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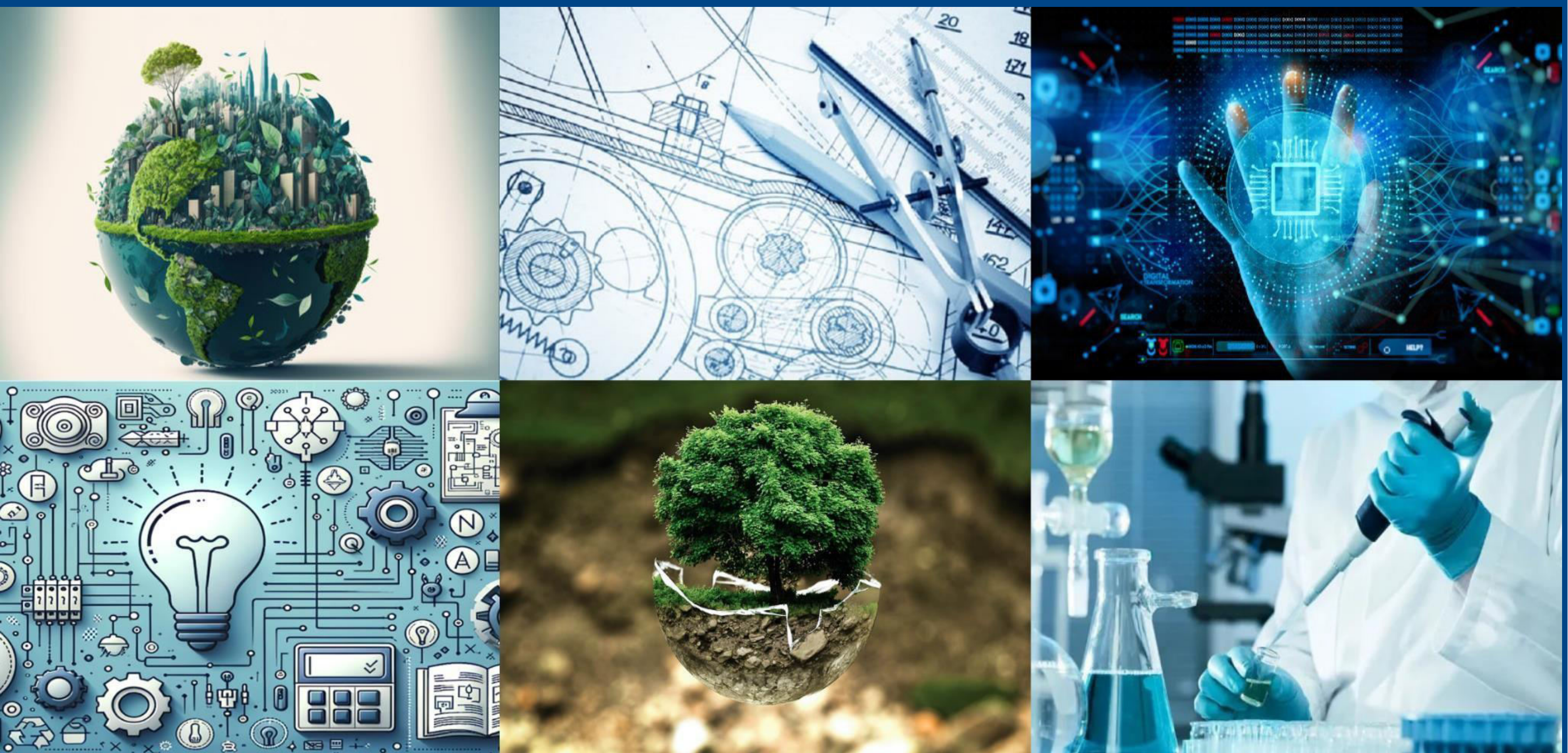

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A MACHINE LEARNING-BASED FRAMEWORK FOR FUEL CONSUMPTION PREDICTION AND REAL- TIME FUEL COST ESTIMATION

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ABSTRACT: As fuel prices rise and vehicle fuel efficiency becomes more of an environmental concern, maximizing vehicle fuel efficiency is of utmost importance. The project formulates a machine learning-based system that predicts fuel consumption precisely and estimates real-time fuel expenditure. Using inputs like vehicle specifications, engine type, and driving conditions, a trained regression model provides accurate fuel efficiency prediction. The system incorporates an interactive web interface developed utilizing Flask, with a responsive user interface. The major features include a live prediction interface, analytics of historical data, chatbot support for fuel-saving tips, interactive visualizations, and cost estimation from dynamic fuel prices. User login and data storage through an SQLite database improve reliability of the platform. Developed as a smart advisory solution, this solution enables users to make smart choices on driving behavior and car servicing, opening the door to green transport and environmental protection.

KEYWORDS: Vehicle Efficiency, Linear Regression Model, Flask, Prediction

I. INTRODUCTION

Fuel usage has emerged as a problem, which is of interest to all companies, as well as governments interested in creating ecologically friendly transport infrastructures. The increased fuel price and, secondarily, environmental considerations—such as greenhouse gas emissions—emphasize the need for intelligent technology-driven solutions. Traditional approaches to fuel estimation are based on calculations or known data, which are prone to errors and inflexibility across different situations.

Machine learning enables robust, dynamic, data-driven fuel consumption predictions. Based on vehicle characteristics (engine size, Vehicle Class, Cylinders, Transmission, CO_2 Rating, Fuel Type) and driving styles, machine learning models provide more precise and actionable data. Real-time fuel cost predictions, adjusted according to prevailing market prices, also enable users to plan and save more effectively. The paper presents end-to-end system developed employing Python technology Flask as frontend and Flask for backend operations. It is provided with a regression-based prediction model, has cost estimation, provides fuel-saving advice via an intelligent chatbot, and saves predictions in an SQLite database. The system, by combining predictive analytics with an interactive interface, allows users to optimize fuel efficiency while encouraging environmentally friendly driving behavior.

II. LITERATURE SURVEY

The accurate prediction of vehicle fuel consumption has attracted significant research attention, particularly with the rise of machine learning (ML) techniques for environmental sustainability and cost reduction. Li et al. [1] provided a comprehensive review of data-driven vehicle fuel consumption prediction models, highlighting how neural networks, hybrid models, and ensemble regressors consistently outperform traditional regression approaches in capturing non-linear relationships. A comparative analysis by recent studies [2] demonstrated the Linear Regression achieved ($R^2 \approx 0.9193$) especially when modeling complex vehicle datasets.

Hamed et al. [3] showcased the efficiency of Support Vector Regression with Radial Basis Function (RBF) kernels in predicting fuel usage from On-Board Diagnostics (OBD) sensor inputs such as mass air flow, vehicle speed, and throttle position, achieving an R^2 of 0.97. Similarly, Yoo et al. [4] incorporated explainability methods like SHAP and

LIME into ML models to identify key influencing features, including engine size, CO_2 ratings, and fuel type, which aligns with the input parameters used in our proposed system. Barbado and Corcho [5] demonstrated that interpretable anomaly detection models could reduce fleet fuel consumption by up to 35% by identifying operational inefficiencies.

To support accurate and context-aware predictions, real-time environmental and location-based data are critical. Google Maps Platform [9] enables geospatial visualization and routing, enhancing location-based analysis of fuel consumption. WeatherAPI [10] provides weather conditions that influence vehicle efficiency, such as temperature and wind speed. The API Ninjas Vehicle API [11] provides comprehensive vehicle details, which can be utilized as input features in the model to enhance prediction precision. Real-time estimation models, such as those proposed by SAGE researchers [6], confirm that integrating such dynamic data streams can significantly improve prediction reliability.

CURRENT SYSTEM

Current fuel consumption analysis usually depends on conventional data like paper-based records, onboard diagnostics, and factory data. These methods are based on static parameters and are not very accurate and do not capture dynamic inputs like traffic, driver behavior, and vehicle condition. Though some newer vehicles display live fuel economy data, such systems are proprietary, costly, and not available to most users, especially in the developing world. Popular mobile apps only offer generic suggestions or basic calculators and don't employ adaptive learning or live machine learning models.

All the currently available tools lack customization, interactive feedback, or historical data analytics, which limits their long-term effectiveness in enhancing fuel efficiency.

PROPOSED SYSTEM

The system described here unfolds an intelligent, data-driven approach to forecasting fuel consumption through machine learning regression models. In contrast to static calculations, the system considers numerous vehicle parameters—engine specifications,weight, horsepower, and fuel type—to offer accurate fuel consumption estimates.

The website hosts a simple web interface by which users are able to enter car specifications and receive instant forecasts backed by graphical analysis. Budgeting is facilitated by real-time fuel costing using live price feeds. An interactive personalized fuel-saving advice chatbot answers questions, and a history logs previous forecasts for users to refer to. By facilitating the combination of advanced predictive analytics, responsive user interface, and real-time data aggregation, the system provides a unified platform for monitoring fuel efficiency, cost control, and promoting environmentally conscious driving habits.

III. SYSTEM ARCHITECTURE

The project follows a modular architecture designed for scalability and easy maintenance. The frontend, developed with Flask, delivers a smooth and engaging interface where users can input data and view results. The backend, also implemented in Flask, processes incoming requests, manages the machine learning prediction workflow, and runs the chatbot system.At its core, the prediction module uses a trained regression model that takes vehicle-related features as input and estimates fuel consumption. Alongside, a rule-based chatbot module interprets user queries, providing fuel-saving tips and relevant assistance.All inputs, outputs, and interaction logs are securely stored in an SQLite database, enabling historical analysis and personalized insights. This layered design ensures that the frontend, backend, ML model, and database components can be updated or extended independently.

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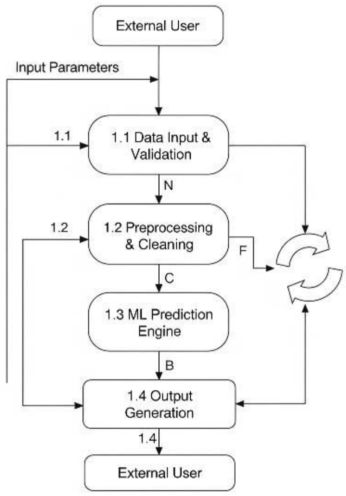

Fig 3.1 Data Processing Flowchart

IV. METHODOLOGY

1. **Dataset Acquisition:** Data was collected from the 2022 car dataset, including parameters such as engine size, fuel type, weight, make, model, and past fuel usage.
2. **Preprocessing:** Missing values were addressed through data cleaning, normalization, and encoding of categorical features.
3. **Model Training:** Linear Regression was selected for its balance of interpretability and accuracy, using key attributes that influence fuel consumption.
4. **Model Deployment:** The trained model was serialized and integrated into the Flask backend, accessible via API endpoints.
5. **User Interaction:** The interface captures vehicle and usage data, sends it to the prediction API, and returns results along with cost and routeinsights.
6. **Live Price & Map Integration:** JavaScript in the frontend fetches real-time fuel prices and displays nearby stations using mapping APIs for better trip planning.

V. DESIGN AND IMPLEMENTATION

The frontend is designed to be fully responsive and built with Tailwind CSS, allowing quick and efficient interface development while maintaining both accessibility and a consistent visual style. JavaScript drives the interactivity — handling asynchronous requests, validating user inputs, and powering dynamic components like the map, chatbot, and fuel calculator. On the other side, the Flask backend takes care of routing, authentication, and communication with the machine learning model and database. The chatbot, built on a set of predefined rules with some dynamic responses, helps answer user queries. All API endpoints are secured, and user feedback is continuously collected for system improvement.

Following a full-stack architecture, the system separates the client-facing interface from the server-side logic, ensuring cleaner code, better maintainability, and scalability. The frontend relies on HTML5 for structure, JavaScript for interactive behavior, and Tailwind's utility-first styling to create a custom, modern interface without being restricted by pre-made components. Key features — such as the real-time fuel cost calculator, interactive charts, and live map — are built in vanilla JavaScript and connect to the backend via fetch() API calls, ensuring smooth data loading without page reloads.

The backend, built with Flask, follows a RESTful API design, offering endpoints such as /predict for estimating fuel consumption, /live-price for retrieving current fuel prices, and /contact for handling user inquiries. The prediction engine uses a Linear Regression model trained on the 2022 vehicle dataset, serialized with joblib, and loaded at server startup for quick responses.

Data storage is managed with SQLite, chosen for its simplicity. It keeps track of user credentials, vehicle profiles, and prediction history. CRUD operations allow users to review their past predictions, while encrypted passwords and session-based authentication protect sensitive data.

The system's modular design means individual components can be upgraded independently — for example, swapping Linear Regression with Gradient Boosting or Neural Networks without affecting the frontend. Similarly, the chatbot works as an independent module, delivering instant fuel-saving tips. This structure ensures easy maintenance today and room for future expansion tomorrow.

VI. OUTCOME OF RESEARCH

The system allows users to:

- Accurately predict fuel consumption for their specific vehicle.
- Calculate trip fuel costs based on live price data and personal driving patterns.
- Access detailed vehicle information and location-based services.
- Receive fuel-saving tips and advice through an integrated chatbot.
- Track previous predictions, build awareness, and adapt driving behavior accordingly.

User feedback emphasized the system's usefulness in managing travel budgets, scheduling vehicle maintenance, and encouraging environmentally friendly driving practices.

VII. RESULT AND DISCUSSION

The Linear Regression model performed with high accuracy metrics upon testing (e.g., $R^2 > 0.85$) outperforming manually computed approaches. The combination of real-time pricing and interactive analytics gave users actionable insights, while the web interface offered high levels of engagement. Disadvantages included reliance on the recency and completeness of input data, and periodic third-party API response lag for live pricing and mapping.

The Linear Regression model's performance was quantitatively assessed using metrics other than the coefficient of determination (R^2). Upon the 2022 vehicle dataset, the model yielded a Mean Absolute Error (MAE) of around 1.15 L/100km, which reflects the fact that its predictions were highly proximate, on average, to actual fuel consumption values. Analysis of the model's coefficients showed that engine displacement, vehicle weight, and transmission type were the most predictive of fuel consumption, which resonated with well-established automotive engineering principles.

The model's interpretability was a major strength, enabling transparent understanding of how various vehicle attributes affect fuel efficiency. Such transparency is valuable for enabling users not just a prediction, but also an understanding of why their vehicle consumes fuel the way it does.

Beyond the predictive validity, the other significant result of this study was the positive user acceptance of the integrated platform design. Combining prediction, live pricing, cost calculation, and mapping capabilities into one simple-to-use interface was repeatedly cited as a significant advantage over piecemeal, single-purpose software packages. The user interface, built with Tailwind CSS, provided a responsive and seamless experience on desktop and mobile. Rates of participation showed high usage of the fuel estimate calculator and live map, suggesting that users valued the flexibility to plan trips and budgets holistically within an integrated environment. Visual analytics, such as plots of estimated cost over different distances, worked well in conveying abstractions as tangible, point-to-point data.

The live data stream support was an important feature for successful real-world decision-making. Users reported that the live fuel prices feature did indeed influence the refueling station choice and led to actual cost savings. Such dependency was troublesome, primarily due to API latency and data consistency. Regular third-party service price updates can cause minute discrepancies between the shown price and the actual pump price. Moreover, the overall system's accuracy is entirely dependent on the quality of user-submitted data. Incomplete or incorrect vehicle data led to less accurate predictions, and an additional advanced input validation system and perhaps an inbuilt vehicle data lookup feature would have to be introduced in future versions.

In the wider context, the findings indicate that the combined system is not just an active calculator but an active agent of behavioral change. By rendering the financial and environmental implications of fuel consumption instantaneously transparent, the platform induces more conscious driving practices. The chatbot aspect of providing contextual, actionable tips (e.g., "Proper tire pressure can make your mileage up to 3% better") further strengthened this pedagogic function.

Although the existing architecture is well-suited to accommodate a moderate user base, future scalability would entail moving away from SQLite to a more scalable database solution such as SQLite3 and incorporating caching mechanisms to cope with the high load from high-volume API calls to live data.

VIII. CONCLUSION

This project demonstrates how the fusion of machine learning and modern web technologies can deliver an intelligent, user-friendly solution for fuel consumption prediction. By combining accurate regression models, live fuel price APIs, and an engaging, responsive interface, the system empowers users to make informed driving and refueling decisions that can save money and reduce environmental impact.

Beyond its current capabilities, the framework holds significant potential for growth. Future enhancements could include incorporating deep learning architectures for more accurate predictions, enabling personalized recommendations based on individual driving patterns, and integrating IoT-connected vehicle sensors for real-time performance tracking. These improvements would not only refine prediction accuracy but also open the door to a fully connected ecosystem for smarter transportation. Ultimately, the project stands as a step toward sustainable and data-driven mobility solutions—offering a glimpse of how technology can transform everyday decisions into smarter, greener choices.

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