While acknowledging the wide specter of benefits that machine translation offers in the process of foreign language acquisition, Urlaub and Dessein (2022) draw attention towards the risk of students (and all regular users of these tools) losing their ability to naturally utilize foreign languages for communication. This would mean that they would lose that 'personal touch' which is possesses by every individual. In this aspect, we agree with Clifford et al. (2013) and Young (2023) regarding the importance that teachers' instructions have in properly incorporating machine translation in foreign language learning practices.

The Relationship between Translation and ESP

When considering the relationship between translation and ESP, many would argue that the former plays an auxiliary role, contributing to the process of foreign language acquisition by facilitating meaning transmission and establishing connections between the terminology in source and target languages (Koteva, 2020). Hence, translation contributes significantly to students' communication skills (Mažeikienė, 2019), especially in cases of collaborative translation tasks which emphasize and develop various skills.

By exposing students to different language structures and idiomatic expressions within their field of study, translation supports the objectives of ESP by enhancing students' language proficiency (especially in terms of terminology), facilitating content understanding, and drawing cultural maps (Zhang, 2016) with relevant phenomena in the target language. The integration of both these elements considerably contributes to building students' analytical and critical thinking skills, fostering a well-rounded language proficiency.

Due to the prevalence of economic-related terminology and its specific contextual usage, instructing students to rely on Functional Translation Method was deemed appropriate. As highlighted by Leonardi (2009), utilizing translation in ESP teaching fosters students' engagement in the acquisition and refinement of various linguistic aspects, while also stimulating their critical thinking skills in addressing cultural-related issues. These skills enable students to make informed decisions in selecting appropriate equivalent terminology and to avoid content-related mistranslations.

Although translation was not the primary focus of their studies, equipping them with certain translation skills was considered beneficial for polishing their performance, enhancing the quality of their research, and increasing prospects for successful projects upon when starting a job. Students were introduced to Weschler's (1997) model through simplified examples, with the expectation that they would identify inappropriate or

ambiguous translations rather than engaging in detailed linguistic analysis. As such, translation was mainly utilized in reading sections to translate texts from English to Albanian, even though this approach was not the only methodology employed during the ESP course. Similarly, while considering various tools, the study exclusively concentrates on the three digital translation tools in question for the purpose of the investigation.

Methodology

This paper aims to assess the effectiveness of Google translate, ChatGPT, and MY AI on Snapchat in translating texts related to economy. Additionally, it examines students' interactions and preferences with different digital translation tools, assessing their impact on foreign language acquisition and proficiency. Students of the first year studying "Finance" are expected to have a B2 level of English proficiency upon entering university, enabling them to identify grammatical and terminological discrepancies. A hands-on methodology was employed, allowing students to explore the functionalities of each tool, identify errors, propose alternative translations, and demonstrate patterns and preferences in tools usage.

In order to achieve better results, the types of texts they worked with were chosen in accordance with the topics covered in other formative subjects, drawn from Leonard Danglli's "Business English" book. This approach allows students to engage with terminology they have previously met in the source language, facilitating the process of drawing parallel connections (Koteva, 2020) between variants in both languages (English and Albanian). At the beginning of each class, students were divided in different groups, with each group assigned a specific text and digital translation tool for completing their initial task. Working with assigned texts improves students' focus and exposes them to a range of specific contexts, each with relevant linguistic, stylistic and cultural features (Danilina, 2020). After translating the text, students conduct comparative translation analyses to identify discrepancies and suggest alternative variants which they consider more appropriate. Subsequently, they compare their versions with other group members (when working individually) and later with groups using the remaining translation tools for the same texts.

In many cases, students were instructed to collaborate on their tasks in order to save time, particularly when the task was carried out in the classroom. In other instances, they discussed their findings on the discussion board in Microsoft Teams. Following these activities, a comprehensive analysis of students' findings was conducted. The 'mistakes' made by the digital translation tools were subsequently categorized based on this analysis, providing insights into the performance and limitations of each tool.

Findings

As mentioned above, this study explores students' experiences with digital translation tools in translating and comparing and contrasting economy-related texts and focuses on their utility in translating complex texts and promoting linguistic proficiency.

Problems with the Tool's Translation

Below are selected a group of examples which reflect mistranslations, problems with naturalness and adaptation encountered during our analysis of the texts worked by the students via the digital tools. The examples in the source language are found in the "Did you know?" section (pp. 18-19).

"The bank sets national interest rates and is responsible for issuing banknotes."

ChatGPT: "Banka përcakton normat kombëtare të interesit dhe është**p**ërgjegjëse për emetimin e **banknotave**."

Google Translate: "Banka përcakton normat kombëtare të interesit dhe është përgjegjëse për emetimin e **kartmonedhave**."

Even though both translations can be considered as clear and grammatically correct, the choice of the parallel term "kartmonedha" for "banknotes" aligns better with the Albanian lexicon, rendering the translated variant more natural. We agree with Mulyanah's (2020) statement that the choice of terminology can significantly influence the clarity and naturalness of a translation.

Below are additional examples highlighting similar problems:

"The main commercial banks, called clearing banks or high-street banks, are Nat West, Barclays, Lloyds, and HSBC."

Google Translate: "Bankat kryesore **komerciale**, të quajtura **banka të kleringut** ose banka të rrugës së lartë janë Nat West, Barclays, Lloyds dhe HSBC."

ChatGPT: "Bankat kryesore **tregtare**, të quajtura **banka të pastrimit** ose banka të rrugëve kryesore, janë NatWest, Barclays, Lloyds dhe HSBC."

Students' suggestion: "Bankat kryesore **tregtare**, të njohura si **bankat e pastrimit** ose bankat e rajoneve kryesore, janë NatWest, Barclays, Lloyds dhe HSBC."

While all translations effectively convey the main idea to some extent, the second and third translations offer more idiomatic and commonly used terms for "clearing banks" and "high-street banks" in Albanian. The term "kleringut" is not found in Albanian lexicon. As such, it is not recognizable by the reader, making the translated variant not only ambiguous and confusing, but even misleading, as it resembles the term "klerikut" (religious figure), which is irrelevant in this context. Moreover, the way the phrase "high-street banks" is adapted and brought in a more naturalized language in Albanian language through its equivalent "bankat e rajoneve kryesore" demonstrates the importance of human interpretation in translation. It ensures that all linguistic and stylistic nuances of the source text are preserved and faithfully conveyed in the target language.

"These are known as the big four and have branches in most towns."

MY AI: "Këto quhen **katër të mëdha** dhe kanë degë në shumicën e qyteteve."

ChatGPT: "Këto njihen si **katër më të mëdhatë** dhe kanë degë në shumicën e qyteteve."

Students' suggestion: "Këto njihen si **katërshja e madhe** dhe kanë degë në shumicën e qyteteve."

While SnapChat's translation is literal and lacks idiomatic expression, the translation from Chat GPT doesn't go very far from it either. Both tools adhere closely to literal translation and fail to convey the intended meaning clearly, resulting in loss of naturalness and clarity. Though less conventional, the translation suggested by students effectively communicates the message in a natural and understandable way.

"*Many people now bank online, and …"*

Google Translate: "Shumë njerëz tani **bëjnë bankë online** dhe …"

ChatGPT: "Shumë njerëz tani **bankojnë** online dhe …"

Students suggested the phrase "**kryejne aktivitete bankare online**" as a corresponding phrase for the Albanian version. It reflects a more appropriate and linguistically accurate translation, which uses existing terminology that is familiar to Albanian speakers. In contrast, the other two variants employ terms that do not exist in the Albanian language and could potentially lead to confusion or unclear information. It is important to note that the term "bankoj" has started to be utilized informally among teenagers and young adults, but it is not widely accepted and remains very informal for formal or professional contexts.

"**Banking** is dominated by large money center banks, such as Chase, which raise money by dealing in the international money markets and lend it to businesses and other banks."

Chat GPT: "**Biznesi bankar** është i dominuar nga bankat kryesore të qendrave të parave, siç është Chase … dhe i japin ato në kredi ndërmarrjeve dhe bankave të tjera."

My AI: **Bankimi** është dominuar nga bankat e mëdha qendrore të parave, siç janë Chase … dhe i dhurojnë ato bizneseve ….

Google translate: "Bankat dominohen nga banka të mëdha të qëndrës së parasë si Chase … dhe i japin ato në kredi ndërmarrjeve …."

The provided translation appears to be a literal translation from English to Albanian. However, to enhance the accuracy and clarity of the Albanian translation, particularly for specialized terms like "banking" and "lending" it is crucial to use language that effectively conveys the intended meaning in the target language. Here is a refined version of the translation:

"**Sistemi bankar** rregullohet nga bankat e mëdha që operojnë në qendrat e financimit të parave, siç është Chase, të cilat grumbullojnë para duke operuar në tregjet ndërkombëtare të parave dhe ua japin në formë kredie bizneseve dhe bankave të tjera."

It should be noted that Snapchat's service poses many challenges when translating specific terminology and as such, in many cases students had to reconsider the entire version translated by this tool.

The cases mentioned below are found in the text: Mark Zuckerberg on p. 70 of the book.

"**By September 2006** anyone with an e-mail address could join a regional network based on where he or she lived."

Google Translate: "**Deri në shtator 2006**, çdokush me një adresë e-mail mund të ***bashkohej*** me një rrjet rajonal bazuar në vendin ku ai ose ajo jetonte."

My AI: "**Deri në shtator 2006**, kushdo me një adresë e-mail mund të ***bashkangjitej*** me një rrjet rajonal bazuar në vendin ku ai ose ajo jetonte."

ChatGPT: "**Deri në shtator të vitit 2006**, çdokush me një adresë e-mail mund të ***anëtarësohej*** në një rrjet rajonal bazuar në vendin ku ai ose ajo jetonte."

As illustrated in the above examples, the time phrase "By September 2006" was translated as "Deri ne shtator 2006" by the three digital tools, whereas more appropriate versions would be "Prej shtatorit të vitit 2006" or "Që prej muajit shtator të vitit 2006". The initial translation "Deri në shtator 2006" does not fully capture the intended meaning of the English phrase. In contrast, the alternative suggestions using "Prej" or "Që prej" provide a more accurate and contextually appropriate translation for expressing the intended time frame.

Moreover, regarding the verb choice used in the translations, the first version uses the verb "bashkohej" (could join), which is in the past tense and subjunctive mood ("bashkohej"), implying a conditional action. The second version uses the verb "bashkangjitej" (could attach/join), which is also in the past tense and subjunctive mood ("bashkangjitej"), but this verb choice does not accurately convey the meaning of "join" in the context of joining a network. The third version, "anëtarësohej" is the most appropriate one as it specifically conveys the action of becoming a member of a network that aligns better with the intended meaning of the phrase.

The examples in question are taken from Stock Exchange (pp. 47-48).

"Depending on the type of brokerage account you have, you may be able to view this flow of price action."

ChatGPT: "Në varësi të llojit të llogarisë së brokerimit që keni, mund të jeni në gjendje të shikoni këtë rrjedhë të veprimit të çmimeve.suggestion."

Google Translate: "Bazuar në llojin e llogarisë së ndërmjetësimit, mund të shihni këtë lëvizje të çmimeve."

MY AI: "Sipas llojit të llogarisë së brokerimit, mund të kuptoni se si çmimet po ndryshojnë."

In the above examples we can see that the phrase "brokerage account" was translated correctly only once with the appropriate financial correspondents in Albanian language. It can be noticed that the version provided by Google Translate is formal and accurate, using appropriate terminology. However, contextualization has been difficult, particularly in the case of the noun "flow" which was conveyed as "rrjedhë", "lëvizje", or implied in the last version. Furthermore, it needs to be noted that the version provided by MY AI is more informal and the phrase "çmimet po ndryshojnë" carries a slightly different connotation compared to "price action", which encompasses broader market dynamics beyond simple price fluctuations.

"At the same time, you might see that the "ask price" is $31, which means somebody else is willing to sell the stock for $31. The difference between the two is the bid-ask spread."
ChatGPT: "Në të njëjtën kohë, mund të vini re se 'çmimi i ofertës' është $31, çka do të thotë që dikush tjetër është i gatshëm të shesë aksionin për $31. Diferenca midis tyre quhet '**bid-ask spread**'".

MY AI: "Po në të njëjtën kohë, ndoshta do ta shihni që çmimi i "ofertës" është $31, që do të thotë dikush tjetër po e shet aksionin për $31. Dallimi midis tyre është ajo që quhet përhapja **'bid-ask'.**

Google Translate: "Në të njëjtën kohë, mund të shihni se 'çmimi i ofertës' është $31, çka do të thotë që dikush tjetër është i gatshëm të shesë aksionin për $31. Diferenca midis tyre quhet "**ofertë-kërkoj përhapje**".

The above examples highlight issues with translating specific financial terms. Although ChatGPT has maintained the style, the expression "bid-ask spread" is left untranslated. The same problem is met with the translation provided by MY AI which has literary translated the noun "spread" as "përhapja". Similarly, Google Translate's version "ofertë-kërkoj përhapje" does not accurately convey the intended meaning. In this case, naturalization of the expression seemed as the right form of addressing it, so in collaboration with the students, it was agreed on the version "dallimi kërkesë-ofertë". Additionally, problems with the register are observed with the version translated by MY AI, indicating a need for improvements in the linguistic appropriateness and style of the translations.

Other Issues with MY AI

In addition to the informal style present in most of the translated versions discussed above, a number of other linguistic issues arose while using MY AI in SnapChat. Students suggested their own variants and refined the language for better conciseness and naturalness. The following examples are taken from the text entitled: *Customer Service* (pp. 55-56).

The first example below is a case of a mistranslation which renders the meaning of the translated variant ambiguous and misleading.

"Sometimes customer service means the act of **taking care of the customer's needs** …."

"Ndonjëherë shërbimi ndaj klientëve do të thotë **marrja e kujdesit të nevojave të klientit**".

Students have suggested substituting the phrase "marrja e kujdesit të nevojave të klientit" with "përmbushja e nevojave të klientit" and expanding the translation to include the broader context of the phrase: "Ndonjëherë shërbimi ndaj klientëve do të thotë që të jeni të gatshëm për të përmbushur nevojat e tyre në një mënyrë të efektshme dhe miqësore."

The natural flow of the language is missed even in the following example:

"**Professionalism**: All customers should be treated professionally. Using this characteristic of good customer service shows the customer that you really care about them."

"**Profesionalizmi**: Të gjithë klientët duhet të trajtohen me profesionalizëm. Duke përdorur këtë cilësi të shërbimit të mirë ndaj klientëve tregon se ju vërtet kujdeseni."

As observed in the example, the above translated version requires some adjustments in order to achieve a balance between accuracy, clarity, and natural language flow. A revised version suggested by the students that aims to address the above issues is:

"**Profesionalizmi**: Të gjithë klientët duhet të trajtohen në mënyrë profesionale. Kjo cilësi e shërbimit të mirë ndaj klientëve tregon se ju i kushtoni vëmendje të veçantë klientit."

Here is another example worth considering.

"Politeness: Saying 'hello', good afternoon', sir', and thank you very much' are a part of good customer service. For any business, a thank you' is appropriate whether the customer makes a purchase or not."

"**Politesia: Thënë** 'përshëndetje', 'mbrëmje të mirë', 'zotëri', dhe 'faleminderit shumë' janë pjesë e shërbimit të mirë ndaj klientëve. Për çdo biznes, një 'faleminderit' është i përshtatshëm, qofshin klienti bën një blerje apo jo." This is one of the many cases of mistranslations observed in the output students have got from MY AI. The following improvements were suggested: "**Mirësjelllja: Të thënit … mirëmbrëma … edhe nëse klienti** ...." Another case is:

"Customers like the idea that who they do business with knows them on a personal level."

"Klientët e duan idenë që ata që bëjnë biznes me ta i njohin ata në një nivel personal."

Focusing on using a more natural language, simplifying the wording, and ensuring clarity and conciseness, students have suggested the following version: "Klientët pëlqejnë të ndihen të njohur personalisht."

The same steps to address issues with clarity and accuracy were followed in the example below:

"A large business will often devote an entire **department to taking** calls from customers who have needs or concerns about the service or product."

"Një biznes i madh shpesh i kushton një **departament të tërë për të pranuar** thirrje nga klientët që kanë nevoja ose shqetësime në lidhje me shërbimin ose produktin."

Another version was suggested: "Një biznes i madh shpesh ka **një departament të posaçëm** që pret thirrje telefonike nga klientët për nevoja apo shqetësime rreth shërbimit ose produktit." This version aims to maintain accuracy while improving clarity and naturalness of expression in Albanian. As seen, the key adjustments include using more concise wording and smoother phrasing to enhance readability.

Below is another example which reflects the inability of digital translation tools to naturalize specific language.

"Technicians and **repair people** are often **face-to-face** representatives of their companies, …"

"Teknikët dhe **persona të riparimeve** shpesh janë përfaqësues **të fytyrës** të kompanive të tyre, …"

The adaptation of the expression "repair people" with "specialistët e riparimeve/riparuesit" and of "face-to-face" with "të drejtpërdrejtë" contributes to the naturalization of the sentence, conveying a clear overall meaning. We agree with Makhachashvili (2023, p. 9) who argues that while improving inappropriate translated versions may be demanding for students, it positively influences their translation competence, resulting in "*an increase in human translation quality*".

In the examples provided above, students utilized various translation procedures to address issues such as naturalization, adaptation, and choice of terminology. This experience sharpened the students' skills in identifying translation issues, grasping the intended meaning based on the content of the text, creating parallel equivalents in the target language, and negotiating meaning and form of terms/phrases, particularly in cases where naturalization and lack of relevant terminology was involved.

Discussion

Having been established earlier and continuously improving its service for a longer period of time, Google Translate demonstrated relatively better translation quality compared to the other two digital tools. Despite being easily accessible (including via mobile phones, which was a 'must' for students who didn't own a laptop/desktop to participate in asynchronous classes) and most of the time providing accurate translations related to terminology, this tool showed that it struggles with lexical nuances and idiomatic expressions. Several cases were presented above to illustrate these challenges. In addition, the study reaffirmed what O'Neill (2013) highlighted: that this translation tool is highly favored by students. This reliance was further evidenced by the study's findings that students heavily depend on this tool for their translation needs.

On the other hand, by acting as a virtual conversational friend, ChatGPT can be helpful in understanding short specific texts and generating quick responses, making its presence useful when time is a constraint. Nevertheless, the study has revealed that the translations generated by this tool have problems with accuracy, naturalness and adaptation. In addition, it is worth noting that while Google Translate leads students rely on it

for all translation purposes, ChatGPT discourages the development and exhibition of their critical thinking skills.

Regarding MY AI on Snap Chat, it can be stated that beyond all the positive and attractive features this tool offers as a social media platform, students had reservations about using its translating service, especially when dealing with specific terminology and formal style, particularly for educational purposes. Moreover, concerns were raised regarding privacy and security, which led students to choose one of the other two when they were given the option to select the tool for translating an assigned text. While there are possible solutions to address several security issues prevalent in social media (Albulayhi & Khediri, 2022), their implementation is often insecure, and under the pressure of the emergence of new threats.

Another important drawback identified by them was the low quality of translation yielded by the tools in question when the text was entered as a whole. In most of the cases, students preferred translating texts in short paragraphs to ensure a more acceptable version in the target language. This approach to translation is supported even by two well-known researchers, Jolley and Maimone (2015), who have studied various aspects of digital translation tools.

According to Urlaub and Dessein (2022), it is important to expose students to learning environments where they confront the necessity for human editing of materials which have been translated by means of digital translation tools. This exposure helps students incorporate natural nuances suitable for the context and, when applicable, the cultural aspects of target country.

Additionally, even though there were instances when students had difficulties with internet access, the flexibility of asynchronous communication using Microsoft Teams as the primary virtual learning platform enabled them to submit their assignments on time. In the same context, this familiar environment minimized confusion and delays, ensuring their effective communication and task competition. Students' final results and their formative assessments indicated that the incorporation of translation as a teaching approach in ESP education positively influenced their language proficiency, critical thinking skills, and overall understanding of specialized content in finance-related topics.

Moreover, despite the effectiveness of virtual platforms, on-site classes, proved to remained a beloved learning environment for students. The sessions provided a physical space where students synthesized their knowledge, clarified any questions/misunderstandings regarding tasks and/or assignments, and collaboratively addressed challenging terms and phrases, ensuring comprehensive understanding of respective contents.

Conclusion

This paper explores the use of digital translation tools like Google Translate, ChatGPT, and MY AI on Snapchat by Finance students in their English for Specific Purposes classes. It highlights that while Google Translate is widely accessible and preferred by students, it struggles with idiomatic expressions and nuanced language. Meanwhile, ChatGPT, although convenient for quick responses, lacks accuracy and may hinder students' critical thinking skills. Similarly, MY AI on Snapchat reflected difficulties with certain terminology and formal language, making it less suitable for educational contexts. Students demonstrated resourcefulness by analyzing and refining translations, which enhanced their critical thinking and linguistic skills. In various cases, the unconventional translations they suggested, effectively communicated the message in a natural and understandable manner. Two important conclusions were drawn from this study: first, that translation serves as a pedagogical tool for enhancing language proficiency and intercultural competence; and second, that accurate and meaningful translations require human interpretation and creativity beyond mere literal conveyance.

Recommendations

This study focuses on a specific group of students studying Finance, at a particular university, so conducting research with a more diverse sample of students from various universities would help in generalizing the findings. Additionally, exploring the long-term effects of translation approaches or technologies in ESP education and comparing different types of translation approaches or technologies could provide deeper insights into their educational benefits and limitations.

Scientific Ethics Declaration

The author, Alma Karasaliu declares that the scientific, ethical, and legal responsibility of this article published in EPSTEM Journal belongs to the author.

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Experimental Investigation of the Wear of Some Polymer Gear Wheels Produced by Three-Dimensional Printer on the Variation of Fill Percentage and Shell Thickness

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Abstract: FDM additive manufacturing method has recently been widely used because it is very attractive in terms of cost and material loss compared to traditional manufacturing methods such as molding and milling. In previous studies, many researches have been carried out on the engineering strength of plastic gears produced by conventional methods, but with the discovery of new plastic forms by material science and the practical application of new production methods, researchers continue the researches on additive manufacturing gears. So far, many studies have investigated the wear variation, rotational speed and torque variation with variations in gear wheels produced with three-dimensional printers. In this study, using the ability of FDM technology to produce in layers, gear wheels with several variations in outer shell thicknesses and internal filling ratios were produced. The wear behaviors of these gear wheels produced with different variations were investigated. On the other hand, PETG and ABS polymers were also produced under the same conditions in order to provide material diversity in addition to PLA polymer, which has been used so far in many studies due to its low melting temperature and good printability. Then wear behaviors were observed under the same conditions using the FZG (Forschungsstelle fur Zahnrader und Getriebebebau) test setup. Thanks to additive manufacturing technology, polymer gear types were produced with fill ratios of 100% and 50% and outer shell thicknesses of 0.4 mm and 0.8 mm. The test specimens were operated against the steel gear at a torque of 1.5 Nm and a rotational speed of 900 rpm and the mass losses as a result of wear were compared. Thus, a comparison was made about the strength of polymer types with the variation of outer shell thickness and filling percentage.

Keywords: Wear, 3D printing, Plastic spur gear

Introduction

While the light weight of plastic gears and their use without lubrication make them attractive in cases where high strength is not required, the low melting points and glass transition points of plastics have caused low heat resistance. Since abrasion brings with it heat generation, heating has been one of the biggest handicaps of plastics. On the other hand, with FDM technology, one of the additive manufacturing methods, it is a great convenience for the user to know the total production time thanks to the printer program. However, compared to the mold production method, this method is more cost-effective in prototype production, but the production time is quite long.

In the previous studies, the relationship between the rotational speed and torque change affecting the wear, heat and material losses as a result of wear were calculated and the microstructure changes occurring in the microscope were observed. The increase in layer thickness caused deterioration in surface quality and reduction in the wear coefficient. When the layer thickness was increased from 0.1 mm to 0.3 mm, it was observed that

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the bending and tensile strength decreased by about 30%. Increasing the nozzle temperature can reduce the wear rate when the polyamide gear is produced by FDM method. (Wang et al.,2024)

The tensile strength of PLA polymer was investigated by producing filling percentages of 25%, 50%, 75% and 100%. It has been shown that the hardness, impact strength and tensile strength of the samples increase in proportion to the filling ratio. (Gunasekaran et al.,2020). The wear resistance of PLA, ABS, PP and PA polymers were compared by scanning the flank area of two teeth of the polymers. When the deviation amounts were examined, it was seen that PLA polymer had the best wear resistance behavior. (Ciobanu et al.,2024). PA6 polymer was produced using a 3D printer and glass fiber reinforcement was made to provide material diversity, and the effects of thermal softening were taken into account and wear resistance and hardness properties were investigated using an electron microscope. (Bolat & Ergene,2024)

Since the production parameters of the three-dimensional printer directly affect the properties of the final product, an algorithm has been produced for the change of printing speed, printing temperature, printer bed temperature and filler percentage from printer parameters. In the study carried out by using GA based ANN model of Nylon material with three-dimensional printer, writing temperature 250 C^o, writing speed 70 mm/bed temperature 25 C^o and filling percentage 80% were suggested (Zhang et al.,2020).

In another study, PLA and ABS polymers were produced by three-dimensional printer with three variations of printing lattice angle as 0^0, 45^0 and 90^0, layer thicknesses as 0.127, 0.254 and 0.33 mm and Pin-on disc test setup was used to investigate the wear resistance. It was stated that the increase in layer thickness provided a decrease in friction force and wear, the best lattice pattern was 45^0 and ABS polymer showed better wear resistance than PLA (Amirruddin & Ismail, 2021).

In a study examining the variation of wear characteristics with filler density, numerous variations were used in experiments by selecting 20%, 40% and 60% as filling ratio and rotational speed as 500, 1000, 1500 rpm. It was stated that extreme wear conditions were observed in the sample with 1000 rpm rotation speed and 40% filling rate, and excessive temperature increase occurred at 1500 rpm rotation speed at 60% filling rate. When the rotation speed was 500 rpm, thermal analysis and microstructure showed high temperature increase and wear caused by friction (Nafiz et al., 2023).

Using three different polymers, PLA, Tok-PLA and TPU filaments, spur gear wheels were produced with a three-dimensional printer and their surface strengths were examined. Thanks to the experimental setup, the effects of 0.5-4 Nm torque changes on the wear behavior were observed by electron microscope scanning at the end of the experiment. In the study where the temperature change on the tooth was observed with a thermal camera, it was determined that the polymer with the best wear resistance under the same conditions was Tok-PLA. It is concluded that the combination of two materials may be useful in terms of increasing wear resistance. (Chenxiao & Lee, 2023)

In this study, ABS, PLA and annealed PLA filaments were produced with a three-dimensional printer. As a result, it was determined that ABS has superior wear resistance compared to PLA by using surface punctuation technique and Minitab19 program (Portoaca et al.,2024). In order to examine the service life with the change of the infill density rate, PLA polymer was produced by additive manufacturing method and fatigue life was examined at 2.5 Nm torque and 1200 rpm rotational speed. Gear wheels were produced with fill percentages of 20%, 40%-60%, 80% and 100%. At the same time, the change in the number of rotations with the increase in torque was examined. In the 20% filled sample, fracture occurred in the tooth root and body, while sample with a filling density of 60%, fracture occurred in the tooth root and melting was observed on the tooth surface. With a filling density of 100%, PLA polymer showed a service life of over 300,000 rotations (Muminović et al.,2023).

Glass fiber reinforced ABS composite gears were produced with a three-dimensional printer and their hardness values were investigated with the change in fiber content. Polymer gears with 100% fill rate were lubricated and unlubricated to reduce wear and weight losses were compared. In the study, it was concluded that with the increase of glass fiber reinforcement, the glass transition temperature increased and better bonding between the layers was obtained, but the hardness decreased due to fiber aggregation. In addition, the highest weight loss was measured in the gear wheel without glass fiber reinforcement, designated as G0, under non-lubricated conditions (Bodaghi et al.,2023). With the decrease in the layer thickness of the gear wheels from 0.28 to 0.12, more than doubled time loss occurred, and deviations in tooth size accuracy with the change of helix angle were examined (Korka, 2022).

Acetal, Nylon 66, and PEEK polymers gear wheels were produced by molding method from granule form. Maximum contact pressures were calculated using finite element analysis. The test was varied by using a steel gear to investigate the wear behavior. In the finite element analysis, it is stated that the contact force is higher at the beginning of the mesh, which causes wear at the top end of the driven gear and in the root region of the driven gear. (Li et al.,2011)

The wear behaviors of HDPE, ABS and POM thermoplastics in granular form produced by molding method were investigated by obtaining different variations under the conditions of 0.8, 1.2, 1.6, 2.0 Nm torque and 600, 800, 1000, 1200 rpm rotational speed. The surface temperature increase, which is a result of wear at all torque values at the tooth roots, was observed mostly in POM plastic and least in HDPE plastic. The highest amount of specific wear rate was observed in ABS and the lowest in POM material. In the service life analysis, the POM gear showed the best performance with 2 million turns. (Singh,2018)

For POM and reinforced GFR-POM polymer gear wheels produced by injection molding method, the torque threshold value, which causes the wear to increase abruptly, was obtained by stepwise load increase method. It was observed that thermal damage rapidly increases the amount of unit wear while the strengthening process provides up to 50% improvement in strength. (Mao et al.,2018)

In the investigation of friction and wear of Acetal and Nylon gear wheels, it was determined that tooth surface temperature and load capacity are the major factors affecting wear. Under high load, the temperature rise approaching the melting point leads to deterioration of wear resistance. The wear development of the nylon gear is completely different from that of the acetal gear wheel in that it occurs at the tooth root and in the rolling circle region instead of on the surface. (Mao et al.,2019)

Materials and Methods

Geometry and Manufacturing of Polymer Gear Wheels

The gear wheels were designed using Solidworks@2013 in the geometry detailed in the Table.1. Three types of polymer materials, PLA, PETG and ABS filaments were used to provide material diversity in the study.

Table1. Dimensions of polymer gear wheels used in the experiments

	Driver (Polymer)	Driven (Steel)
Number of teeth	17	22
Pitch Diamater (mm)	102	132
Base Diamater (mm)	87	117
Outside Diamater(mm)	114	144
Module (mm)	6	6
Face width (mm)	10	10
Pressure Angle (degree)	20^o	20^o
Pitch (mm)	18.85	18.85

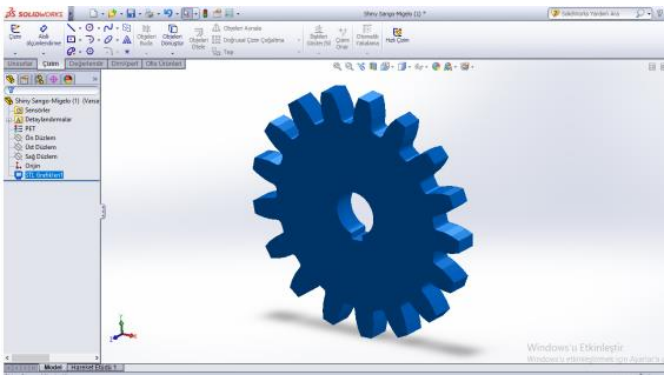

Figure 1. Design of polymer gear wheels

Colourfabb brand filaments with a diameter of 1.75 mm were used for the production of the designed polymer gears. For the wear of the driven (pinion) gear wheels, a gear wheel made of St-32 steel was used as abrasive. By using a steel gear wheel, it is aimed to obtain the accurate service life and the sufficient time for wear and

also prevent from forming cohesion between polymer gears. The amount of wear of the steel gear wheel against the plastic gear wheels is negligible. Polymer gear wheels were drawn in the design program and then transferred to the running program that control the printer. Since each polymer type has different characteristics, different parameters are saved for printing before starting production for each polymer type. These parameters are given in Table 2.

Table 2. Printer parameters for each polymer

Printer Settings	PLA	ABS	PETG
Nozzle Diameter	0.4 mm	0.4 mm	0.4 mm
Filament Diameter	1.75 mm	1.75 mm	1.75 mm
Heated Bed Temperature	60 C^o	85 C^o	70 C^o
Extruder Temperature	210 C^o	245 C^o	245 C^o
Nozzle Diameter	0,40 mm	0,40 mm	0,40 mm
Infill pattern	Rectilinear	Rectilinear	Rectilinear
Infill percentage (%)	100/50	100/50	100/50
Shell Thickness (mm)	0.8/0.4	0.8/0.4	0.8/0.4
Printing Speed (mm/s)	3600	3600	3600

In the test setup, BCN3D Sigma R19 ® brand printer was used for the production of polymer gears whose wear rates will be investigated. Since this new model has two extruders compared to the old version, it provides the advantage of producing geometrically identical products simultaneously and halving the total production time.

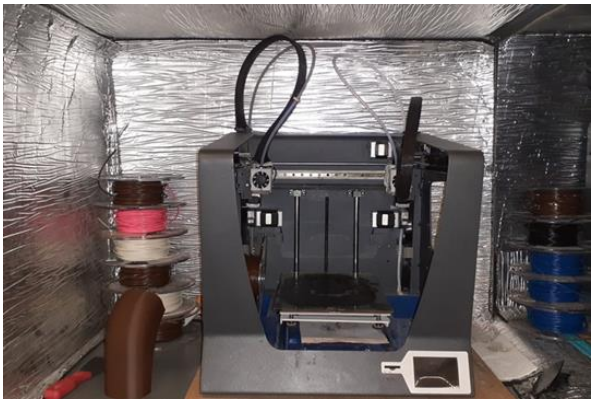

Figure 2. Printer used for the production of polymer gear wheels

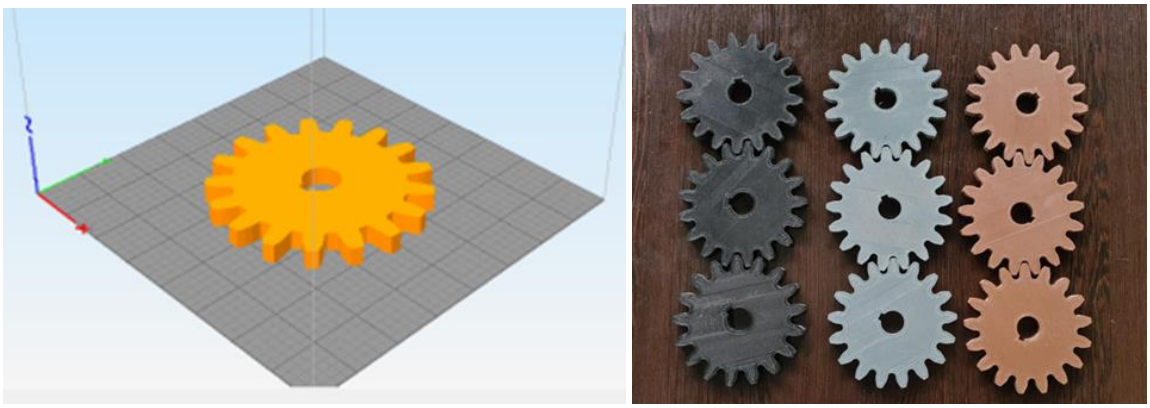

Figure 3. a) Slicing of polymers in the printer program b) PLA, PETG, ABS samples

One of the difficulties encountered in the study is the warpage caused by rapid cooling. The polymer material, which melts above 200 C^o during production, starts to cool down with the ambient temperature. Due to this rapid temperature drop, cooling occurs faster in thin section areas as a rule of heat transfer. For this reason, warping occur at the tooth ends as cooling occurs faster. Since the ambient temperature is lower especially in winter season, environment need to be heated or the printing machine can be insulated. Thus, it is aimed to slow down the cooling rate. Figure 2. shows that the three-dimensional printing device is in an isolated environment. On the other hand, in order to prevent the warping problem, a special solution was applied to the surface of the printer platform to stabilize the base of the product during printing. In this way, the tooth tips, which are

normally expected to cool faster, are stabilized on the table. The Figure 4. clearly shows the stabilizing solution applied to the platform.

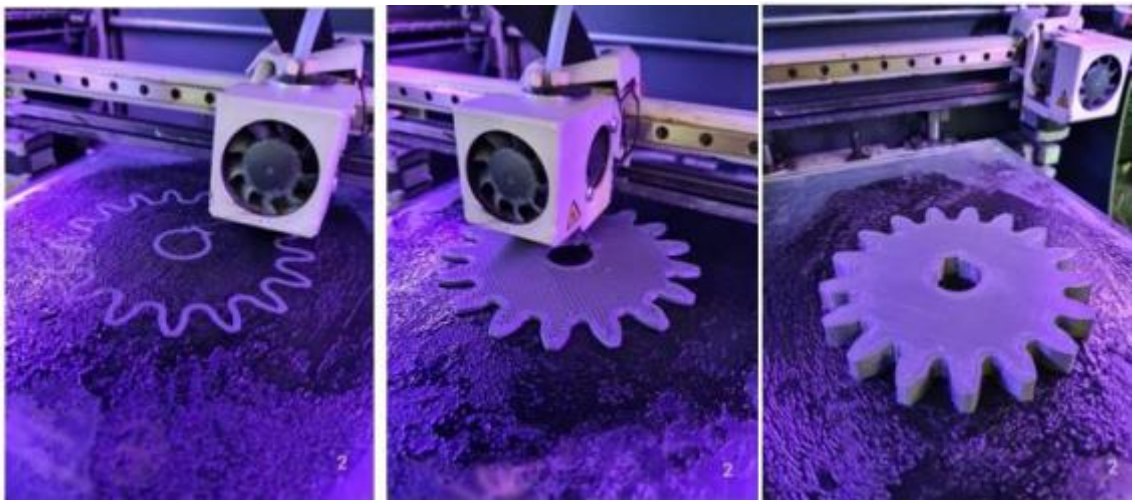

Figure 4. Production stages of PETG spur gear

Investigation of the Variation of the Outer Wall Thickness

Wear can be defined as the removal of chips from the surface of a softer material and it starts from the outer wall of the worn gear wheel. As can be seen in Figure 5, the development of wear on the tooth profile starts from the outer shell of the tooth and progresses by forming a profile towards the center. Therefore, the effect of outer shell thickness variation on wear was investigated in this study.

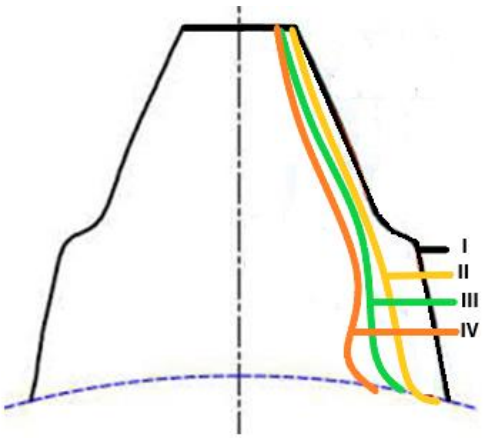

Figure 5. Wear progress from outer shell to center

On the other hand, one of the advantages of the additive manufacturing method is capability of controlling of the number of layers. Thus, the outer wall thickness of the gear can be intervened thanks to FDM technology. While the impact load resistance can be improved by increasing the material density on the outer surface of the tooth, weight and cost can be saved by obtaining a hollow structure in other regions.

Due to the fact that the wear of the gear wheels starts from the outer wall and the ability of the FDM method to make the desired number of walls, the wear rates of the gear wheels with different outer wall numbers are investigated in this section. For this reason, ABS, PLA and PETG spur plastic gear wheels with 50% filling rate from each material type were produced in two groups with outer walls of 0.4 mm and 0.8 mm. In this way, the effect of doubling the outer wall thickness on the wear resistance of the gear wheels was tested by applying certain loads with the help of a test rig.

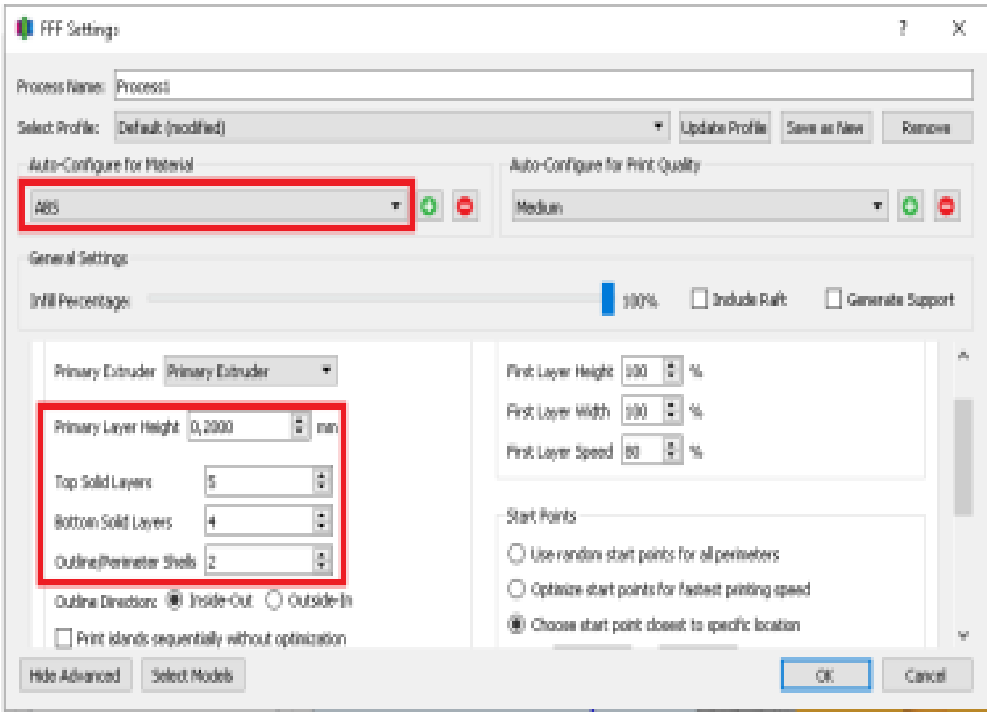

Figure 6.-Setting the outer wall thickness as 0.4 mm

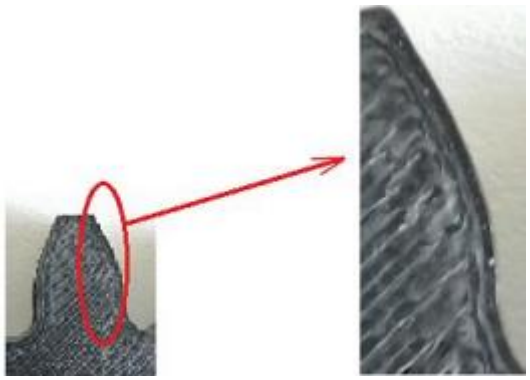

Figure 7. Specimen with wall thickness as 0.4 mm

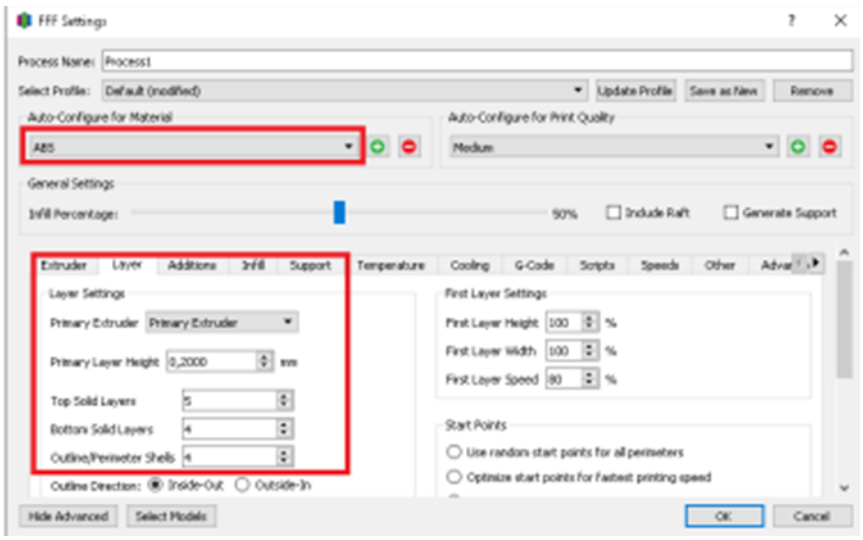

Figure 8. Setting the outer wall thickness to 0.8 mm

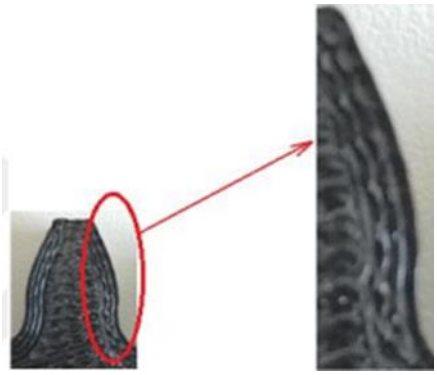

Figure 9. Production of outer wall thickness as 0.8 mm

Influence of Infill Density on Wear

One of the biggest advantages of FDM technology compared to traditional manufacturing methods is that the filling density of the product can be adjusted during production. (Nafiz,2023). It was examined the effect of filler density on strength in previous studies and stated that the minimum filler value can be 10-20% in order to maintain strength of body (Muminović,2023). One of the advantages of controlling the infill density is to reduce the total production time. In this section, the filling ratio of polymer spur gears is halved, less material consumption is aimed and the change in production time is analyzed. For this reason, two groups of spur gear wheels were produced from PLA, ABS and PETG filament materials with fill percentages of 100% and 50%. The produced samples were rotated 10^5 turns with the help of the test rig with 900 rpm rotation speed and 1.5 Nm torque load.

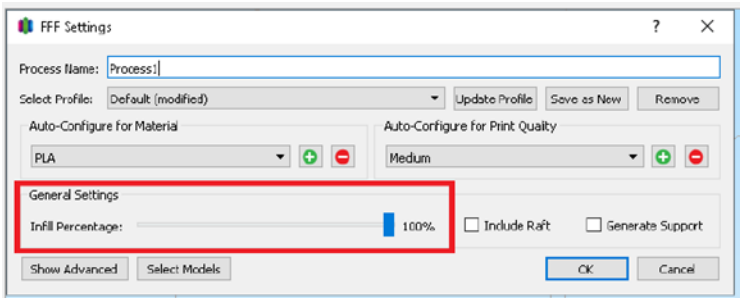

Figure 10. Setting the percentage of internal filling to 100%

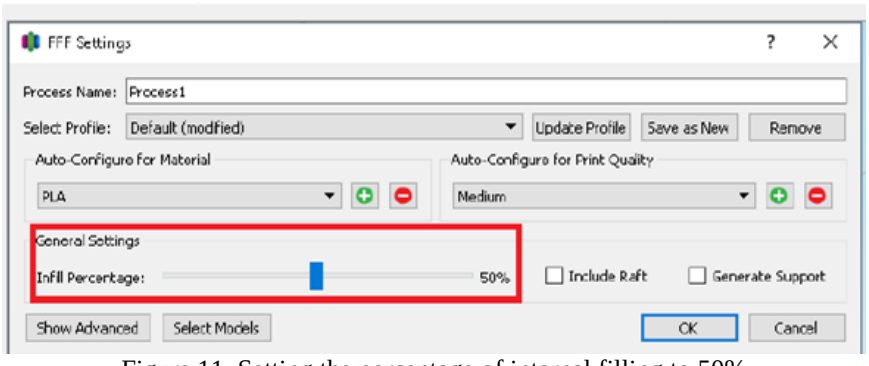

Figure 11. Setting the percentage of internal filling to 50%

Test Procedure

In the study, the FZG (Forschungsstelle fur Zahnrader und Getriebebebau) closed circuit test rig, which has been previously experienced in the literature, was used to determine wear and the service life of the gears. This test rig has been used many times to compare gear wear, corrosion, lubrication efficiency and oil classes by temperature control. (Lacey,1997)

In the test set-up, an electric motor with a power of 0.75 kW gives the first movement to the pinion gear via coupling connection. The electric motor can provide speeds of 300, 600 and 900 rpm. The components of the test rig are numbered in Figure 12.

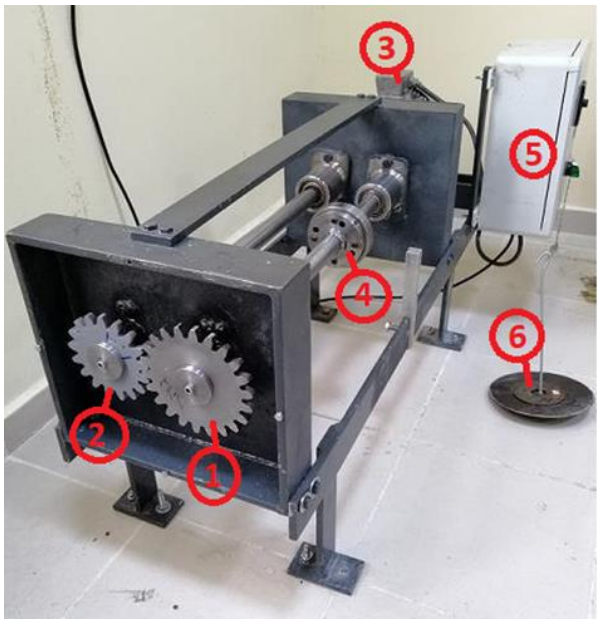

Figure 12. Test setup and components

Table 3. Illustration of test rig components

Test Rig Components	
1	Driven Gear (Steel)
2	Driver Gear (Polymer)
3	Motor Drive
4	Flange Coupling
5	Switch board
6	Scale pan

Relationship between Filling Percentage and Production Time

As mentioned earlier, one of the biggest handicaps of FDM technology is the long printing time. One of the advantages of the printing software is that the printing time can be seen before the process starts. Thus, the user can control the production more effectively and provide raw material supply. The production duration of the polymer gear wheels to be used in the study with the change of the infill rate are shown in Figure13.

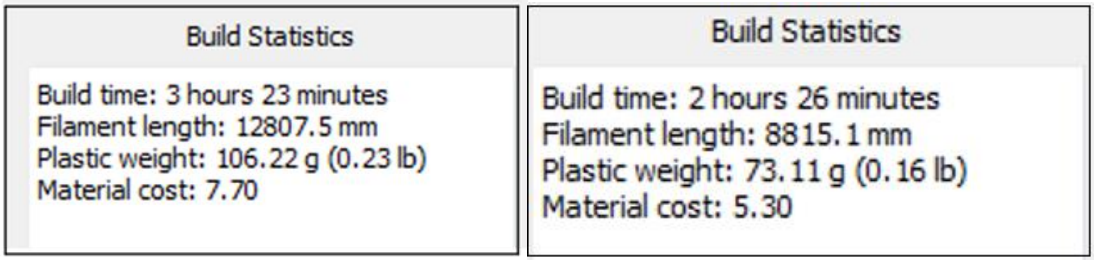

Figure 13. a) 100% filled polymer gear b) 50% filled polymer gear

Looking at the required printing time data obtained through the printer interface, 203 minutes are needed for a polymer gear to be produced as 100% full, while 146 minutes are needed for a polymer gear wheel to be produced as 50% full. This means that the reduced filler rate provides the user with a saving of approximately 25% in terms of time, energy and maintenance costs. When the effect of the reduction of the infill percentage in terms of material consumption is examined, 106.22 g of filament is required for a 100% full polymer gear wheel, while 73.11 g of filament is required with a 50% infill percentage. It can be noted here that although the filling percentage is reduced by 50% through the program, the weight is reduced by approximately 31%. The

reason why the weight does not decrease in the same way as the fill percentage is that the printing machine saves filament more intensively in the center of the product in order to ensure product strength by producing a thinner pattern.

Investigation of Wear with Change in Filler Percentage

In this section, the effect of filler density, which is one of the advantages of additive manufacturing, on wear is analyzed. The obtained ABS, PLA and PETG gear wheels with 50% and 100% filler percentages were rotated at 900 rpm with the load placed on the scale pan (number 6) with a torque of 1.5 Nm and the rotation speed shown was adjusted from the selection panel (number 5) shown in Figure 12. REDWAG brand, seen Figure 14, analytical weighing scale was used to calculate the material loss. Each polymer was weighed electronically before the experiment and again after being subjected to abrasion with a steel gear at 100.000 cycles.

Figure 14. Analytical weight scale

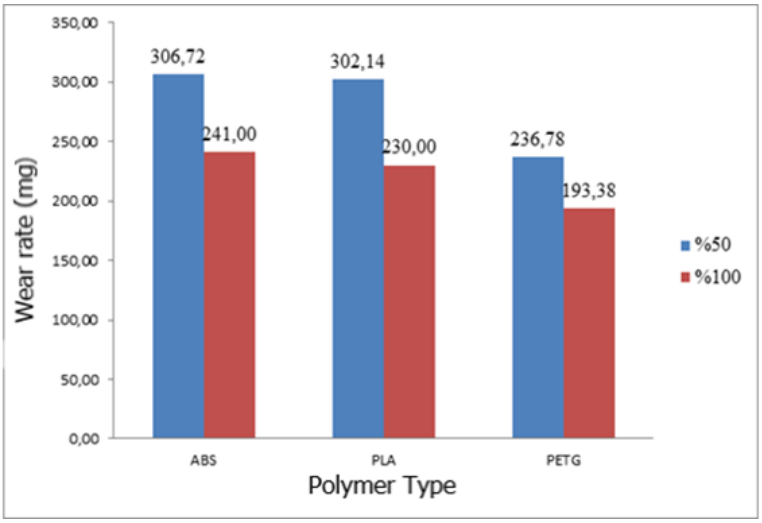

Figure 15. Change in infill percentage versus loss material due to abrasion

Effect of Outer Shell Thickness on Gear Wear

It was previously stated that wear develops in a profile starting from the outer shell towards the center. Therefore, in this section, the effect of the variation of the tooth shell thickness on the wear is investigated by measuring the mass losses. ABS, PLA and PETG polymer gear wheels with a 0.4 mm and 0.8 mm shell

thickness were rotated 100,000 revolutions with a rotational speed of 900 rpm against a steel gear wheel and weighed with an electronic scale to measure the mass losses.

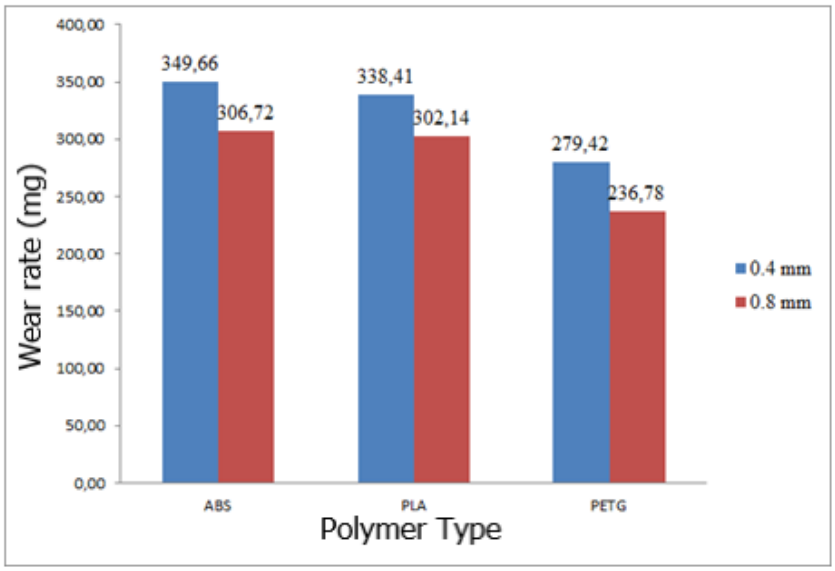

Figure 16. Material loss with the change of shell thickness

Results and Discussion

In the study, ABS, PLA and PETG gear wheels with identical geometry produced with FDM technology. Polymer spur gears were subjected to wear by operating with a steel gear using a test setup in which the rotational speed and torque can be controlled. In the study, the plastic gears were tested under the same conditions and the innovations of the additive manufacturing method were utilized as well as understanding which polymer type has higher wear resistance.

One of the benefits of FDM technology is the ability to intervene in the fill percentage as the printer working. In this way, by reducing the fill percentage in conditions where the strength conditions are not demanding, production time is reduced and labor and energy savings are achieved. For this reason, wear tests were carried out in this study using 100% and 50% samples. When filler rates were halved, wear rates showed growth; it was observed that 31.4% for PLA polymer ,27.2% for ABS polymer, 22.4% for PETG polymer respectively. In other words, PLA was the most affected polymer type when the filling percentage was halved. In general, in case 50% drop in the filling percentage cause an increase of approximately 30% in the amount of abrasion.

Another result obtained in the experiments was that the strengths of the polymers were PETG, PLA and ABS, respectively, even though the filling percentage changed. It was previously stated that wear starts from the outer wall of the gear wheel and that this thickness affects the gear wheel strength. As a result of the experiments, it was seen that the wear change with increasing the outer shell thickness from 0.4 mm to 0.8 mm is calculated as 10.71% for PLA polymer, 12.28% for ABS polymer and 15.26% for PETG polymer. It can be said that the increase in outer shell thickness equally for all polymers, the highest durability and lowest wear were observed for PETG, ABS and PLA respectively. When the effect of increasing the outer shell thickness on the strength is considered in general, it caused an average improvement of 12% for all polymers.

Conclusion

FDM technology firstly melts filament and molten material forms the desired geometry. Then polymer starts to solidify on the platform. The key point is here obtaining a progressive cooling rate, because the cooling rate is vital for making vigorous bonds among the layers. That is why printing machines can be insulated to control cooling rates instead of running in an exposed atmosphere. Table 2 shows the amount of bed temperature for each polymer type. According to the table, because PLA has a minimum bed temperature, as 60C^{o}, it can be assumed that it has the ability to print better than the other polymers. Conversely, the highest energy is needed to print for ABS polymer that has a bed temperature of 85 C^{o}.

Recommendations

As plastics have poor thermal conductivity, they tend to emit heat energy. This energy gives rise to become softer and subsequently lose their toughness. Because of this drawback of plastics, Researchers faced distortion problems at the tips of gears. To overcome this problem, the tip of plastic gears can be glued with a chemical solution which can be dissolved after printing process.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

Acknowledgements or Notes

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* Researchers conducted the experiments in the laboratory at Hitit University and meet all the costs without getting any incentives.

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Comparative Analysis of the Flight Characteristics and Energy Efficiency of a Quadcopter and an Octacopter

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Abstract: This publication is part of a study aimed at finding the optimal configuration (tricopter, quadcopter, octacopter, etc.) in terms of flight stability, payload and energy efficiency. For this purpose, full non-linear quadcopter and octacopter models have been created. Data from real objects (linear and weight characteristics, parameters of the engine-propeller system) were used to create them. Quadcopter and Octacopter use the same motors and propellers. In the simulations, the mass of the two objects is the same. Both models are controlled with PID controllers in four channels (Yaw, pitch, roll and height). The initial adjustment of the regulators was carried out according to the second method of Ziegler-Nichols. A secondary adjustment of the regulators was carried out, with the goal of minimal over-adjustment, speed and accuracy. A parallel simulation of the nonlinear models in the Simulink environment was performed, on the basis of which the conclusions about the stability and energy efficiency of the quadcopter and the octacopter were made.

Keywords: Quadcopter, Octacopter, Energy efficiency, Sustainability, PID controller

Introduction

At the beginning of the twentieth century, a number of models of human-controlled quadcopters appeared. These vehicles are one of the first that can successfully be used for vertical take-off and landing. However, early prototypes performed poorly and later ones were difficult to steer due to their instability and limited control capabilities. The Breguet brothers' Gyroplane No.I was one of the earliest attempts to create a propeller-driven aircraft (Figure 1.) On September 29, 1907, Gyroplane No.I flew for the first time, albeit at altitude only 0.6 meters. It was neither controllable nor maneuverable, but it was the first time a rotorcraft lifted itself and a pilot into the air. Later the apparatus rose to a height of 1.52 m above the ground (Aviastar.org, n.d.).

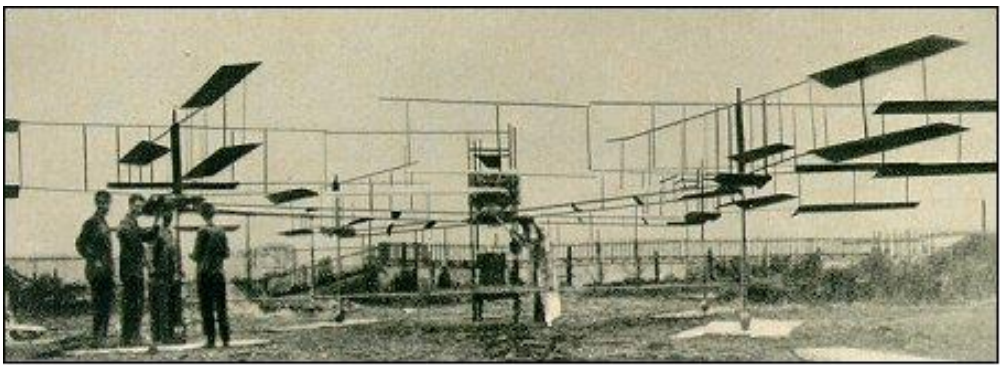


Figure 1. Breguet brothers gyroplane No.I - 1907

In recent years, the development of unmanned aerial vehicles has been very rapid. They are widely used in the civil and military spheres. Civilian applications of UAVs range from transportation and media to agriculture and construction. The wars in Ukraine and the Middle East show in practice the diverse application of unmanned aerial vehicles in real combat operations. Their use has become a must-have element for achieving success on the battlefield. Their widespread use does not mean that UAVs are ideal. They are in a stage of rapid development, especially in relation to the stability and safety of the flight (Biliderov, 2024), its duration and energy efficiency (Georgiev, 2022). This post is part of a study that will compare the features of different types of copters. This is a study on the properties of a quadcopter and an octacopter with the same engines, propellers, and weight. The aim of the research is to determine the optimal configuration in terms of sustainability and energy efficiency.

Mathematical Models

A quadcopter and an octacopter differ in the number of motors, their placement, and the controls required. To make it possible to compare the characteristics of the two models, the same engines, propellers and batteries were used in their creation. The mass of both devices is the same 1.5 kg. This corresponds to a class 450 copter type UAV.

Non-linear mathematical models of quadcopter and octacopter have been created. The two models consist of 12 nonlinear differential equations each. The motion of the center of mass of an unmanned aerial vehicle in an inertial coordinate system is described by the vector equation of Newton's second law:

$$m\frac{d\vec{V}}{dt} = \sum \vec{F} \tag{1}$$

After equation (1) is developed along the axes of the coupled coordinate system, the complete differential equations for the translational motion of the center of mass are obtained:

$$\begin{aligned} \dot{V}_x &= \frac{dV_x}{dt} = \frac{F_x}{m} - \omega_y V_z + \omega_z V_y \\ \dot{V}_y &= \frac{dV_y}{dt} = \frac{F_y}{m} - \omega_z V_x + \omega_x V_z \\ \dot{V}_z &= \frac{dV_z}{dt} = \frac{F_z}{m} - \omega_x V_y + \omega_y V_x \end{aligned} \tag{2}$$

The kinetic momentum change theorem is used to describe the rotational motion around the axes of the connected coordinate system.

$$\frac{d\vec{K}}{dt} = \sum \vec{M} \tag{3}$$

The complete equations for the rotational motion around the center of mass are:

$$\begin{aligned} \dot{\omega}_x &= \frac{1}{I_x}\left[M_x - \left(I_z - I_y\right)\omega_y\omega_z\right]; \\ \dot{\omega}_y &= \frac{1}{I_y}\left[M_y - (I_x - I_z)\omega_z\omega_x\right] \\ \dot{\omega}_z &= \frac{1}{I_z}\left[M_z - \left(I_y - I_x\right)\omega_x\omega_y\right] \end{aligned} \tag{4}$$

Quadcopter and Octacopter are symmetrical aircraft. The lifting force in them is created respectively by two pairs of engines, in the case of the quadcopter, and four pairs of engines, in the case of the octacopter. The propellers rotate (in pairs) in opposite directions as shown in Fig.1 and Fig.2. They don't have the problem with the reactive moment created by the rotating propellers. Before deriving the expressions for the forces and moments acting on the aircraft, the following assumptions must be made:

- Quadcopter and Octacopter are treated as an absolute rigid body, which means that the distance between two arbitrarily chosen points of it remains constant during the flight;
- The mass of the aircraft does not change during flight;
- The mass of the aircraft is symmetrically distributed. From this assumption it follows that the cross moments of inertia $I_{zx} = I_{xz} = I_{yz} = I_{zy} = I_{xy} = I_{yx} = 0$.

After the assumptions made, the motion of each of the two apparatuses can be described as the motion of an absolutely rigid body with six degrees of freedom. For reliable modeling of the movement of aircraft, it is necessary to take into account the dynamics of changes in the lift force and the reactive moment created by each engine. The lift force and the reactive moment are calculated using formula 5. The angular velocity of the rotor i, denoted ω_i creates an axial force f_i. The angular velocity and acceleration of the rotor also create a reactive moment around the rotor axis.

$$\begin{aligned} f_i &= k\omega_i^2, \\ \tau_{M_i} &= b\omega_i^2 + I_M\dot{\omega}_i, \end{aligned} \tag{5}$$

Where: k is a constant proportional to the thrust. It depends on the geometric characteristics of the propeller;
b is a constant proportional to the reactive moment;

- I_M the moment of inertia of the rotor.

In the mathematical modeling of the aircraft and the simulations, the following right-oriented rectangular coordinate systems were used:

- Earth or starting coordinate system Figure 2. Its origin M_1 is fixed on the earth's surface. It is the departure point or the first point of a partially orthodromic route. The M_1Zg axis is directed up the local vertical, and the direction of the other two axes is chosen according to the task so that they form a right-oriented rectangular coordinate system. Normally, the M_1Xg axis is directed in the direction of the runway for airplane-type aircraft (actually the direction of the first partial orthodrome) or in the north direction for copter-type aircraft
- The origin O of the body-fixed coordinate system is located at its center of mass fig. 3 and fig. 4. Axes OX, OY and OZ are rigidly connected to the aircraft, coincide with the main inertial axes and set its position in space.

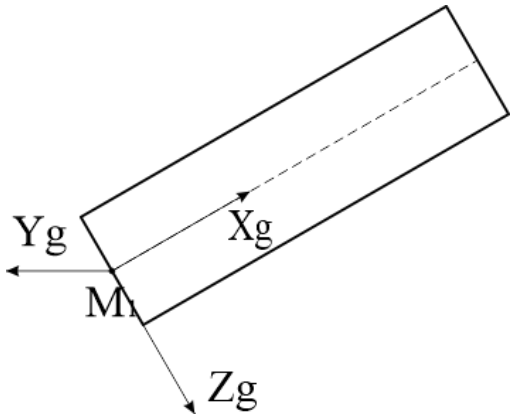


Figure 2. Starting coordinate system

Mathematical Model of a Quadcopter

The mathematical model of a quadcopter is created based on expressions (2) and (4). In equations (2) F_x F_y F_z denote the external forces acting on the aircraft. They are described in more detail with the following expressions:

$$\begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix} = \begin{bmatrix} -G.sin(\vartheta) \\ f_1 + f_2 + f_3 + f_4 - G.cos(\gamma)cos(\vartheta) \\ G.sin(\gamma)cos(\vartheta) \end{bmatrix}, \tag{6}$$

where: G – force of gravity directed along the local vertical;
f_1, f_2, f_3, f_4 - forces created by the four engines;

γ, ϑ – bank and pitch angles. Determine the mutual position between the Earth and the body-fixed frame.

Substituting (6) into (2) yields the first three differential equations (7) of the mathematical model.

$$\begin{bmatrix}\dot{V}_x\\ \dot{V}_y\\ \dot{V}_z\end{bmatrix}=\frac{1}{m}\begin{bmatrix}-G.sin(\vartheta)\\ f_1+f_2+f_3+f_4-G.cos(\gamma)cos(\vartheta)\\ G.sin(\gamma)cos(\vartheta)\end{bmatrix}-\begin{bmatrix}0 & -\omega_z & \omega_y\\ \omega_z & 0 & -\omega_x\\ -\omega_y & \omega_x & 0\end{bmatrix}\times\begin{bmatrix}V_x\\ V_y\\ V_z\end{bmatrix} \quad (7)$$

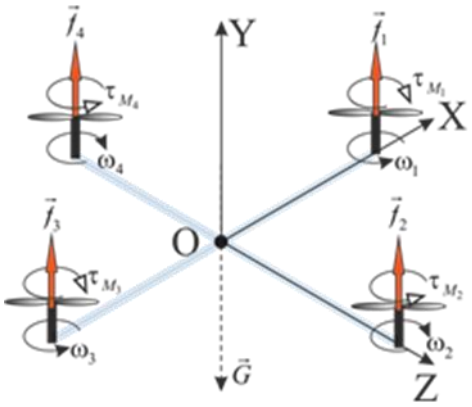


Figure 3. The distribution of external forces and moments acting on a quadcopter

The rotation around the center of mass is described by expressions (4). In them $\begin{matrix}M_x\\ M_y\\ M_z\end{matrix}$ are the external moments acting along the axes of the connected coordinate system of the copter. They are described in more detail with the following expressions:

$$\begin{bmatrix}M_x\\ M_y\\ M_z\end{bmatrix}=\begin{bmatrix}h(f_4-f_2)\\ \tau_{M_1}-\tau_{M_2}+\tau_{M_3}-\tau_{M_4}\\ h(f_1-f_3)\end{bmatrix}, \quad (8)$$

where o τ_{M_i} reactive moment created by the i-th engine;

h – the distance from the center of mass to each of the engines.

Substituting (8) into (9) and expanding the expressions along the axes of the connected coordinate system, we obtain the three differential equations that describe the rotation around the center of mass.

$$\begin{bmatrix}\dot{\omega}_x\\ \dot{\omega}_y\\ \dot{\omega}_z\end{bmatrix}=\begin{bmatrix}\frac{1}{I_x} & 0 & 0\\ 0 & \frac{1}{I_y} & 0\\ 0 & 0 & \frac{1}{I_z}\end{bmatrix}\left[\begin{bmatrix}h(f_4-f_2)\\ \tau_{M_1}-\tau_{M_2}+\tau_{M_3}-\tau_{M_4}\\ h(f_1-f_3)\end{bmatrix}\begin{bmatrix}0 & -\omega_z & \omega_y\\ \omega_z & 0 & -\omega_x\\ -\omega_y & \omega_x & 0\end{bmatrix}\begin{bmatrix}I_x & 0 & 0\\ 0 & I_y & 0\\ 0 & 0 & I_z\end{bmatrix}\begin{bmatrix}\omega_x\\ \omega_y\\ \omega_z\end{bmatrix}\right] \quad (9)$$

The angular position of the quadcopter relative to the earth coordinate system $M_1X_gY_gZ_g$ is set by three angles: ψ - yaw angle, γ - roll angle, ϑ - pitch angle. The relationship between these angles and the angular velocities around the axes of the body-fixed coordinate system is given by the following differential equations:

$$\begin{bmatrix}\dot{\psi}\\ \dot{\gamma}\\ \dot{\vartheta}\end{bmatrix}=\begin{bmatrix}\frac{\omega_y\cos\gamma+\omega_z\sin\gamma}{\cos\vartheta}\\ \omega_x+\tan\vartheta\left(\omega_y\cos\gamma+\omega_z\sin\gamma\right)\\ \omega_y\sin\gamma+\omega_z\cos\gamma\end{bmatrix} \quad (10)$$

The relationship between the connected and the ground coordinate systems is given by a matrix of the direction cosines (11) of the yaw, roll and pitch angles.

$$C_{(\psi,\gamma,\vartheta)}=\begin{pmatrix}\cos\vartheta\sin\psi & \sin\gamma\cos\psi-\cos\gamma\sin\vartheta\sin\psi & \cos\gamma\cos\psi+\sin\vartheta\sin\gamma\sin\psi\\ \cos\vartheta\cos\psi & -\sin\gamma\sin\psi-\cos\gamma\sin\vartheta\cos\psi & -\cos\gamma\sin\psi+\sin\vartheta\sin\gamma\cos\psi\\ \sin\vartheta & \cos\gamma\cos\vartheta & -\sin\gamma\cos\vartheta\end{pmatrix} \quad (11)$$

The spatial displacement of the aircraft is described by the guidance cosine matrix (11) and the linear velocities in the body-fixed coordinate system.

$$\begin{bmatrix} \dot{X} \\ \dot{Y} \\ \dot{Z} \end{bmatrix} = C_{(\psi,\gamma,\vartheta)} \begin{bmatrix} V_z \\ V_y \\ V_z \end{bmatrix}. \tag{12}$$

The system of differential equations describing the movement of the quadcopter consists of the expressions (7, 9, 10, 12). The state vector contains the following variables $(V_x V_y V_z \omega_x \omega_y \omega_z \psi \gamma \vartheta XYZ)$.

Mathematical Model of an Octacopter

The mathematical model of the octacopter is analogous to the model of the quadcopter. The difference between the two models is in the expressions for the external forces and moments acting on the two apparatuses. The external forces acting on the octacopter are described by the following expressions:

$$\begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix} = \begin{bmatrix} -G.sin(\vartheta) \\ f_1 + f_2 + f_3 + f_4 + f_5 + f_6 + f_7 + f_8 - G.cos(\gamma)cos(\vartheta) \\ G.sin(\gamma)cos(\vartheta) \end{bmatrix} \tag{13}$$

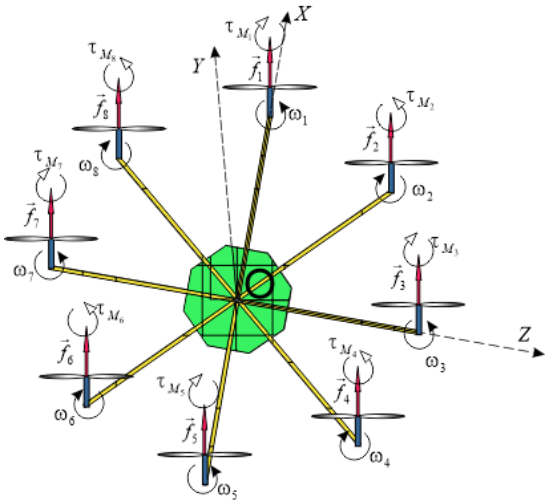


Figure 4. The distribution of external forces and moments acting on a octacopter

The external moments acting on the octacopter are:

$$\begin{bmatrix} M_x \\ M_y \\ M_z \end{bmatrix} = \begin{bmatrix} h(f_7 - f_3) + \text{hcos}\,45^{\circ}(f_8 + f_6 - f_4 - f_2) \\ \tau_{M_1} - \tau_{M_2} + \tau_{M_3} - \tau_{M_4} + \tau_{M_5} - \tau_{M_6} + \tau_{M_7} - \tau_{M_8} \\ h(f_1 - f_5) + h\cos 45^{\circ}(f_2 - f_4 - f_6 + f_8) \end{bmatrix} \tag{14}$$

Substituting (13) into (2) and (14) into (4), we obtain the differential equations for the translational and rotational motion of the aircraft. The mathematical model of the octacopter also includes equations (10) and (12). The state vector is analogous to that of the quadcopter and contains the following variables $(V_x V_y V_z \omega_x \omega_y \omega_z \psi \gamma \vartheta XYZ)$.

Implementation of Mathematical Models in SIMULINK

The simulation of the mathematical models of the quadcopter and the octacopter was performed in the Simulink environment. Each of the two models represents a classical control system with negative feedback and a PID controller (Salih et al.,2010). The initial setting of both regulators was performed according to the second method of Ziegler-Nichols (Copeland, 2008). After receiving working regulators, their coefficients were re-adjusted in order to achieve minimal over-regulation, maximum speed and accuracy. The parallel

implementation in Simulink is shown in Figure 5. The simulations were carried out under the same initial conditions and with the same input signals (desired values of yaw, roll, pitch and flight altitude).

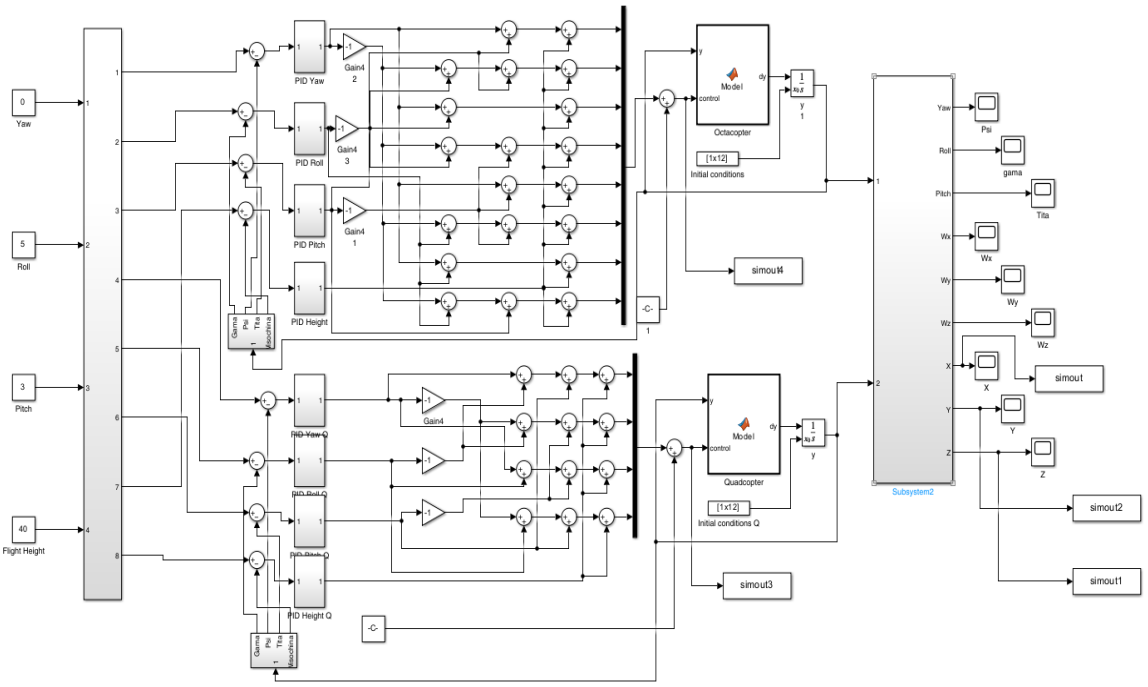
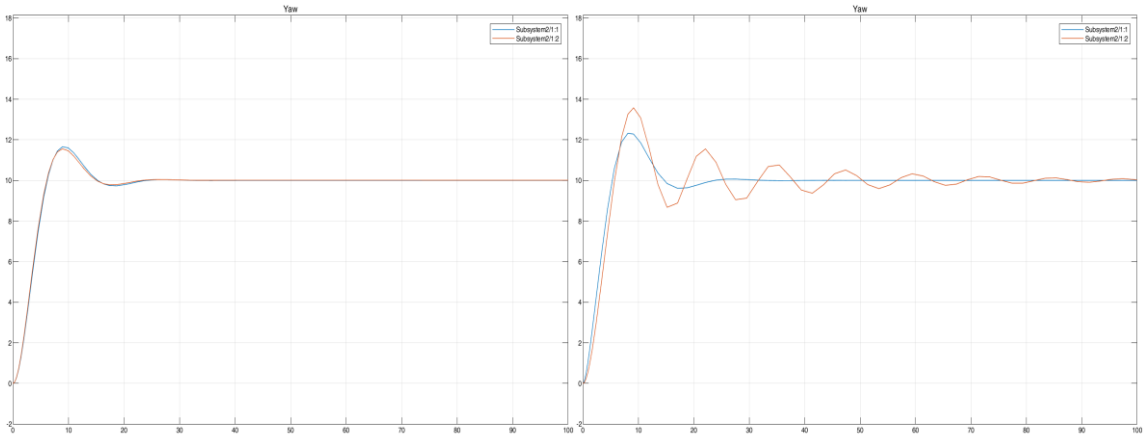


Figure 5. Quadcopter and octacopter model in simulink.

The parallel simulation results are shown in Figures 6 , 7 8 and 9 , where the red graph is the quadcopter response and the blue graph is the octacopter response. The initial conditions of both models are the same$\left(V_x = 0;\ V_y = 0;\ V_z = 0;\ \omega_x = 0;\ \omega_y = 0;\ \omega_z = 0; \psi = 0; \gamma = 0;\ \vartheta = 0;\ X = 0;\ Y = 0;\ Z = 20;\right)$. The initial conditions shown correspond to hovering at a height of 20m. at yaw $\psi = 0^{\circ}$.

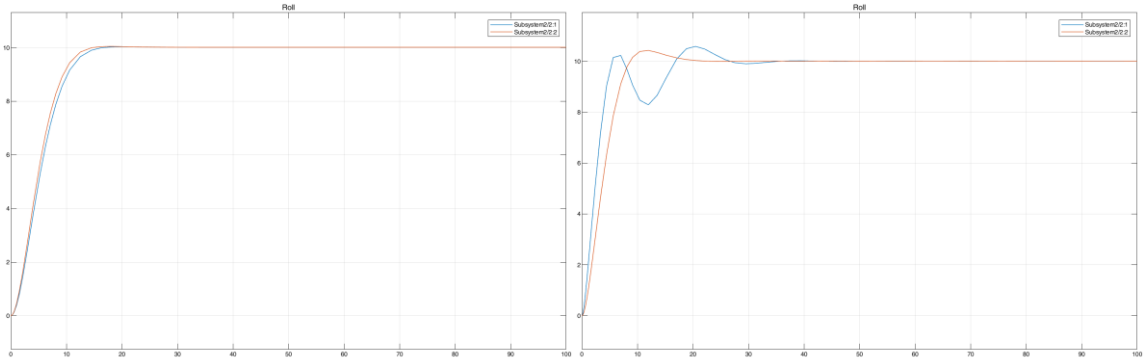


a) b)

Figure 6. Quadcopter

Figure 6a shows the response of the two models when the heading input changes from 0 to 10°. The other inputs (for roll, pitch and height) are equal to zero. Figure 6b shows the course variation of the two models when the input signals change simultaneously, respectively:

- for a yaw from 0 to 10°;
- for roll from 0 to 10°;
- for pitch from 0 to 3°;
- for a height of 20 to 30 m.

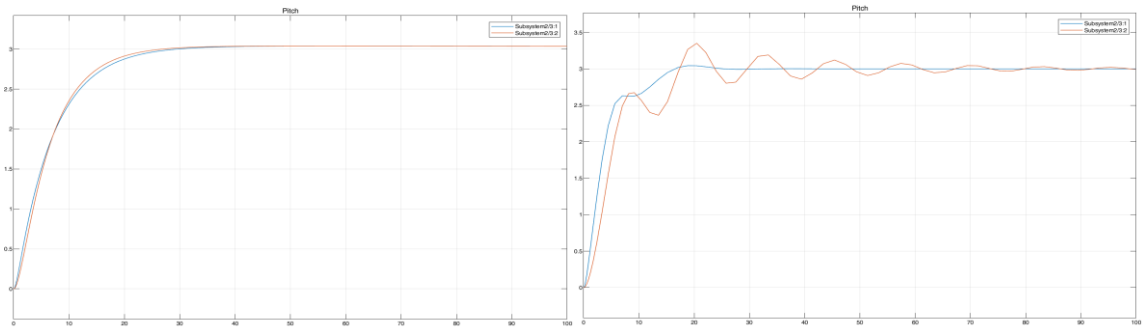


a) b)

Figure 7. Quadcopter

Figure 7a shows the response of the two models when the roll input changes from 0 to 5°. The other inputs (for heading, pitch and altitude) are equal to zero. Figure 7b shows the variation of the roll of the two models when the input signals change simultaneously, respectively:

- for a course from 0 to 10°;
- for roll from 0 to 10°;
- for pitch from 0 to 3°;
- for a height of 20 to 30 m.

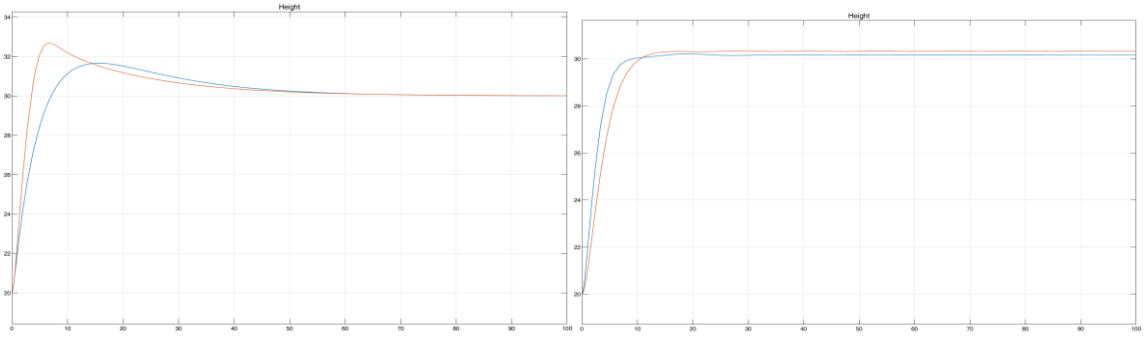


a) b)

Figure 8. Quadcopter

Figure 8a shows the response of both models when the pitch input changes from 0 to 3°. The other inputs (for course, roll and altitude) are equal to zero. Figure 8b shows the change in the pitch of the two models when the input signals change simultaneously, respectively:

- for a course from 0 to 10°;
- for roll from 0 to 10°;
- for pitch from 0 to 3°;
- for a height of 20 to 30 m.



a) b)

Figure 9. Quadcopter

Figure 9a shows the response of the two models when the input signal changes for a height of 20m to 30m. The other inputs (for course, roll and pitch) are equal to zero. Figure 9b shows the change in height of the two models when the input signals change simultaneously, respectively:

- for a course from 0 to 10°;
- for roll from 0 to 10°;
- for pitch from 0 to 3°;
- for a height of 20 to 30 m.

To determine the energy efficiency of the quadcopter and the octacopter, it is necessary to determine the energy consumed by them when performing the same tasks. The created models, shown in Figure 5, allow the revolutions of the engines to be counted at any moment.The engines used in both models are pre-tested. Figure 10 shows the consumption of an engine with propeller when the revolutions vary from 0 to maximum. Figure 11 shows the same data after polynomial smoothing.

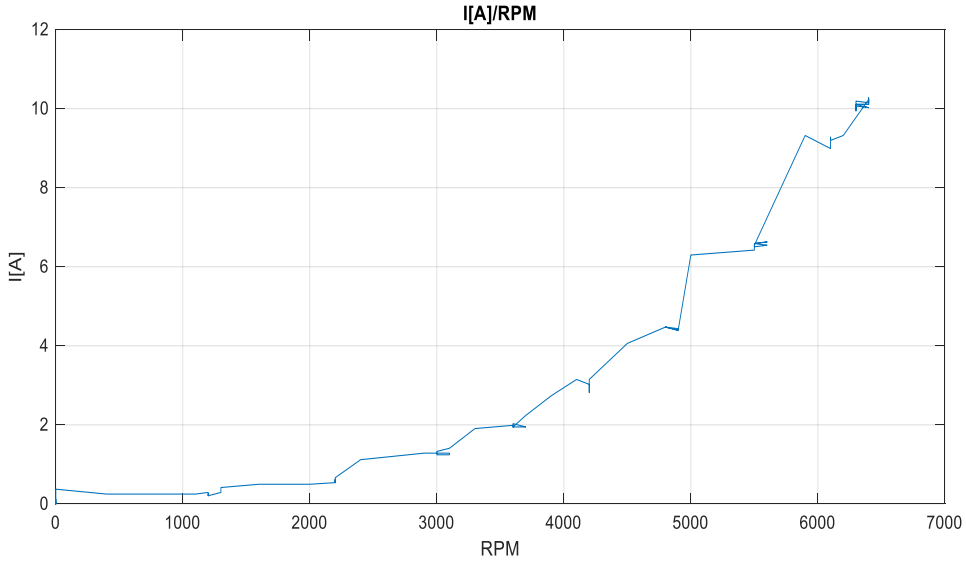


Figure 10. Real data on the consumption of the engines used

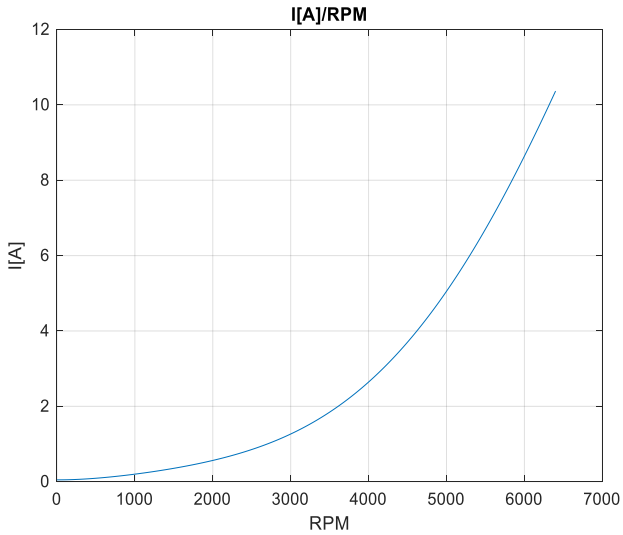


Figure 11. Polynomially smoothed engine consumption data

The duration of the simulation is 100 seconds. The created model allows the revolutions of each engine to be recorded every second, which makes it possible to calculate the energy consumed by them. On average, each of the quadcopter's motors rotated at 5,751 rpm. This means its consumption is 7.6440[A], which for the quadcopter's four motors is 30.5762[A]. On average, each of the octacopter's engines rotated at 4,491 revolutions per minute. Each of its motors consumes 3.6826[A]. The total consumption of the Octacopter is 29.4607[A].

Conclusion

As a result of the simulations and research, the following conclusions can be drawn:
1. Figures 6, 7, 8 and 9 show the faster and more accurate reaching of the desired course, roll, pitch and height values by the octacopter.
2. For the simulation, the octacopter has a lower consumption than the quadcopter. This is due to the higher RPM of the quadcopter motors and the exponential relationship between RPM and energy consumed
3. The results of the present study and those published in Kambushev (2024) show that:
- increasing the number of copter-type drones' engines increases stability and the speed of reaching the desired flight parameters;
- at the same flight weight of the aircraft, those with more engines have a lower energy consumption.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

Acknowledgements or Notes

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ICATI 2024: International Conference on Advances in Technology and Innovation

Energy Audit of an Enterprise for Powder Coating and Blasting Details

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Abstract: An energy audit of an enterprise for powder coating and blasting details was carried out. The production process in an enterprise was examined. A description of technological processes and technological equipment was made. Primary information regarding energy costs incurred in an enterprise for three year period was collected and analyzed. The baseline for energy consumption, depending on the energy consumption in an enterprise for the considered period of the survey was determined. Specific energy costs of an enterprise before and after energy saving measures was calculated and compared. Energy-saving measures, object of investment intention, were presented. Energy and non-energy cost savings from the applied energy saving measures were analyzed. The increase in productivity and competitiveness of the enterprise as a result of the proposed energy-saving measures was shown. On this basis an economic and ecological assessment of the proposed energy-saving measures was carried out. Energy savings in an enterprise are presented as saved energy in kWh/year and as saved carbon emissions in tons of CO_2/year.

Keywords: Technology, Energy engineering, Energy efficiency

Introduction

To mandatory energy efficiency audit in accordance with regulation act in Bulgaria are: large enterprises for the production of goods, large service providers, industrial systems whose annual energy consumption is over 3000 MWh (AYEP, 2016a, 2016b). Small and medium-sized enterprises most often have lower annual energy consumption than the above-mentioned value. Their competitiveness on the European market depends on the following three factors:

- high quality of the produced product;
- low energy costs in production;
- good working conditions for workers.

In addition to improving quality of their products, enterprises strive to achieve European requirements of product quality (Baev et al.,2015; Kaloyanov et al, 2020; Ivanov et al., 2021; Kamburova et al., 2017; Iliev et al., 2013). This allows them to implement quality standards in their production and to sell their products on the European market. The product produced must be manufactured in such a way that during its production minimal CO_2 emissions are released into the environment. Furthermore, for an enterprise to be competitive, the specific energy costs of the enterprise per unit of output product must be as low as possible.This includes energy-saving measures in:

- implementation of highly efficient boilers burning fuels emitting low levels of carbon dioxide;
- implementation of energy-efficient technological equipment in the technological scheme of the enterprise - machines and devices with low consumption of electrical and thermal energy;
- implementation of equipment operating with renewable energy sources - photovoltaic systems, solar systems for hot water, heat pumps, etc.

- implementation of equipment that utilizes waste heat in enterprise - ventilation recuperation systems, heat pumps, etc.
-

The use of highly energy-efficient equipment also has an additional beneficial effect - a significant reduction in operating costs in the enterprise, related to maintenance and repair activities of technological and auxiliary equipment. The direct losses of the enterprise due to unforeseen interruptions of the production process are also reduced. It is important for owners to have real-time information about all costs in the enterprise. In terms of energy costs, this is achieved by introducing energy management and monitoring systems into production. By introducing this type of system, a reduction in energy costs in the enterprise is guaranteed due to the absence of long periods in which the equipment in the enterprise will operate in an inefficient mode. The presence of an energy management and monitoring system is a mandatory condition for the enterprise to implement a certain European quality standards, which will open up new markets for the sale of its products. In addition to the presence of energy management and monitoring systems, low energy costs in the enterprise are also guaranteed by conducting periodic training for personnel. These trainings discuss guidelines for reducing energy costs, which are mandatory for those working in the enterprise.

The increase in the production capacity of the enterprise after the introduction of energy-saving measures should not lead to a deterioration in working conditions for its workers. The implemented technological equipment should have a high degree of automation, which will lead to the possibility of the operator to perform more activities. In order to increase the productivity of labor activities, the worker should also be provided with good working conditions such as:

- optimal air temperature in work premises;
- optimal amount of fresh air in work premises;
- optimal lighting in work premises;
- provision of hot water for sanitary and hygienic needs, etc.

Assessment of the need and effectiveness of energy-saving measures in an enterprise is carried out with the help of energy audit (Rasheva, 2011; Thuman & Younger, 2008; Turner, 1997; Capeheart, et al.,2012; Doty,2016).

In the current energy audit of the enterprise for powder coating and blasting details, the following are proposed:

- energy-saving measures related to the implementation of highly efficient technological equipment;
- energy-saving measures to improve working conditions in the enterprise - temperature, amount of fresh air and lighting of work premises;
- energy-saving measures related to real-time monitoring of electricity consumption in the enterprise.

Method

The object of the present energy efficiency audit of an industrial system is a machine enterprise in Bulgaria. The enterprise provides services related to powder coating and blasting metal details. The following technological processes in process are carried out:

- manual degreasing and drilling on details;
- hooking of detail on a rail track;
- applying a powder coating to detail;
- detail calcination in furnace;
- detail cooling;
- detail packaging.

Detailed energy analysis of the enterprises includes:

- collection of primary information on the energy costs of the enterprise for a period of 3 consecutive years and analysis in order to determine the potential for energy savings;
- determination of a reference year, on the basis of which the baseline of energy consumption of the enterprise is determined;
- determination of specific energy consumption depending on the production in the enterprise;

- determining the amount of energy savings as saved energy and as saved carbon emissions to the environment.

Results and Discussion

In Table 1 are shown data on installed electrical power of the facilities in the enterprise.

Table 1. Installed electrical power of the facilities in the enterprise

Name	Value	Power, kW	Total power, kW
Main technological equipment			
Electrical furnace	1	75.00	75.00
Electrical furnace	1	45.00	45.00
Powder gun	3	0.00	0.00
Auxiliary technological equipment			
Screw type compressor for compressed air, working pressure 8 atm	1	7.50	7.50
Refrigeration air dryer	1	0.41	0.41
Screw type compressor for compressed air, working pressure 6 atm	1	4.50	4.50
Groundwater pump	1	2.00	2.00
Water deionization installation	1	0.25	0.25
Lighting	16	0.054	0.86
Heating devices (Others)	2	6.00	12.00
Hot water tank	1	3.00	3.00
Total usable power			150.52

The main problems in the production process are two and they are:

- Low degree of automation of the available basic facilities involved in the technological process;
- Impossibility of fulfilling the requirements of the European Union regarding the quality of the coatings of the metal parts.

In Table 2 are shown data for annual consumption of electrical energy in enterprise for 2021, 2022 and 2023 year.

Table 2. Annual consumption of electrical energy in enterprise for 2021, 2022 and 2023 year

Year	2021	2022	2023
Month	kWh	kWh	kWh
January	19056	18654	19882
February	19724	18964	18885
March	18879	19542	20158
April	18645	18999	20004
May	19120	18563	19532
June	18774	19004	19556
July	19005	17642	18658
August	18507	19112	19957
September	17597	17209	17888
October	19649	20266	21422
November	20544	20333	20741
December	19056	18854	19357
Total	228556	227142	236040

Data in table show that annual consumption of electrical energy in enterprise is higher for 2023 year.. This is why this year was chosen as a reference year for energy audit. On Figure 1 are shown correlation between used energy in enterprise and number of manufactured unit, which is specified in square meters.

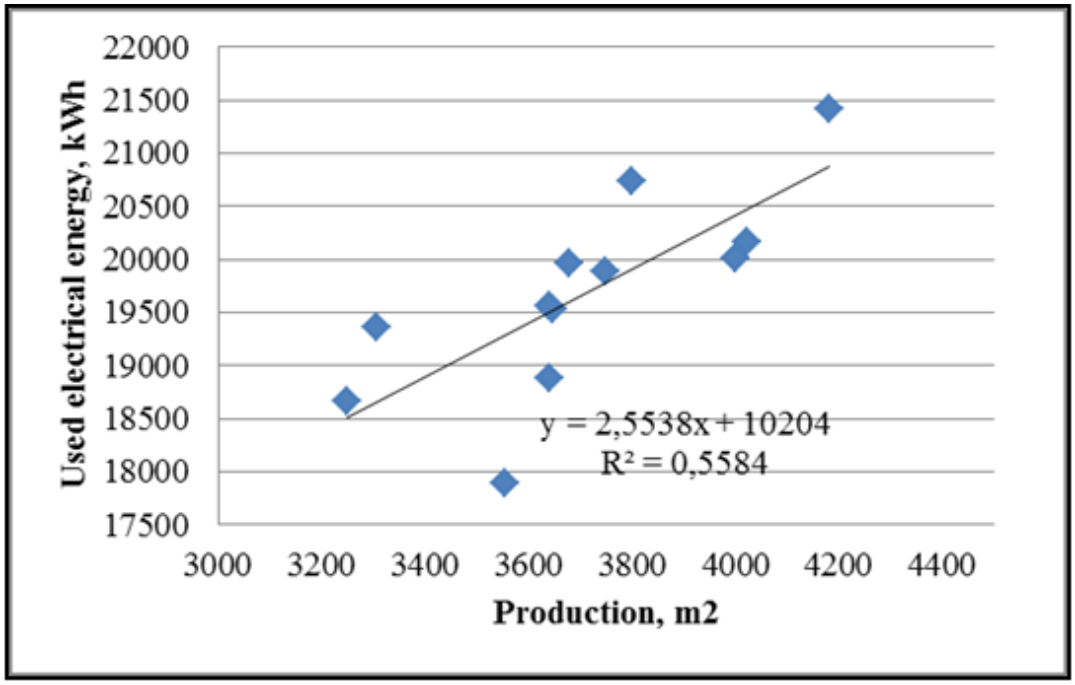

Figure 1. Correlation between used energy in enterprise and number of manufactured unit.

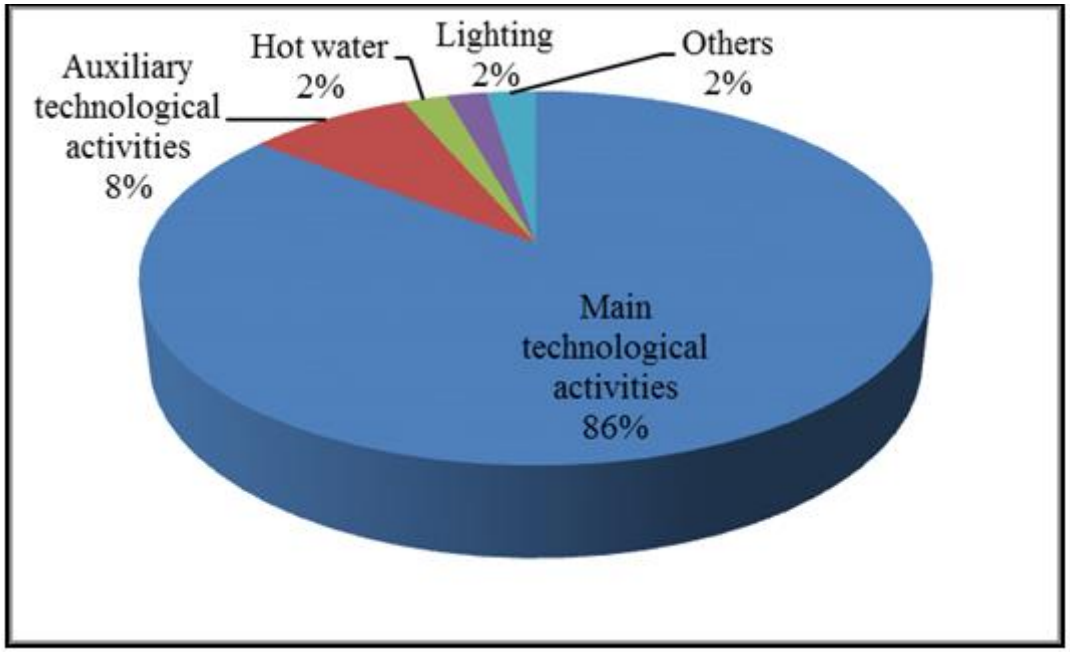

Figure 2. Percentage distribution of electrical energy for reference year

On Figure 2 is shown percentage distribution of electrical energy for reference year. The graph shows that there is a potential for saving energy in machines – main and auxiliary technology equipment. This requires optimization and replacement of facilities consuming electrical energy for production activity.

The enterprise intends to make the following investments:

- automated technology line for cataphoresis coating of steel details;
- replacement of old lighting fixtures with energy-efficient ones;
- recuperation ventilation system for the utilization of waste heat energy;
- energy consumption monitoring system.

In Table 3 are shown data on installed electrical power of facilities in enterprise after energy saving measures.

Table 3. Installed electrical power of facilities in enterprise after energy saving measures.

Name	Value	Power, kW	Total power, kW
Main technological equipment			
Electrical furnace	1	75.00	75.00
Electrical furnace	1	45.00	45.00
Powder gun	3	0.00	0.00
Line for cataphoresis coating	1	40.00	40.00
Auxiliary technological equipment			
Screw type compressor for compressed air, working pressure 8 atm	1	7.50	7.50
Refrigeration air dryer	1	0.41	0.41
Screw type compressor for compressed air, working pressure 6 atm	1	4.50	4.50
Groundwater pump	1	2.00	2.00
Water deionization installation	1	0.25	0.25
Lighting	16	0.04	0.64
Heating devices (Others)	2	6.00	12.00
Hot water tank	1	3.00	3.00
Recuperative ventilation installation	1	2.73	2.73
Energy consumption monitoring system		0	0
Total usable power			193.03

Data for the baseline of energy consumption in enterprise after energy saving measures are shown in a Table 4.

Table 4. Baseline of energy consumption in enterprise after energy saving measures

Name	Value	Unit of measure
Energy consumption automated technology line for cataphoretic coating – good practice	241580	kWh/year
Quantity produced before energy saving measures	57820.2	m^2/year
Energy consumption automated technology line for cataphoretic coating – new line	141480	kWh/year
Energy consumption old lighting fixtures	4636	kWh/year
Energy consumption new lighting fixtures	3709	kWh/year
Energy consumption heating installation changing room without recuperation system	3420	kWh/year
Energy consumption heating installation changing room with recuperation system	1519	kWh/year
Baseline energy consumption	249636	kWh/year
Energy consumption for related with measures activities after energy-saving measures	146708	kWh/year

The implementation of a new technology line for cataphoresis coating of steel details, new lighting fixtures, recuperation ventilation system and energy consumption monitoring system are accordingly marked as energy-saving measures ESM 1, ESM 2, ESM 3 and ESM 4. A comparison of specific costs before and after energy saving measures is shown in Table 5.

Table 5. Comparison of specific costs before and after energy saving measures

	Before ESM			After ESM			
	Energy consumption for related with measures activities	Produced output	Specific energy consumption	Corrected energy consumption for related with measures activities	Energy consumption for related with measures activities	Produced output	Specific energy consumption
	kWh/year	m^2/year	kWh/m^2	kWh/year	kWh/year	m^2/year	kWh/m^2
ESM 1	241580	57820.2	4.18	241580	141480	57820.2	2.45
ESM 2	4636	-	-	4636	3709	-	-
ESM 3	3420	-	-	3420	1519	-	-
ESM 4	-	-	-	-	-	-	-
Total:	249636	-	-	249636	146708	-	-

Energy savings in kWh on ESM 4 are calculated as 8% of total energy consumption for related with measure activities after energy saving measures (based on information of good practices for use energy management systems in practice). The share of enterprise's energy savings compared to the reference year has been determined in energy value (in kWh) and ecological equivalent (t CO_2/ year). The results are shown in Table 6.

Table 6. Energy savings

Energy saving measures	Energy carrier	Energy savings		Ecological equivalent
		kWh	%	t CO_2/ year
ESM 1	electricity	100100	41.44	146.5
ESM 2	electricity	927	20.00	0.8
ESM 3	electricity	1901	55.58	1.6
ESM 4	electricity	11737	8.00	9.6
Total	-	114665	45.93	158.5

Conclusion

With the introduction of energy-saving measures, additional benefits will be realized, as follows:

ESM 1 - with implementation of new automated technology line for cataphoresis coating of steel details degree of automation of production process and quality of production will increase, work errors will be reduced, conditions for greater flexibility in use of materials in production process will be created. This will enable implementation of an efficient production process, growth of manufactured product (up to 30 %), as well as meeting European requirements regarding quality of the applied coating and environmental protection. In addition, there will be an opportunity for highly qualified operators of the new line to perform additional activities;
ESM 2 – installation of new lighting fixtures will lead to reduction of electricity cost for lighting, as well as to an increase in quality of the working environment in enterprise;
ESM 3 - installation of new recuperation ventilation system will lead to reduction of electricity cost for heating, as well as to an increase in quality of the working environment in enterprise;
ESM 4 - with the implementation of energy consumption monitoring system degree of automation and competitiveness of enterprise will increase.

Upon implementation of energy-saving measures, the enterprise will realize an energy savings of 45.93% compared to the baseline of energy consumption, which is equal to an energy savings of 114665 kWh/ year with an ecological equivalent of 158.5 tons of CO_2 emissions saved.

Scientific Ethics Declaration

The author declares that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the author.

Acknowledgements or Notes

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Technological and Innovative Transformation in Marketing: Examination of Social Media Text Stream Visualization Concept with Bibliometric Analysis: Future Agenda

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Abstract: Changes in technology and innovation processes affect many areas. The impact of technology and innovative applications lead to radical changes in marketing strategies. Social media text stream visualization stands out as one of the most important tools of these changes. Social media text stream visualization allows the analysis of text data coming from social media platforms through graphics and infographics. In this way, social media text stream visualization allows the development of more effective and efficient strategies by combining technology and innovation in marketing. In this study, the Web of Science database is used to reveal in which areas the concept of social media text stream visualization has been used in the last 10 years through bibliometric analysis. After the inclusion and exclusion criteria are applied, the final sample consists of 12 refereed articles. Five separate analyses were conducted to test the sample. Performance analysis determined the publication years of the articles, their contributions by country, the outputs of relevant journals, and the sectors where this concept is used most intensively. The findings of the study provide a broad perspective on the research conducted to date and identify potential research gaps. Accordingly, it is seen that the studies within the scope of social media text stream visualization are mostly conducted in the fields of social media, advertising, e-commerce and market research. It was concluded that machine learning, big data, text analysis and time series methods were used in the studies. It is recommended that studies be conducted in the retail, tourism and accommodation and technology sectors for future research. This research aims to contribute to the field of marketing by revealing the gaps in the literature. The study also offers suggestions for future research to be conducted by academics and sectoral researchers.

Keywords: Technology and inovation, Digital transformation, Social media text stream visualization

Introduction

In today's world of rapid digitalisation, social media has become one of the most important platforms that reshape the interaction between individuals and businesses. Social media text flow refers to the dynamic presentation of user interactions, shares and content on these platforms. Visualisation refers to the graphical representation of complex data and information. The combination of these two concepts plays an important role in increasing the impact of content while making social media text flow more understandable.

Visualisation is a critical tool in demonstrating the impact of social media text streams on marketing strategies. Through text streams supported by visual content, brands can reach their target audiences more effectively and attract the attention of users. In this context, the digitalisation of marketing strategies and the visualisation of campaigns carried out on social media shape consumer behaviour and increase brand loyalty.

Technological advancements offer innovations in the management and analysis of social media text streams, enabling brands to make data-driven decisions. Tools such as data analytics and artificial intelligence provide a better understanding of visualised text streams and optimise marketing processes. The digital transformation

process helps businesses strengthen their presence on social media and respond quickly to changing consumer expectations. For a thorough grasp of the subject, a number of factors were examined, including academic journal publications, performance by decade, contributions by nation, and keyword co-occurrence.

Social Media Text Stream Visualization

Social media offers a multitude of data that can be mined to support a variety of business intelligence applications and better inform marketing campaigns, in addition to providing companies with new avenues for customer engagement through online advertising (Royle & Laing, 2014; Osatuyi, 2013; Rud, 2009). The idea of Visualization gives viewers a compiled picture of a dataset that is accessible. It provides a visual interface that allows people to comprehend and examine the dataset. Visualization technology helps people view, browse, distinguish, and comprehend information. It was inspired by scientific computational Visualization, which first emerged in the 1980s (Qi et al., 2015). Creating pictures or other visual representations from massive datasets is the art and science of Visualization.

As a social network that draws people together to share interests and activities, social media platforms like Facebook, Instagram, and Twitter are becoming more and more significant. Numerous photographs with intriguing information are available for information extraction from social networks like Instagram (Miguéns et al., 2008; Nebhi, 2012). Instagram is a relatively new type of social network that allows users to take photographs or videos and share them with others while also giving them a fast option to do so with friends (Hu et al., 2014).

Geolocation-based social media Visualizations were introduced by a few studies. Hochman and Schwartz (2012) used Instagram photo analysis to present a technique for tracking cultural visual patterns. A system architecture for extracting situation awareness information from Twitter posts created during various crises and disasters was given by Yin et al., (2012). Systems for text extraction analysis of social media content were created by several researchers (Zhao et al., 2011; Yin et al., 2012).

Social Media Text Stream Visualization Phases

1. *Data Collection and Preparation*: Gathering and preparing the pertinent data sources is essential before visualising social media data. This could entail using third-party technologies, scraping webpages, or gathering data from APIs. After being collected, the data must be filtered, cleaned, and formatted so that it may be visualised.

2. *Visualization Approaches*: Data from social media can be represented using a variety of Visualization techniques. Bar charts, line graphs, scatter plots, and treemaps are a few popular methods. Every technique has advantages and disadvantages and can be applied to various data types and analytical objectives. For instance, a treemap can represent the distribution of content categories, and a line graph can efficiently show the rise of followers over time.

3. *Interactive Visualizations*: By enabling users to examine and engage with the data, interactive Visualizations offer a more customised and captivating experience. Users can concentrate on particular areas of the data and obtain deeper insights by using features like zooming, filtering, and sorting. Users can examine geolocation data and examine regional trends, for example, using an interactive map.

4. *Sentiment Analysis:* Sentiment analysis is a useful component of social media Visualization since it provides insight into the feelings and viewpoints of users. Sentiment analysis algorithms can categorise social media messages as neutral, negative, or positive by examining text data. Results from sentiment analysis can be visualised to reveal important information about public opinion on particular subjects, brand impression, and customer satisfaction.

5. *Real-time Monitoring*: Real-time monitoring of social media activity is another application for social media Visualization. Businesses may monitor brand mentions, stay up to date on the newest trends, and quickly address customer feedback by consistently gathering and visualising data. Businesses can quickly make data-driven choices thanks to real-time visualizations like live dashboards.

Social Media Text Stream Visualization Tools and Techniques

1. ***Application Programming Interfaces (API):*** The foundation of social media data harvesting is APIs. They enable programmatic interaction between developers and social media sites such as Facebook, Instagram, LinkedIn, and Twitter. Access to information like posts, comments, likes, and user profiles is made possible by each platform's own API. As an illustration, Twitter's API offers endpoints for retrieving tweets based on user handles, hashtags, or particular phrases. This data can be used by researchers to observe trends, examine user behaviour during events like elections or product debuts, or investigate sentiment analysis.

2. ***Web scraping:*** Data extraction from websites, especially social media platforms, is known as web scraping. Web scraping enables you to gather unstructured content, including comments, photos, and videos, while APIs offer structured data. For instance, user-generated material, captions, and hashtags linked to a specific brand can be scraped while evaluating Instagram posts about that brand.

3. ***Social listening tools:*** These tools keep an eye on discussions about particular companies, keywords, or subjects on social media. They compile engagement metrics, sentiment, and mentions. For instance, social listening services are available through Hootsuite, Brandwatch, and Sprout Social. Marketers are able to measure campaign performance, find influencers, and monitor brand perception.

4. ***Analysis of Hashtags:*** Hashtags categorise information across platforms by acting as metadata labels. Understanding user preferences and trends can be gained by examining trending hashtags.

5. ***Analysis of Networks:*** Social media platforms are networks that are connected to one another. Understanding influence, community structures, and information flow can be gained by examining relationships (friends, followers, and retweets).

6. ***Data based on location:*** Location tags are frequently used in social media posts. By gathering geotagged data, you can investigate regional patterns and habits.

7. ***Content Created by Users (UGC):*** User-generated content (UGC) consists of user-generated reviews, photos, videos, and posts. Collecting user-generated content yields genuine insights.

Method

A bibliometric analysis of the studies conducted so far in the field of marketing on the concept of social media text stream visualization is carried out. One useful statistical method for examining publishing trends in a topic is bibliometric analysis. Researchers may effectively pinpoint existing trends and research gaps by using this strategy, which will help guide future investigations (Guo et al., 2019). This method provides a quick understanding of the discipline, which is very helpful for scholars who are eager to investigate a certain field. Science mapping and performance analysis are the two primary bibliometric analytic methodologies. By examining publications, authors, and citations, performance analysis evaluates the impact of science. In the meantime, science mapping uses co-word and co-citation analyses to produce a visual depiction of the organization and development of scientific research (Feng et al., 2017).

Bibliometric Database Selection

Initially, a thorough search was conducted in the chosen Web of Science database. Articles from a greater variety of nations and sources could be analyzed thanks to this approach. One of the most popular and well-known research databases in the world is Web of Science. This made it easier to do a thorough analysis of the material that was available, which enhanced knowledge of the subject.

Identifying the Main Results and Defining the Keywords

In the first search, the keywords ‘social media text stream’, ‘visualization’ and ‘marketing’ in the research questions were used. These keywords were entered into the Web of Science database using the ‘all fields’ search function. As can be seen in Table 1, 51 articles were collected from all these possible combinations. After the inclusion and exclusion criteria, a total of 12 articles related to the field were reached.

Table 1. Keyword results

Database	**Web of Science**
Keywords	‘’Social media text stream’’ and ‘’Visualization’’ and ‘’Marketing’’
Inclusion criteria	Research field: Business/ Marketing Language: English Source type: Article
Exclusion criteria	Research field: Engineering Language: Articles written outside English Source type: Book, book chapter and paper
Number of studies	12

Although a comprehensive search was conducted, the results were filtered according to two main criteria relevant to the topic of the study. Firstly, publications had to be in English. Secondly, studies conducted outside the field - particularly in engineering - were not included. However, the research findings included reviews conducted in the field of business. As a result, 12 peer-reviewed articles on the visualization of social media text streams in marketing were found to be relevant to the field.

Bibliometric Analysis Process

The data were examined after the final sample was determined. VOSviewer software was used in the study to organize the sample in a cluster-oriented manner and to show the visual connections between terms (Van Eck & Waltman, 2010). By producing a cloud map based on numerous pertinent characteristics, such as authors, journals, and keywords, VOSviewer is a tool that builds and presents bibliometric networks (Srivastava & Sivaramakrishnan, 2021).

Analyzing the Most Contributing Author

The information about the authors who contributed the most studies on the concept of social media text stream visualization is as shown in the figure below.

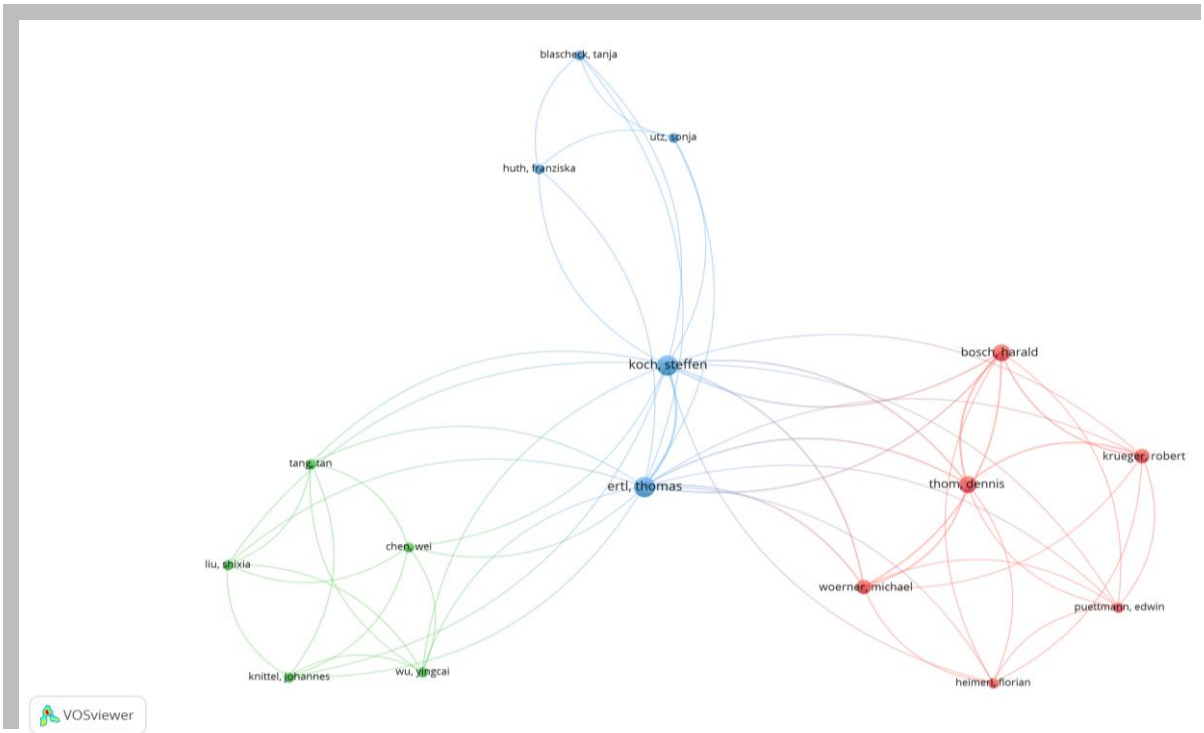

Figure 1. Authors who contributed the most

The top 5 authors with the most publications on social media text stream visualization are shown in Table 2.

Table 2. The most prolific authors

Number	The Author
1)	Steffen Koch
2)	Thomas Ertl
3)	Harald Bosch
4)	Dennis Thom
5)	Robert Krueger

As a result of the analysis, it is seen that Steffen Koch, Thomas Ertl, Harald Bosch, Dennis Thom and Robert Krueger are the authors who contributed the most to the field.

The Most Contributing Institutions Analysis

The figure and table showing the most contributing authors and their institutions in the field subject to the research are given below.

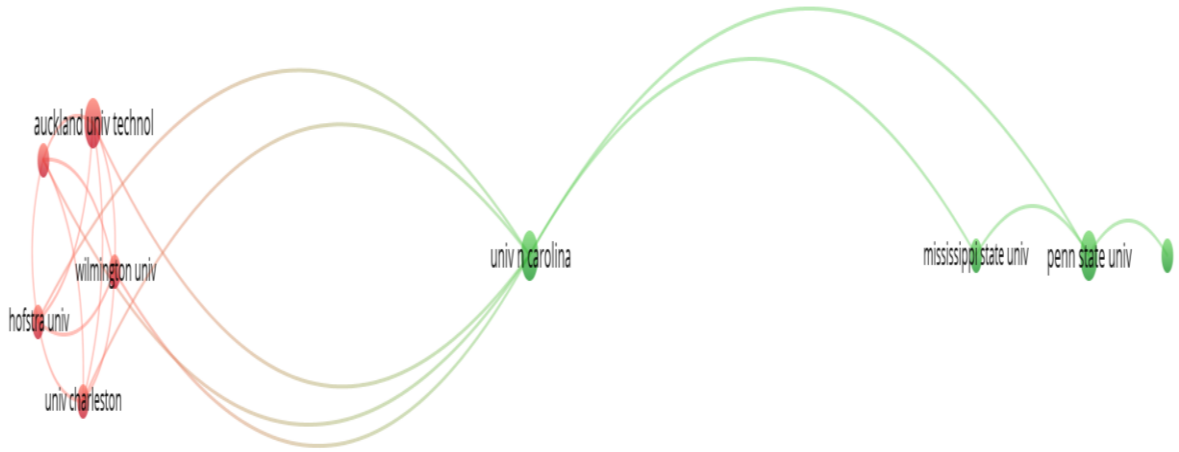

Figure 2. The most contributing institutions

The top 5 institutions contributing the most to the field of social media text stream visualization are given in the table below.

Table 3. The most productive institutions

Number	Institution
1)	The University of Auckland
2)	University of North Carolina
3)	Pennsylvania State University
4)	Wilmington University
5)	Mississippi State University

The top 5 universities producing the most publications are the University of Auckland, University of North Carolina, Pennsylvania State University, Wilmington University and Mississippi State University.

Countries Contributing the Most to the Field Analysis

The countries where the most articles are produced within the scope of social media text stream visualization are shown in the Figure 3. The list of the top 5 countries contributing the most to the field of social media text stream visualization is shown in Table 4. The top 5 countries that contribute the most to social media text stream visualization are USA, China, India, Australia and England, respectively.

Table 4. The most contributing countries

Number	Country
1)	USA
2)	China
3)	India
4)	Australia
5)	England

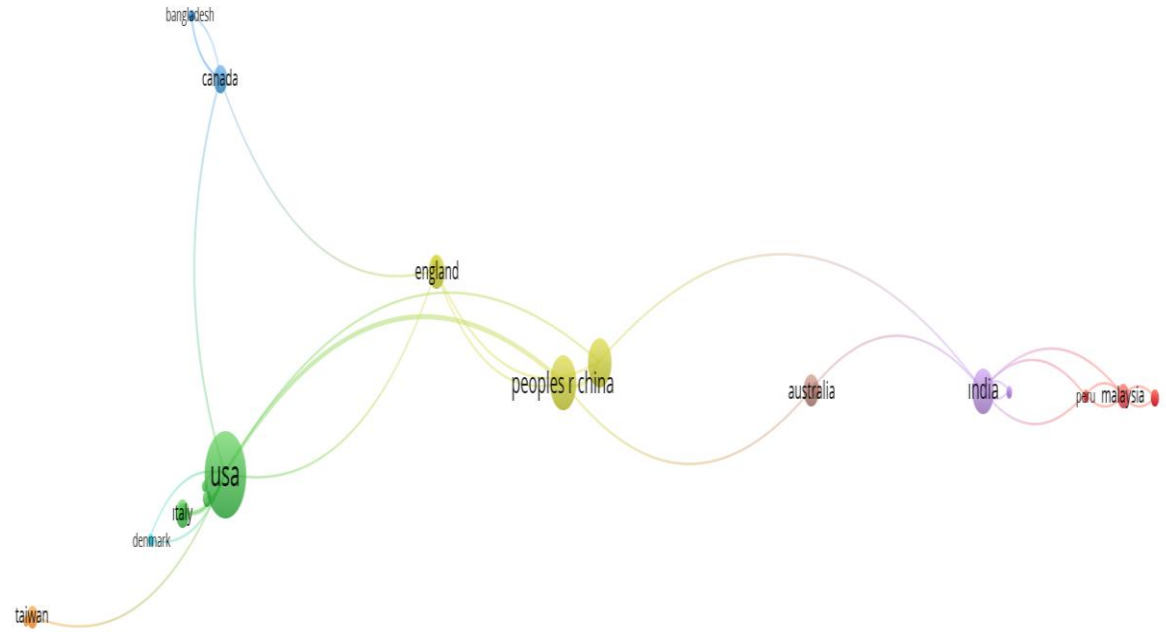

Figure 3. The most contributing countries

The Most Used Keywords Analysis

The result of the analysis of the most commonly used words related to the field within the scope of social media text stream visualization is shown in the Figure 4 below.

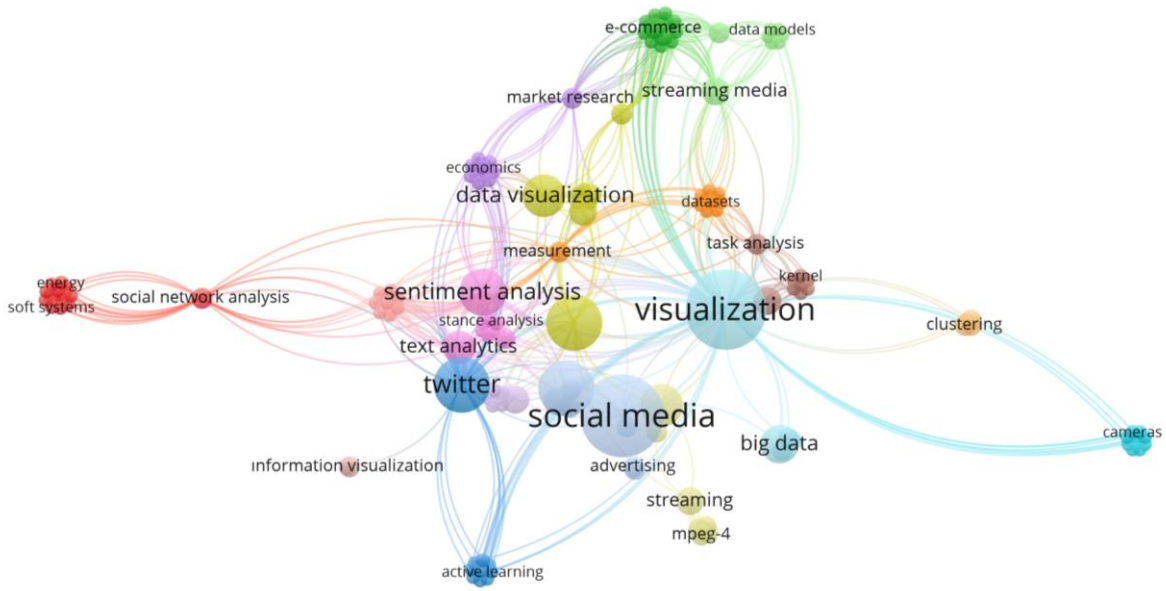

Figure 4. The most used words

The top 10 most used words together within the scope of social media text stream visualization are given in the table below.

Table 5. The most used words

Number	Word
1	Social media
2	Visualization
3	Twitter
4	Sentiment analysis
5	Text Analysis
6	E-commerce
7	Big data
8	Streaming
9	Advertising
10	Market research

When the studies conducted in the field are analyzed, the words that are most frequently used together and subject to studies are shown through figures and tables. Accordingly, while it is seen that the concept of social media text stream visualization has an intensive use on Twitter as a social media tool, it is concluded that the most commonly used areas are e-commerce, advertising and market research.

Number of Publications by Years

In this part of the bibliometric analysis, the distribution of studies on social media text stream visualization according to years is presented. The number of publications by years is shown in Figure 5.

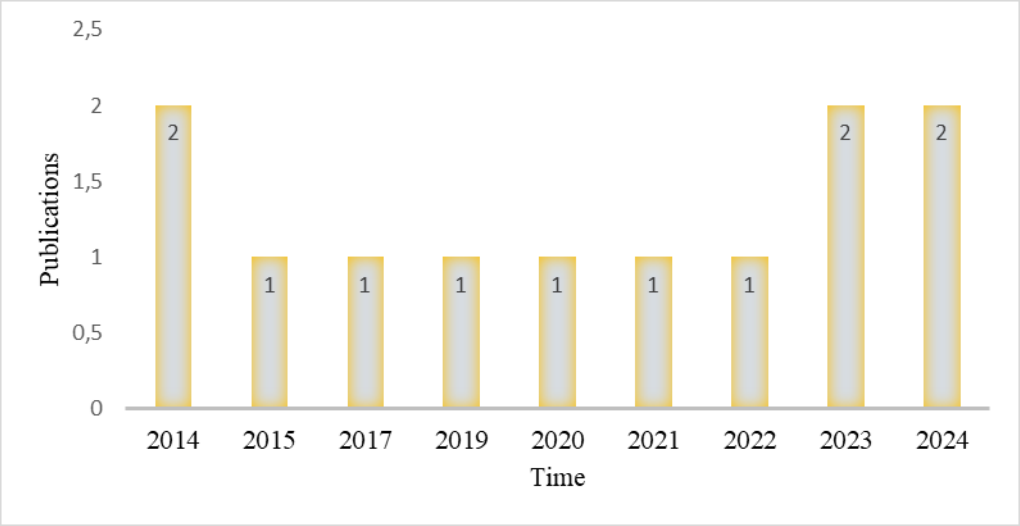

Figure 5. Number of publications by years

It is seen that studies on the concept of social media text stream visualization have increased especially in the last 10 years. As a result of the literature analysis, it has been determined that the number of studies in which the studies on the field are handled together with marketing is very few. It can be stated that the most publications were carried out between 2023 and 2024. Accordingly, it is seen that there are relatively fewer studies in the field within the scope of marketing and that there are studies that can be written about the field. It is seen that there were two studies on the field in 2014, 2023 and 2024, and one study on the field between 2015 and 2022.

Analysis According to Publication Sources

The figure below shows the journals in which the studies carried out within the scope of social media text stream visualization was published. The journals of the 12 articles that were bibliometric analyzed in the study are also indicated in the Figure 6.

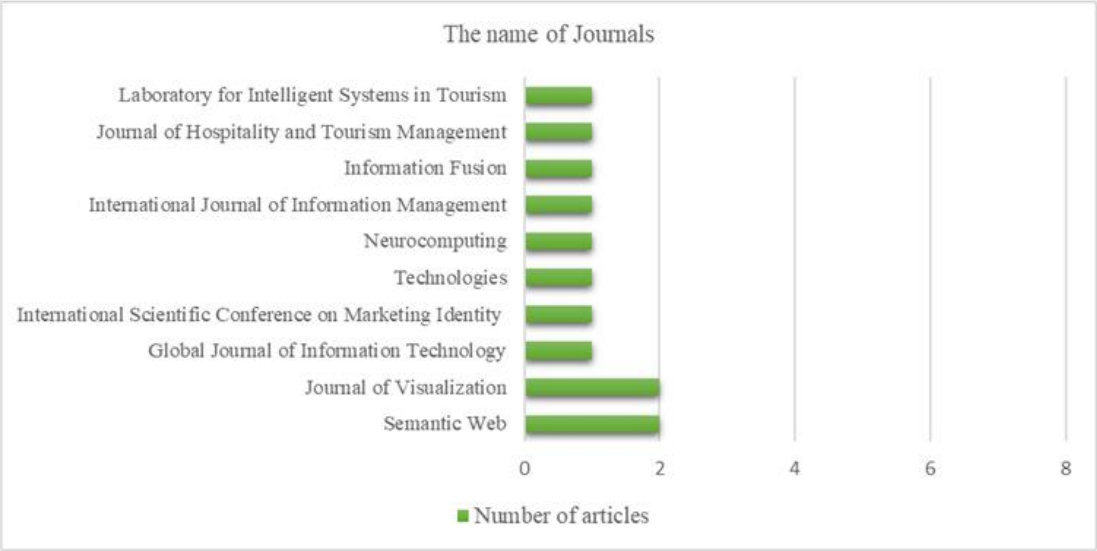

Figure 6. The ten most prominent academic journals

As a result of the analysis, it is seen that there are a total of 12 articles on social media text stream visualization in the field of marketing. In this context, in Table 7, which includes 10 journals with 12 articles, it is seen that the most studies are in Semantic Web and Journal of Visualization. It is seen that the studies on the field are mostly published in journals focusing on information systems, technology and tourism. Accordingly, Laboratory for Intelligent Systems in Tourism, Journal of Hospitality and Tourism Management, Information Fusion, International Journal of Information Management, Neurocomputing, Technologies, International Scientific on Marketing Identity and Global Journal of Information Technology.

Results and Discussion

One of the methods performed within the scope of bibliometric analysis was the analysis of words. Accordingly, the most commonly used words within the scope of social media text stream visualization were brought together and cluster analysis was performed. Accordingly, it is seen that there are five different clusters related to the field. After the word analysis shown in Figure 4, the grouping of the clusters is shown in Figure 7.

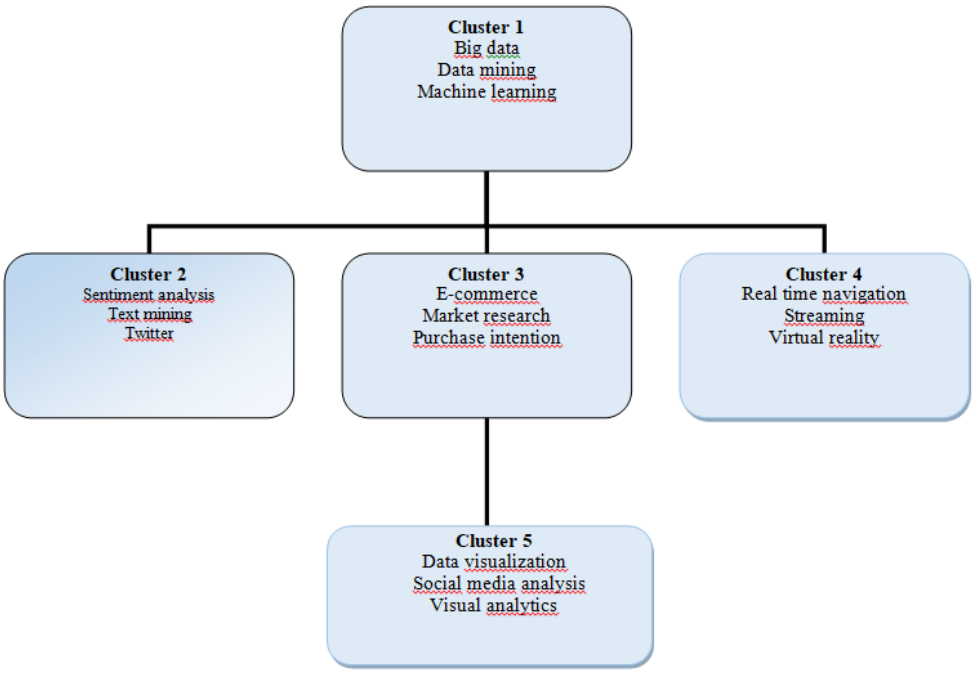

Figure 7. Cluster analysis

After the analysis, the most intensively used words were grouped together and five cluster structures emerged as a result. Accordingly, the structure of each cluster group was analyzed as follows.

Cluster 1: In the first cluster group, it is seen that data processing within the scope of social media text stream visualization is mostly addressed. Accordingly, it can be stated that a visualization analysis focused on technology and digitalization was carried out and tools such as big data, data mining and machine learning were used extensively in the studies. It can be stated as another result obtained that the use of technological tools is more intense within this cluster. After the process of transforming big data into more useful data, the findings obtained from social media through machine learning are used for the purposes of businesses and brands with the visualization technique.

Cluster 2: In the second cluster group, it is seen that sentiment analysis, text mining and twitter elements are more prominent. In this context, it can be stated that emotions are analyzed and texts are examined through text mining during social media text stream visualization. Another result obtained is that Twitter, one of the social media tools, is used more intensively in the studies carried out within the scope of sentiment analysis and text mining. Although there are a wide variety of social media tools, it is seen that the studies carried out in this field are mostly carried out on Twitter. Based on the posts made by Twitter users, emotions are analyzed through text mining and as a result, visualization can be performed.

Cluster 3: In the third cluster group, it is seen that the concepts of e-commerce, market research and purchase intention are used together in social media text flow visualization studies. Accordingly, especially in studies conducted through e-commerce, visualization and analysis processes for market research are carried out by analyzing the behavior of consumers. Through market research, consumers' purchase intentions can also be evaluated. In this context, it can be stated that the third cluster group mostly consists of visualization studies on consumers' online purchasing behaviors.

Cluster 4: In the fourth cluster, it is seen that the studies carried out are on real-time navigation and virtual reality. Real-time navigation provides users with access to dynamic data and in this way, the text stream showing the location of users on a map can be improved with instant updates. This helps users to understand the changes more easily. Virtual reality offers users a completely different and interactive environment. Text streaming can be an effective method for presenting information in these environments. For example, as users navigate through a virtual city, historical and cultural information about that region can be visualized virtually. Text stream, combined with data visualization, helps make complex information more understandable. In a virtual reality environment, users can see text and graphics together, allowing them to process information in a more intuitive way.

Cluster 5: In the fifth cluster, it is seen that the studies carried out are mostly in the context of data visualization, social media analysis and sana analysis. Carrying out studies by bringing these three concepts together is very important within the scope of feature digitalization and innovation processes. Data visualization makes complex data understandable through graphs, tables or other visual formats. For social media analytics, visualising data such as consumer behaviour, engagement rates and trends allows for quick analysis of this data.

Virtual analytics refers to the study of data sets, often using simulations and virtual environments. Social media analytics can use such methods to understand users' behaviour in virtual environments. Data visualisation also comes into play here; by visualising the results of virtual analytics, it is possible to better understand user behaviour and develop strategies Social media analysis is a process of analyzing users' interactions, content sharing and general trends. Data visualization presents the results of this analysis more effectively.

Data visualization enables brands and organizations to be more effective in decision-making processes by presenting the results of social media analysis clearly. Virtual analytics helps to predict possible outcomes by simulating scenarios in these processes. Working together, these three components can enhance consumer experience and engagement.

Conclusion

As a result of the bibliometric analysis, studies related to the field of marketing within the scope of social media text stream visualization were examined and 12 studies conducted between 2014 and 2024 were examined in detail. Accordingly, five different cluster structures have emerged and the relationship of each cluster with social media text stream visualization is explained.

As social media becomes a powerful marketing tool for brands, visualisation of text flow enables data to be presented in an understandable and effective way. This visualization allows brands to better interact with their target audience, follow trends and make strategic decisions. Especially in today's age of digitalisation and innovation, it is of great importance for businesses and brands to examine and analyse the behaviour of consumers. In the digitalisation process, social media text stream visualisation plays a critical role in optimising marketing strategies and improving user experience. In this context, it is important for brands to adopt data-driven approaches in order to gain competitive advantage.

As a result of the analyses, it is seen that the studies conducted are mostly on e-commerce, market research, advertising and consumer purchase intention. Understanding the studies carried out by consumers through social channels is of critical importance for both academic and business world. Another result obtained is that the use of marketing and digital tools and technology together is quite intense. Accordingly, when we consider both academic and business world, studies are carried out through the use of machine learning and big data.

Recommendations

Social media text stream visualization is of great importance for marketing, innovation and strategic decision-making processes of businesses in today's age of digitalization. This process not only makes data more understandable, but also enables businesses to interact more effectively with their target audience. From a marketing perspective, visualising social media text stream is a critical tool to increase the impact of brand messages and campaigns. Understanding users' behaviour on social media platforms helps brands create more personalised and effective content for their target audience. Visualization enables data to be analysed instantly, allowing marketing strategies to be updated quickly. This improves campaign performance and provides the opportunity to increase customer satisfaction.

In the field of innovation, social media data can be used as an important resource in new product development processes. Customer feedback and interactions help to understand which features are requested or which problems need to be solved. Visualised data speeds up this process, allowing businesses to create more innovative solutions.

In the context of digitalisation, social media text stream visualization helps businesses strengthen their digital presence. Data analysis and visualization allow organisations to optimise their digital strategies. Especially when developing multi-channel marketing strategies, presenting data on social media in an integrated way contributes to businesses making more effective decisions.

As a result of the analysis, it is seen that the studies are concentrated especially in the fields of e-commerce, advertising and market research. In this context, it is recommended to increase sectoral diversity in future studies. Another suggestion is that it is also possible to make a different evaluation by comparing the results of these studies on a sectoral basis.

It is important to deepen the research on social media text flow visualization, marketing, digitalisation and innovation on a sectoral basis in order to increase the effectiveness of applications in different fields. In this context, suggestions for studies that can be carried out in different sectors can be listed as follows:

- *In the retail sector,* examining the relationship between social media data and consumer behaviour can increase customer satisfaction. Analysing consumer comments and feedback should be integrated into product development processes. In addition, the effects of social media campaigns on customer loyalty can be investigated.
- *In the finance sector,* firms providing financial services can increase customer trust and brand perception through social media analysis. In this field, research should be conducted to measure the impact of financial advice given through social media. The reflections of crisis management practices on social media should also be considered as an important area of investigation.
- *In the health sector*, health organisations can increase patient interaction by actively using social media platforms. Information sharing and visualisation of educational materials can be effective in increasing health awareness in the community. In addition, the effects of social media campaigns on health can be analysed in detail.
- *In the tourism sector*, integration of visualization techniques to enhance consumer experiences through social media is recommended. Analysing customer comments and experiences is important to understand their impact on travel choices.

- *In the technology sector*, firms can improve user experience by incorporating social media data into product development processes. Research on the effectiveness of social media strategies in the promotion of innovative products can be encouraged.
- *In the automotive sector*, social media interactions should be integrated into product development processes by collecting and analysing customer feedback. Studies examining the impact of social media campaigns on sales can help brands optimise their strategies.

These recommendations will contribute to the deepening of research in the field of social media text stream visualisation, digitalisation and innovation and the development of more effective marketing strategies by strengthening cross-industry collaboration.

In conclusion, social media text stream visualization offers great opportunities to businesses in terms of marketing, innovation and digitalisation. By using these tools effectively, businesses can gain competitive advantage, increase customer loyalty and achieve sustainable growth. Therefore, the implementation of social media text stream visualization has become an inevitable necessity in today's business world.

Scientific Ethics Declaration

The author declares that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the author.

Acknowledgements or Notes

* This article was presented as an oral presentation at the International Conference on Advances in Technology and Innovation (www.icati.net) held in Antalya/Turkey on November 14-17, 2024.

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Use of Unmanned Aircraft in the Logistics Support of Military Formations

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Abstract: The present development describes an experiment using an unmanned aerial vehicle (UAV) conducted at the Vasil Levski National Military University - the town of Veliko Tarnovo, and the purpose of the experiment is to determine the possibilities of using a drone in the logistical support of military formations of tactical level. The experiment was carried out in field conditions, and for this purpose a logistics company from the composition of a mechanized battalion was deployed in field conditions in rugged terrain. The drone used is a DJI MAVIC PRO 2.

Keywords: Unmanned aircraft, Logistics support, Drone

Introduction

The modern security environment and dynamic changes on a global scale require the use of alternative and modern methods of conducting and securing combat operations in a different environment. The large-scale use of unmanned aerial vehicles in the war in Ukraine shows that this type of means has effectiveness in conducting combat operations, which necessitates the expansion of their application in various military spheres. Modern military UAVs perform a wide range of functions, for the implementation of which they perform multiple tasks above the territory of combat operations and in the depth of the enemy's position. At the same time, as a result of the development of high technologies and innovations in military affairs, the functions and tasks of UAVs often change in real time. (Zagorski, 2021)

Army UAV capabilities have evolved from a theater reconnaissance asset to core tactical roles such as surveillance, reconnaissance, attack, targeting, communications transmission, convoy surveillance, and more. The Army uses UAS as an extension of the tactical commander to locate, fix, track, facilitate and terminate targets. Army UAS missions are integrated into the commander's mission planning, as a combat multiplier in a modern operational environment (Kappenman, 2008). The categories for military drones are quite different from those for civilian drones. They are categorized based on their weight, range, speed as well as their specific capabilities. The classification is used by NATO groups and is according to the US Department of Defense:

- CLASS I (< 150 kg): SMALL – this class includes micro, mini or small drones with primary reconnaissance, surveillance and targeting purposes. They are often fixed wing with an average weight of about 20-100 kg, a maximum speed of 100 km/h and a flight height of up to 4 km. Main application is for espionage.
- CLASS II (150–600 kg): TACTICAL – includes drones with the size and capabilities of small aircraft. They feature a combination of flexibility, durability and robustness and are used for surveillance and monitoring in damage analysis and assessment, border surveillance, reconnaissance and emergency response.
- CLASS III (> 600 kg): STRATEGIC – This category includes aircraft-sized drones. They have a wide range of applications, being used to determine the position of the enemy or the movement of certain targets.

Based on the specific role they must play in a particular military operation, military drones are divided into target and decoy, reconnaissance, attack, and research and development. They are applied and will continue to be applied in various military operations due to their great convenience in reducing losses and providing the ability to perform narrow profile and risky missions. Drones are also used in border security and coast guard. The future is in the increasingly complete autonomy and most innovation of military unmanned aerial systems - military drones. (Jelev, 2018)

Logistics Support System

A single system has been built to provide effective logistical support for the Armed Forces (AF) at the strategic, operational and tactical levels. The system for logistical support of the Armed Forces is a set of management bodies, forces and means for carrying out the activities of providing the troops, connected in a single network of interconnections and also represents a complex organizationally complete economic system, which consists of units interconnected in a single process of management of material and accompanying flows transforming logistics resources with activities and processes in logistics chains, in accordance with the mission, objectives, tasks and performance criteria, supporting the normal functioning of the life cycle of the Ministry of Defense and the Bulgarian Army. The logistics support system includes the following elements:

- command staff.
- forces and means of logistical support.
- infrastructure and transport communications.
- consistency, forms and principles of interaction in organizing and implementing logistics provision.
- communication and information system.
- protection of the forces and means of logistical assurance (Figure 1) (Botev, 2002).

Figure 1. Logistic support system

Functional Areas of Logistics

The overall logistics provision is formed by the uniform and coordinated implementation of various logistics functions, grouped in the following functional areas:

- supply of material resources.
- logistics information management.
- operation, maintenance and repair.
- movement and transportation.
- securing the military infrastructure.
- provision of services.
- medical insurance.
- negotiation.
- host nation support (Figure 2). (НП-4, 2019)

Through the present development, the areas of possible application of the unmanned aerial vehicles in the system of logistical support of the military formations at the tactical level will be determined.

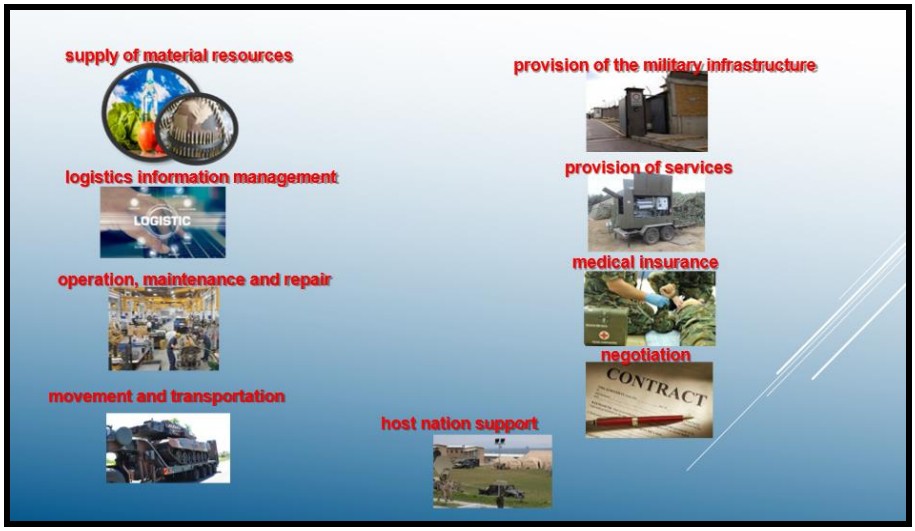

Figure 2. Logistic functional areas

Method

The present experiment was carried out using a DJI Mavic Pro 2 unmanned aerial vehicle, and tasks related to the logistical support of a mechanized battalion in field conditions were planned and executed. After completing the tasks, an analysis was made for the performance such as time, data transmission, difficulty of performance. During the execution of the tasks, the information from the UAV is transmitted to live data in a deployed logistic support control center (LSCC). The UAV is managed by a specialist operator from the control center, and the received data is recorded and processed by officials in the composition of the LSCC. The drone used has the following technical characteristics (Table 1).

Table 1. DJI Mavic Pro 2 specs

Take off Weight	**Mavic 2 Pro: 907 g**
Dimensions	Folded: 214×91×84 mm (length×width×height) Unfolded: 322×242×84 mm (length×width×height)
Diagonal Distance	354 mm
Max Ascent Speed	5 m/s (S-mode) 4 m/s (P-mode)
Max Descent Speed	3 m/s (S-mode) 3 m/s (P-mode)
Max Speed (near sea level, no wind)	72 kph (S-mode)
Maximum Takeoff Altitude	6000 m
Max Flight Time (no wind)	31 minutes (at a consistent 25 kph)
Max Hovering Time (no wind)	29 minutes
Max Flight Distance (no wind)	18 km (at a consistent 50 kph)
Max Wind Speed Resistance	29–38 kph
Max Pitch Angle	35° (S-mode, with remote controller) 25° (P-mode)
Max Angular Velocity	200°/s
Operating Temperature Range	-10°C to 40°C
Operating Frequency	2.400 - 2.483 GHz 5.725 - 5.850 GHz
GNSS	GPS+GLONASS
Hovering Accuracy Range	Vertical: ± 0.1 m (when vision positioning is active) ± 0.5 m (with GPS positioning) Horizontal: ± 0.3 m (when vision positioning is active) ± 1.5 m (with GPS positioning)
Internal Storage	8 GB

Results and Discussion

Tactical tasks were planned and carried out in the following functional areas of logistics - supply of material resources, medical provision, repair and evacuation of equipment.

Supply of Material Resources

Execution of task 1 – The drone is brought into working mode for reconnaissance and determination of the most suitable route for delivery of material resources (Photo 1). During the execution of the task, the air temperature was 29 ^{0}C, moderate wind with light rain showers. After analyzing the transmission of the data in the LSCC, officials can choose a route for the movement of vehicles loaded with material resources to provide the formations from the front end. Here, the main advantage of using UAVs is the significant shortening of the time for conducting the reconnaissance of the planned routes for the delivery of material resources and ensuring timely supply.

Photo 1. Routs for supply with material resurces

Execution of task 2 – is directing and escorting the transports of material resources along the reconnaissance route (Photo 2). Here, the experience and training of the drone operator to observe uncharacteristic properties of the area, to avoid improvised explosive devices and possible sabotage plays a major role. The early warning of a possible danger will prevent the decommissioning of the means of transport and will be a guarantor for the implementation of the logistical operations of the provision of material means.

Photo 2. Optimal rout for supply

Execution of task 3 – is directing the means of transport to obtain material resources at meeting points of the next line of logistics provision (Photo 3). The main advantage of the UAV in the performance of this task is to accompany and guide the means of transport in an unfamiliar environment and to support the recognition of formations at the opposite points, by using predetermined signals and signs.

Photo 3. Reception and transfer of material resources

Execution of task 4 – When the operational situation changes, the drone can be used to redirect the delivery of material resources to another end user in case of disruption of the communication-information system (Photo 4).

Photo 4. Change route

Medical Insurance

Execution of task 5 – Search for wounded and sick on the battlefield and their timely evacuation. The main advantage of this task when using UAVs is the ability to observe the battle field from a high altitude and cover a

fairly large observation perimeter. This will ensure the timely search and finding of the wounded and the provision of timely medical assistance, which in turn will reduce the combat losses of the military formation (Photo 5).

Photo 5. Surching for injury military personel

Execution of task 6 – is directing the sanitary facilities of the medical station to the places of injury and transporting the injured to the nearest medical stations and medical facilities (Photo 6).

Photo 6. Medical post

Repair and Evacuation of Damaged Equipment

Execution of task 7 – is the use of UAVs for technical intelligence. Advantage – a large radius of the observed perimeter and provides an additional technical observation post and obtains timely information on the required degree of repair, through visual observation directly from the crew of the affected machine. In this way, the time required to return the machine to service through the repair and evacuation stages is shortened.

Photo 7. Second degree repair

Execution of task 8 – is technical provision and reconnaissance during the march. The UAV moves above the military column and observes for technical malfunctions and accidents during the movement of the main forces to the commanded area.

Photo 8.Technical support

Conclusion

The current experiment shows that unmanned aerial vehicles have a place in the logistical support of military formations at the tactical level. The results show that the use of drones in logistical support supports decision-making by commanders at the tactical level and shortens the time for carrying out logistical operations for the

provision of mechanized military formations. The implementation of this type of apparatus in the logistics formations at the tactical level will improve many times the activities of the all-round logistics provision of the maneuver formations.

Scientific Ethics Declaration

The authors declares that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

Acknowledgements or Notes

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