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REAL-TIME DECISION SUPPORT SYSTEM FOR TRACTOR LOAD MANAGEMENT

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ABSTRACT

This research focuses on creating a real-time monitoring system for agricultural tractors that improves load management by continuously tracking essential parameters such as PTO RPM and fuel consumption. By accurately predicting engine load, the system allows operators to take timely actions to prevent overloading and enhance fuel efficiency. A detailed regression model was developed, yielding an R-squared value of 0.9368, indicating a strong correlation with engine load. The model also achieved a Root Mean Square Error (RMSE) of 448.26 and a Coefficient of Variation (CV) of 16.98%, showcasing its reliability and accuracy. These results demonstrate the system's effectiveness in real-world agricultural applications, offering a cost-efficient approach to optimize tractor performance and promote sustainable farming practices. This advancement not only improves operational efficiency but also extends the lifespan of agricultural equipment, addressing the need for enhanced load management in contemporary farming.

Keywords: Arduino, Engine output, Fuel consumption, Load computation, PTO rpm

Efficient load management is a critical factor in the optimal operation of agricultural tractors, directly influencing their performance, fuel efficiency, and longevity. In modern agriculture, where productivity and resource management are paramount, the ability to monitor and manage tractor loads in real-time has become increasingly important. However, traditional methods of load management often rely on the operator's experience or static calculation models, which can result in suboptimal performance, increased fuel consumption, and accelerated wear on machinery (Zhu *et al.*, 2022).

From the farmers' perspective, tractors are the most expensive farming input. The value of a tractor is measured by the amount of work accomplished relative to the cost incurred as an ideal tractor converts all the energy from the fuel into useful work (Prakash *et al.*, 2013). Therefore, the availability of accurate data is crucial for minimizing the operating costs of both tractors and implements. Further, the optimum use of the tractor in particular farm situation depends on the correct pairing of tractor and the implement in terms of power and size (Prakash, 2009; Mahal *et al.*, 2012). This becomes more crucial in farm situations where the availability of tractors and implements is limited. Thus, in order to facilitate the computation of tractor data, a model was developed by Rencin and Polcar (2016) which included partial calculations of engine load and engine speed to determine engine power. Further, an IOT based digital setup to measure, project, and record tractor performance parameters with higher precision was developed on 28.3 kW tractor. It transmitted and monitored the tractor's performance parameters like engine speed, fuel consumption, draft, wheel slippage, location wirelessly on cloud platform (Singh *et al.*, 2021). Despite recent advancements, there is significant potential to enhance tractor load calculation systems, as current methods often lack real-time accuracy across varying conditions. Future innovations utilizing sensors and data analytics will improve monitoring of engine load, power output, and fuel consumption, enabling better tractor-implement matching, reducing costs, and increasing productivity. As agriculture adopts data-driven practices, developing advanced load calculation systems will be crucial for efficient and sustainable machinery use.

Several leading tractor manufacturers, such as John Deere and Mahindra & Mahindra, have developed advanced systems like JDLink™ and DigiSense™ that provide comprehensive monitoring and decision support for load management. These systems utilize cutting-edge technology to offer real-time data and insights, enabling operators to make informed decisions that enhance overall tractor performance (Nutakki and Mandava, 2024). However, these sophisticated systems are primarily available only on newer tractor models, leaving a significant gap in the market for older tractors that are still widely used, particularly in developing regions (Lenzgeiger *et al.*, 2018). Many farmers continue to rely on older tractor models that lack the advanced technology necessary for efficient load

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management (Hagerty, 2023). This creates a pressing need for a time-efficient and cost-effective power measurement system that can be retrofitted to existing tractors, ensuring that a broader range of farmers can benefit from real-time load management technologies.

To address the persistent challenges faced by operators, this study aims at the development of a Real-time Decision Support System for Tractor Load Management. This system leverages advanced sensors, microcontrollers, and custom algorithms to continuously monitor and assess the load on a tractor during operation. By providing real-time feedback and actionable insights, the Real-time Decision Support System enables operators to make informed decisions that optimize load distribution, enhance fuel efficiency, and reduce mechanical stress on the tractor. Furthermore, the effectiveness of the system was evaluated through field trials.

MATERIALS AND METHODS

During the study, the basic material used for the development of loading equipment were Bakelite sheets, heater rods (20 ohm), 4mm single-core wire, Arduino Uno, LCD display, jumper wires, breadboard, proximity sensors, 3-phase alternator, Fuel consumption meter, Main switch (32 Amp) and MCB's, 10 K potentiometer, header pins, 9 Volt battery.

Fabrication process of thermal load emulator for the experiment

Bakelite sheets (15"×18") were chosen to make the frame of load measuring equipment due to its electric insulating nature and high melting point. Two frames having a theoretical load capacity of 5kW each were manufactured, so the total load of both frames was 10kW.

Collection of data and database development

After assembling the loading equipment, it was attached to tractor PTO via 32 kva alternator. The different sets of electric rods were connected to the tractor through three-phase PTO operated alternator, starting without connecting any rod in the first set and subsequently increasing upto 3 kw on each phase for last set on each category of throttle. The fuel consumption, PTO rpm and power output for the system were measured at different fixed sets of PTO rpm i.e. 25% (265±5 rpm), 50% (375±5 rpm), 75% (540±5 rpm) and full throttle (660±5 rpm). In order to measure fuel consumption volumetric method of determination of fuel consumption was used. A digital tachometer was used to measure P.T.O. rpm. The reading of PTO rpm was taken in two different conditions i.e., by keeping the no load rpm and after load rpm as reference. Simultaneously, readings of voltage and current were noted.

Implementation of regression model for real-time engine load calculation

The readings from the developed database of the tractor were analyzed, and regression analysis was applied to establish a relationship among PTO RPM, fuel consumption, and engine load. A C++ code was developed using the open-source Arduino Integrated Development Environment (IDE) and subsequently uploaded to an Arduino board. To compute the engine's stationary load, the Arduino Uno board was programmed with code that utilized the derived regression equation correlating PTO RPM, fuel consumption, and stationary load. In this setup, proximity sensors provided the values for PTO RPM and fuel consumption, and the engine load was calculated through the Arduino board. The system processes the input values of fuel consumption and PTO RPM from the sensors and displays the calculated engine load on LCD screen using the regression model.

Flowchart of connections of different devices with Arduino UNO board

The Arduino microprocessor of the entire system was connected with the different sensors and the devices using the jumper wires, breadboard and connection wires (Fig. 1).

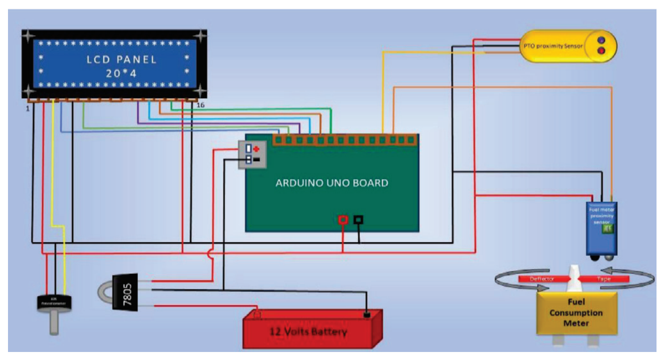

Fig. 1. Circuit diagram of different components in the circuit

Installation of the equipment and the system on the tractor

The final setup consists of three portions, i.e., the PTO rpm detection unit, Fuel consumption detection unit and the output unit. The proximity sensor was installed above the tractor PTO projecting toward the welded platform of the shaft in such a way that whenever the strip cuts the path of the proximity sensor beam, it gives the pulse on the output wire which is detected by the Arduino using D3 pin hence the rpm of PTO is determined using this unit. Similarly fuel consumption detection system consists of the fuel meter and proximity IR sensor assembly connected to the fuel line using connection pipes and the joints. The fuel passes through the fuel consumption meter and it rotates the plastic strip with reflector tape pasted on it. As the reflector taped plastic strip comes in the path of the proximity IR sensor's beam, it generates a pulse that is detected and recorded. As each rotation of fuel flow meter designated 0.5 ml but as strip was cutting path of IR sensor's beam two times each revolution therefore, each pulse meant 0.25 ml of fuel flowing through fuel line (Fig. 2). These pulse values in both the units are converted to rpm values using the inbuilt RTC function of Arduino and thus the values of PTO rpm and fuel consumption were obtained.

Fig. 2. Fuel consumption meter mounted with plastic slit covered with reflector tape

The output unit consists of a housing that contains all the remaining devices and components, such as an LCD display, Arduino board, breadboard, potentiometer, etc. The data input from both the proximity sensors was processed in the Arduino board and the output is displayed on LCD module.

RESULTS AND DISCUSSION

The real-time decision support system for tractor load management was tested under various load conditions, and regression analysis was conducted to model the relationship between engine load, fuel consumption, and PTO rpm. The regression analysis was conducted using SAS OnDemand for Academics, ensuring robust and accurate statistical computation. The results of the regression analysis are summarized in Table 1 which represents the parameter estimates, standard errors, t-values, and p-values, for highlighting the significance of fuel consumption and PTO rpm in predicting engine load.

The regression analysis highlights the importance of understanding how different factors influence engine load. The intercept, which is -977.778, provides a baseline in the model, and its negative value is essential for accurately predicting engine load. Although it might seem counterintuitive, the statistical significance of this intercept indicates that it plays a crucial role in adjusting the model's predictions.

Among the factors analyzed, fuel consumption emerges as the most significant, with a coefficient of 115.304 and a very small *p*-value (<0.0001), as shown in Table 1. The *p*-value here is crucial because it tells us how confident we can be that fuel consumption is genuinely influencing engine load and not just a result of random chance. Since the *p*-value is less than 0.05, it confirms that fuel consumption has a strong, statistically significant impact on engine load. In simpler terms, as fuel consumption increases, engine load also increases significantly, making it a key factor in the model.

The other factor, PTO RPM on load, also plays a role, though to a lesser extent. Its coefficient is 2.860, indicating a positive relationship with engine load, but its effect is much smaller compared to fuel consumption. The *p*-value for PTO RPM on load is *0.0275*, which is still below the *0.05* significance threshold, indicating that its effect is statistically significant. This shows that while PTO RPM does influence engine load, its effect is more subtle.

The *p*-values for both factors are crucial as they enhance confidence in the results. A lower *p*-value suggests that the observed effect is unlikely to be attributable to random variation, thereby reinforcing the significance of these factors in predicting engine load. Among them, fuel consumption is the predominant factor, while PTO RPM has a smaller yet still meaningful effect. A thorough understanding these relationships is essential for optimizing engine performance.

The regression model provided the following equation:

$$W = [115.30380 \times F] + [2.86016 \times R] - 977.7796 \quad \text{- - - - - - - (i)}$$

where:

W = Engine load (Watts)
F = Fuel consumption (ml/min)
R = PTO rpm on load (RPM)

Table 1. Regression analysis for significance of fuel consumption and PTO rpm in predicting engine load

Parameter	Estimate	Standard Error	t-Value	p-Value
Intercept	-977.77796	201.90131	-4.84	<0.0001
Fuel consumption	115.30380	11.43505	10.08	<0.0001
PTO RPM on load	2.86016	1.25559	2.28	0.0275

The overall model fit is assessed using key statistics presented in Table 2, which includes R-squared, adjusted R-squared, RMSE, and the coefficient of variation (CV).

Table 2. Model fit statistics summary for regression analysis

Statistic	Value
R-Square	0.9368
Adjusted R-Square	0.9339
Root Mean Square Error (RMSE)	448.26
Coefficient of Variation (CV)	16.98%

The model's effectiveness in predicting engine load is demonstrated through several key metrics. The R-squared value of 0.9368, as shown in Table 2, indicates that the model explains 93.68% of the variance in engine load. This high R-squared value signifies a strong fit, meaning the model accurately captures the relationship between the independent variables and engine load. Additionally, the Root Mean Square Error (RMSE) of 448.26 reflects the average deviation between the predicted and actual engine load values. A lower RMSE suggests that the model's predictions closely align with the observed values, confirming its accuracy for practical applications. The Coefficient of Variation (CV) of 16.98% indicates the model's precision relative to the mean engine load. For experimental data, particularly in agricultural engineering, this CV value is reasonable, suggesting that the model is both reliable and effective in predicting engine load with a consistent level of accuracy. These statistical results demonstrate the robustness of the system in providing real-time engine load predictions, making it a valuable tool for optimizing tractor performance.

The data and results obtained from the experiments conducted in real-time were used to generate the regression equation (eq. 1) which was further installed in the open-source Arduino Software (IDE) using C++ Language. The equation written in Arduino Software resulted in computing the values of power consumed and projecting the fuel consumption and PTO rpm digitally on the LCD display as shown in Fig 3.

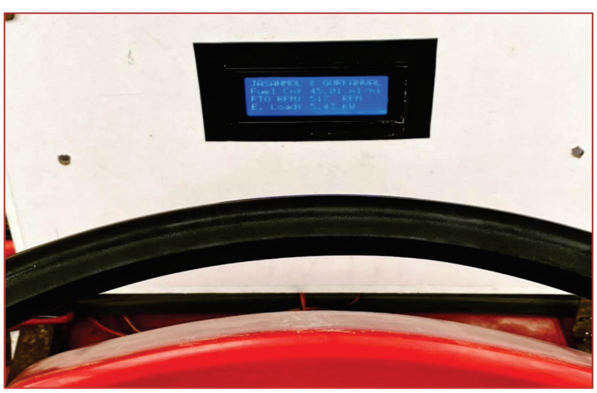

Fig. 3. Real-time data display on output panel

CONCLUSION

The following points summarize the key findings and implications of the study:

1. The study identified fuel consumption and PTO RPM on load as significant predictors of engine load. The strong positive relationship between these variables and engine load, as confirmed by the regression analysis, highlights their critical role in tractor load management.
2. The regression model demonstrated a high degree of accuracy, with an R-square value of 0.9368, indicating that the model explains 93.68% of the variance in engine load. This strong fit suggests that the model is reliable for predicting engine load under various operating conditions.
3. The real-time decision support system proved to be effective in monitoring and predicting engine load with an acceptable level of accuracy, as indicated by a low Root Mean Square Error (448.26) and a reasonable Coefficient of Variation (16.98%). These findings support the DSS's practical application in real-world agricultural settings, particularly where advanced systems may not be available.
4. The implementation of the real-time decision support system can significantly enhance tractor efficiency by providing accurate, real-time monitoring of engine load. This system allows for better management of fuel consumption and PTO RPM, leading to optimized tractor performance and potentially reducing operational costs.

The proposed system was designed to integrate seamlessly with existing tractor systems, providing a user-friendly interface that delivers critical information directly to the operator. The system provides real-time displays of engine load, fuel consumption, and PTO RPM, offering crucial data that assists operators in selecting the optimal gear, choosing the appropriate implement, and making other adjustments that enhance operational efficiency and overall performance. The real-time nature of the Decision Support System ensures that adjustments can be made on the run, significantly improving the overall efficiency and safety of tractor operations.

Authors' contribution:

Conceptualization and designing of the experiments (GS, JS, AP, AD, RK); Execution of the experiments and data collection (GS, JS); Data analysis (GS, JS, AP and RK); Preparation of manuscript (GS, AP, AD).

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