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EMBEDDED SYSTEM FOR REAL-TIME MONITORING OF AGRICULTURAL TRACTORS SLIPPING AND FUEL CONSUMPTION

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KEYWORDS

Arduino, tractor test, mechanization, machine performance, slippage.

ABSTRACT

Wheel slipping and fuel consumption are variables influenced by tire pressure, speed, ballasting, and soil surface. Once the tractor is present in all agricultural operations, knowledge of these variables is essential to achieving the most operational efficiency. This study aimed to develop an embedded system to collect data and show tractor slipping and fuel consumption in real-time via smartphone. The system was developed using prototyping platforms and validated through randomized field tests under four speeds and two terrain conditions. Three methods for determining slippage under different conditions were compared. The developed embedded system determined an agricultural tractor's slipping and fuel consumption conditions. The slip and fuel consumption rates varied depending on the type of rolling surface (ground preparations) and the tractor's operating speeds. Conventional tillage surface increased fuel demand by 6% and slippage by 17% compared to no-till rates. The proposed embedded system found similar results and could present the slipping values in the developed Android to real-time operation compared to a conventional method. This application shows both slipping and fuel consumption values over time on graphs, which can be very useful during machine operation, helping to define better configuration and reduce environmental impacts.

INTRODUCTION

Tractors play a very important role on farm production costs and environmental impact (Lovarelli et al., 2018; Lanças et al., 2021; Melo et al., 2022). The fuel consumption and, consequently, the engine exhaust gases emissions are the main factors of these impacts (Lovarelli & Bacenetti, 2019; Lopes et al., 2023). Although optimizing tractor efficiency has been a subject of considerable research (Cutini et al., 2020; Mattetti et al., 2022), there is a need to provide real-time information on tractor performance parameters, such as fuel consumption and wheel slip, through embedded monitoring devices using recent prototyping microcontrollers (Kumar et al., 2017; Hensh et al., 2021).

Machine's information would be very valuable to aid the operator's decision making during the field operation. The tractor's hourly fuel consumption depends on its slip; the higher the tractor's slip, the greater its fuel consumption (Lanças et al., 2021). Thus, the slipping should not exceed 15-16%, which yields lower field performance and increases the soil structure disruption (Battiato & Diserens, 2017; Keller et al., 2019). On the other hand, slip lower than 5-7% is unacceptable due to power wasting carrying excessive weight, which can also increase the fuel consumption of up to 15% (Damanauskas & Janulevicius, 2015).

Moreover, monitoring the amount of fuel consumed is one of the most important aspects to evaluate an engine performance, i.e., its performance as a heat energy-converting machine, besides its environmental impact (Lovarelli et al., 2018; Janulevicius et al., 2018; Janulevicius & Damanauskas, 2023).

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This study aimed to develop an embedded system to collect data related to tractor performance, specifically tire slipping and hourly fuel consumption on two soil surfaces. Besides, a smartphone application was developed, rendering a friendly human-machine interface from which it is possible to visualize the measured parameters in real time.

MATERIAL AND METHODS

Site of study

The research and prototyping were developed in the Department of Agricultural Engineering and Automation laboratories at the Federal University of Lavras–MG. Field tests to validate the data acquisition system were carried out on the Federal University of Lavras experimental campus, in an area designated for tests and operations, between coordinates 21° 16" S and 44° 92" W, at 853m altitude. The climate was classified as Cwa, according to Köppen-Geiger, mesothermal, temperate humid with dry winter, with an average temperature of 20.4° C and an average annual rainfall of 1508 mm. The soil in the experimental unit was classified as Red Yellow Latosol, according to Santos et al. (2018) or Typic Hapludox according to Soil Taxonomy (USDA, 2014).

Proposed measurement system

The electronic monitoring system was developed based on product development methodology (Rozenfeld et al. 2015). This occurred due to the need to "monitor fuel consumption and slippage of a tractor in real time" using common systems, to meet the need to make decisions when operating with agricultural tractors.

Due to the diversity of materials available, sensors and actuators in the prototyping electronics market, the Arduino MEGA microcontroller was chosen for the project due to its processing capacity and possibility of connection with pulse counting sensors (encoders) and fuel flow (flow meters). Therefore, the proposed measuring system consists of four-pulse generators (revolution encoders) model GIDP-60-U-12V, and one LSF41L8-M2 OVAL flow meters, an Arduino Mega with datalogger and an application for Android operating system with real-time operating interfaces via Bluetooth. This architecture is shown in Figure 1.

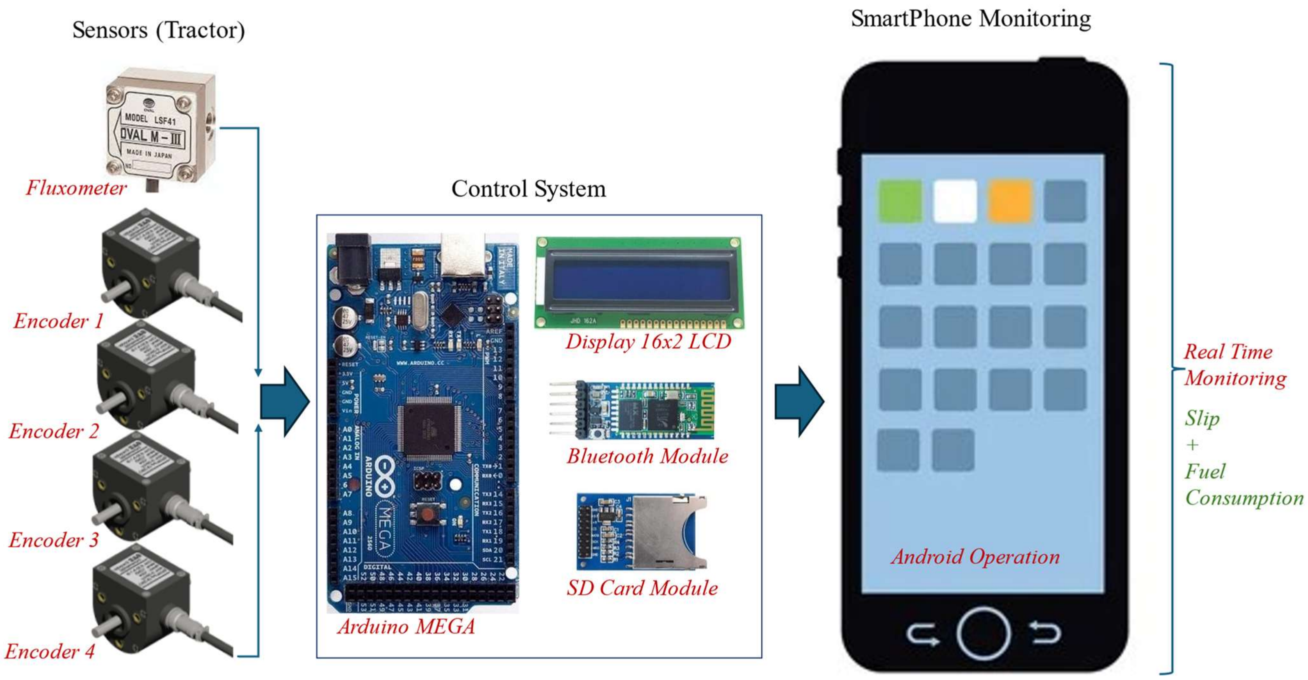

FIGURE 1. Measurement system architecture.

The encoders were installed in the tractor wheels, with their axles coupled in supports concentric to the wheels so that each revolution of the tractor wheels generates 500 pulses in the encoders. The encoders measure the wheel's revolution rate and send this value to the Arduino as electric pulses. A flow meter was installed after the fuel filters to read fuel consumption. All fuel system engine returns were placed after the sensor. This sensor sends the microcontroller a pulse for each milliliter (ml) that travels through it. This pulse is sent to the microcontroller's interrupt, which executes a subroutine each time the interrupt is triggered.

The acquisition system is also equipped with a 16x2 LCD display, installed on the front panel, whose function is to show the fuel consumption values and slipping rate. Besides the display, three colored LEDs are inserted in the colors green, yellow and red, whose function is to present the wheel slipping levels to the operator, being 0-10%, 10-15% and +15%, respectively. Thus, from the schematic shown in Figure 2, the system was constructed.

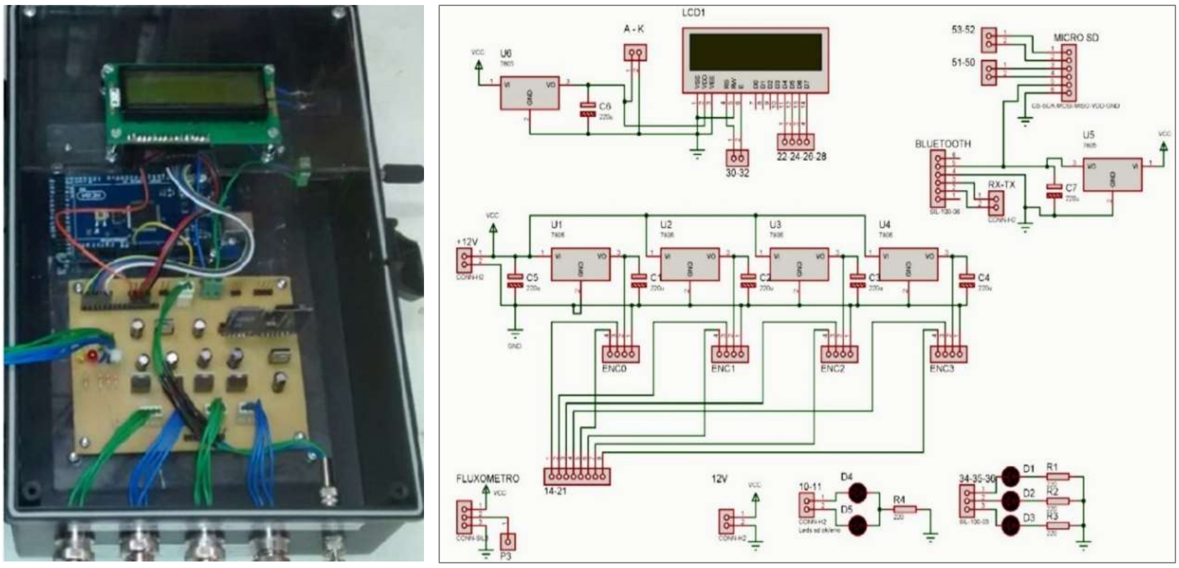

FIGURE 2. Architecture of the proposed measurement system prototype.

Electronic configuration of the proposed system (Figure 2). Furthermore, the system has an SD memory card module to store the collected data locally for later analysis and a Bluetooth communication module, which provides communication between the measurement system and an application installed on a smartphone with the Android operating system. The interface screen was developed in MIT App Inventor software.

Validation methodology and field tests

Two performance parameters (rear wheel tractor slipping and hourly fuel consumption) were evaluated through operational tests with a tractor Ballast mass coupled to the agricultural tractor. The specifications of the tractors used for the tests are shown in Table 1.

TABLE 1. Tractor characteristics.

Tractor tested – Tractor 1	Brake Tractor – Tractor 2
Brand Valtra AGCO	Brand Agrale S/A
Engine AGCO (69,8 kW) @2200rpm	Engine MWM (77,2 kW) @2300 rpm
Model - A950	Model - BX 6110
Traction - 4X2 TDA	Traction - 4X2 TDA
Rear Tires - 18.4-34 R1 (124kPa inflation pres.)	Rear Tires - 23.1-30 R1(110kPa inflation pres.)
Front Tires - 14.9-24 R1 (138kPa inflation pres.)	Front Tires - 14.9-30 R1(97kPa inflation pres.)

Tractor 1 pulled tractor 2 (train brake) always at a fixed speed imposed by the brake tractor, data acquisition occurred whenever tractor 1 reached the standard speed with an engine rotation of 1850rpm. Thus, determining the load on the drawbar of the tested tractor was imposed by tractor 2, this tractor train controlled the operating speed during the tests.

The treatments adopted in the field tests were composed of 4 operational speeds in two rolling surfaces (two soil preparation types), namely no till and conventional tillage (soil disturbed with a harrow). Operating speeds were determined by adjusting gears on tractor 2 and their respective theoretical travel speeds 3, 3.5, 4.5 and 9 km h^{-1} respectively in tractor 2 gears 3M, 4B, 2A and 4A.

The soil in the no-tillage system had a plant cover of brachiária and native vegetation; this surface was mown superficially seven days before the tests. For this, a Cadioli RCU500 model brush cutter was used, with a cutting width of 1500mm and a total mass of 265kg coupled to the tractor's hydraulic system. Cover vegetation and straw were spread evenly over the tractor transit area.

In the conventional tillage area, it was carried out with two passes of a heavy Civemasa plowing harrow with 14 30” discs and a total mass of 18.2 kN. In this way, working strips measuring 30 meters long by 4 meters wide were determined and the treatments were randomized in each plot (speed x method x surface).

During the tests, the instrumented tractor equipped with data acquisition equipment and sensors was coupled to a brake tractor (Figure 3). Thus, the brake train set moved until the speed stabilized (after 5 meters) on the tracks and the data acquisition system was activated.

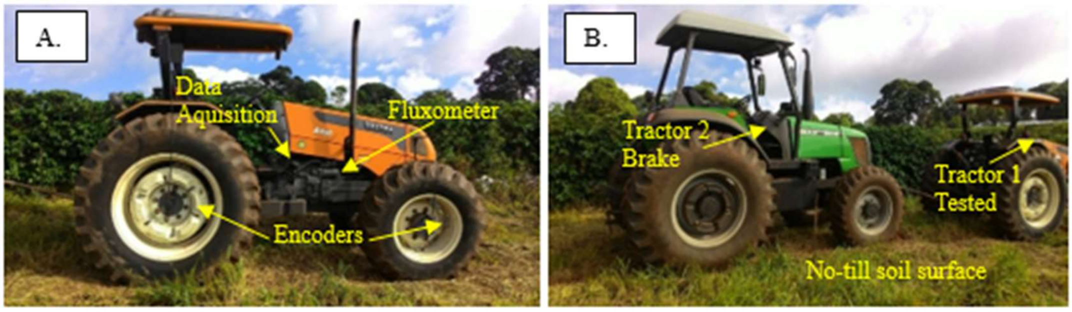

FIGURE 3. Electronic system on tractors for field validation tests. A. sensors and data acquisition system; B. brake train in tests on no till soil surface.

Slipping determination

To validate the data acquisition system, slippage was determined using three different methods, described in Table 2. Methods 1 and 2 were obtained through the automatic data collection system, present on the Android device and developed controller. However, Method 3 was obtained in a traditional direct way with the aid of a manual centesimal stopwatch and the time relationships to cover the plots with and without load on the brake tractor.

TABLE 2. Description of the methods to determine the slippage of the tractor's driving wheels.

Method	Description
1	Method used by the proposed and developed system using the Arduino control board and front wheels as a distance and odometry reference system.
2	Relationship between the number of revolutions of the driving wheelsets during a 30m distance in conditions with and without load.
3	Relationship between travel time on the plot by driving wheels during a 30-meter journey with and without load.

In all collections with an automated system (Method 1 and 2), the variable number of pulses to traverse the plot without load was stored as a variable in the controller programming. The tractor wheel slipping was determined through the number of pulses obtained by the encoders and calculated using the [eq. (1)].

$$S = 100\frac{N_1 - N_2}{N_1} \tag{1}$$

Where:

S corresponds to the driving wheel slipping, given as percentage (%);

N1 is the number of pulses in the loaded condition during the tractor's displacement, and

N2 is the number of pulses in the unloaded condition.

Fuel consumption determination

The fuel consumption was obtained using the flow meter data. The flow meter readings were converted to L h^{-1} according to [eq. (2)].

$$FC = \frac{360N_p}{t} \tag{2}$$

Where:

FC is the hourly fuel consumption, given in L h^{-1};

Np is the flowmeter pulses number, and

t is the route time of the plot, given in seconds.

Statistical analysis

A randomized block design was used, with the four speed levels, three modes of slipping determination and two soil surfaces (no-till and conventional tillage), with 3 replicates and 72 plots. All data were subjected to Anderson-Darling normality and homogeneity of variance tests. The obtained averages were analyzed by the F test at 5% of confidence level, ANOVA and Tukey test. The statistical data analyses were performed using the SISVAR statistical software version 5.0.

RESULTS AND DISCUSSION

Embedded data acquisition and monitoring device

The human machine interface to acquisition and monitoring system can be seen in Figure 4. The development of the data acquisition system using the Arduino platform allowed monitoring of the tractor's operating conditions in real time to operating smartphone. Figure 4 (a.) describes the initial basic information screen and screen 4 (b.) details the behavior of the variables in the time domain.

(a)

(b)

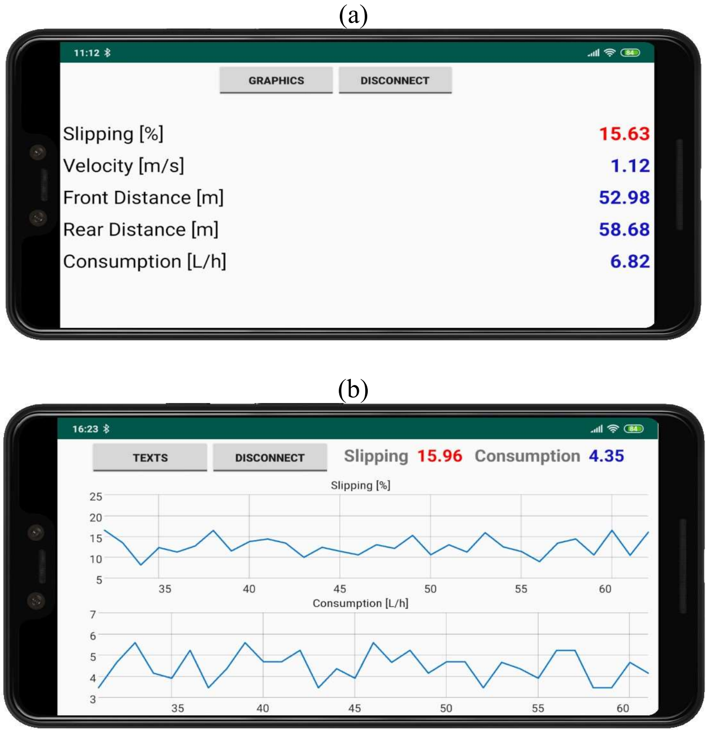

FIGURE 4. Android application screens.

The applications of machine monitoring systems during agricultural operations allow adjustments to be chosen to increase the efficiency of the tractor-implement, thus optimizing the use of energy resources. Lanças et al. (2021) inferred that tractor tests serve to determine the optimal working conditions in the field and minimize losses. Our results contribute to improving the operating efficiency of agricultural tractors, in addition to being suitable for installation on any tractor model and field operation. According to Lovarelli et al. (2018), the operational and energy efficiency of machines can be improved and estimated by modeling methods. Therefore, our results contribute to better relating estimates and mathematical simulation systems.

Slippage methods analysis

The slippage assessment methods showed significant differences to the results obtained in the data acquisition system only for reduced operating speeds, in conditions of greater slippage. Table 3 describes the slip behavior depending on the different deterministic methods.

TABLE 3. Tukey test for the method used at different braking tractor speeds.

Speed	Metod 1	Metod 2	Metod 3
9.0	6.80 c	6.46 c	6.13 c
4.5	6.32 c	5.52 c	6.96 c
3.5	8.94 b	8.39 b	8.76 b
3.0	11.19 a	10.21 a	8.76 b
Error	0.40	0.40	0.41
Coefficient Deviation %	9.71	10.42	21.68

Means followed by different letters represent significant results at a 5% probability level using the Tukey test.

The slip found for speeds above 3.5 km h^{-1} did not vary according to the deterministic methods adopted. However, for the lowest speed (3 km h^{-1}), methods 1 and 2 differed from method 3. Method 3 underestimated slippage, indicating that the manual slippage acquisition and determination system may affect the results. However, in the automatic data collection methods 1 and 2, the means were statistically equal in all conditions; this represents an advantage in applying automatic acquisition equipment, as developed in this research.

Operator training can affect the performance of tractors in the field and their slippage rates (Lopes et al., 2023). Thus, embedded systems that show changes in real-time become important for optimizing resources. According to Cutini et al. (2020) heavy work for tractors on disturbed soil is one of the main challenges for reducing slippage, since in these conditions the soil friction coefficient is reduced, increasing the tractor's sliding and energy demand. Table 4 describes the slippage of the tested tractor, using the average of the three slippage methods and speeds on different soil types.

TABLE 4. Average slippage for different soil preparations.

Soil System Management	Slip
No-Till	6.67 b
Conventional Tillage	8.10 a
Error	0.22
Coefficient Deviation %	21.68

Means followed by different letters represent significant results at a 5% probability level using the Tukey test.

Melo et al. (2022) inferred that the ground surface is decisive in determining tractor slippage. The authors sought an ideal slip range for their tests on electric tractors between 9.6 and 9.8% in firm soil surface. Our findings show smaller slippage for the two surfaces tested, however, the slip gain in the conventional tillage was 17%.

According to Keller et al. (2019), machines have increased in mass and power over the years, this means that in soil conservation systems there are compacted layers on the surface, which generates lower rolling resistance of the wheelsets, providing better traction conditions for the machines.

Fuel consumption and slip

Slip rates are closely related to fuel consumption, as they represent the demand for unused traction during agricultural operations. Regardless of the type of soil preparation, slippage did not reach critical limits according to Cutini et al. (2020). Table 5 describes the fuel consumption in each soil preparation system.

TABLE 5. Wheel slippage and fuel consumption in no till and conventional tillage.

Soil System Management	Fuel Consumption (L h^{-1})
No-Till	7.37 b
Conventional Tillage	7.84 a
Error	0.11
Coefficient Deviation %	5.27

Means followed by different letters represent significant results at a 5% probability level using the Tukey test.

In the conventional tillage, fuel consumption was increased, representing an of 6% to direct planting. This finding indicates that the high levels of slip obtained in this condition increased the energy demand of the tractor for agricultural operations. According to Janulevicius & Damanauskas (2023), variations in a tractor's performance throughout a field operation can be related to the way the machine is driven and terrain factors. Our research showed differences in performance in prepared soil and vegetation cover systems.

In addition to the soil management mode, the operational speed of mechanized sets can change fuel consumption and tractor slippage (Askari et al. 2021). Our findings showed that increasing operational speed reduced slippage. Table 6 describes slippage and fuel consumption at each operating speed of the mechanized set.

The lowest operating speeds had the greatest slippage, this was due to the high loads imposed by the brake tractor (ballast) to reduce speed. With greater traction demand and more load on the drawbar, the tested tractor had increases in slippage and fuel consumption. The data acquisition system developed in this research allowed monitoring and detecting changes in each operational condition of the set.

TABLE 6. Wheel slippage and fuel consumption at different braking speeds.

Speed	slip (%)	Fuel Consumption (L h^{-1})
9.0	6.83 c	7.37 b
4.5	6.46 c	7.43 a
3.5	9.31 b	7.73 a
3.0	11.57 a	7.87 a
Error	0.34	0.15
Coefficient Deviation %	9.71	9.71

Means followed by different letters represent significant results at the Tukey test's 5% probability level.

The lowest fuel consumption was obtained at 9 km h^{-1}, not statistically different at other speeds (Table 6). However, the greatest slippage of 11.57% was obtained in the lower speed condition, due to the greater load on the traction bar of the tested tractor. The increase in slippage, in absolute terms, increased the tractor's fuel consumption. These results are in line with Lanças et al. (2021) and Damanauskas & Janulevicius (2015).

CONCLUSIONS

In this study, an embedded system for real-time estimation of an agricultural machine’s slipping rate and fuel consumption was developed. The electronic board developed was introduced and can be easily reproduced elsewhere without additional costs.

The proposed embedded system was found to provide slipping measurement results similar to those of a conventional method. It presents slipping values in real-time through an Android application, displaying fuel consumption values over time. This practical application can assist users in optimizing machine configuration, thereby reducing costs and environmental impacts.

The slippage and fuel consumption rates varied depending on the type of rolling surface (ground preparations) and the tractor's operating speeds. Compared to no-till rates, conventional tillage increased fuel demand by 6% and slippage by 17%.

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