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AUTOMATIC DATA ACQUISITION SYSTEM-ADAS FOR ENERGY OPTIMIZATION IN TRACTORS AND IMPLEMENTS

ABSTRACT - The technical dimensioning of the tractor set and implements for each crop and respective areas to be explored establishes the width of the implement, tractor power, and management characteristics to be used. Fuel consumption (l/h), operational work performance (ha/h), and quality of work are the most critical operational performance indicators in the set. The Automatic Data Acquisition System – ADAS (SIAD in Portuguese), developed in 2018, was improved in 2020, to an easy-to-handle system aimed at managing field operations of the tractor+implement set, with a programmable acquisition module, with real-time records, georeferenced and stored in memory at one-second intervals. The ADAS was tested on a bench, and validated with the tractor+implement set plowing in alluvial soil, in 12 data collection cycles, for an operational evaluation. Comparing the traction efficiency of 43.07% obtained by the tractor+plow set for a slippage of 17.3%, it can be seen that it falls short of the values presented by Janulevičius et al. (2019). In addition, Table 4 indicates that the tractor is working with a very high range of slipping values, ranging from 17.3 to 41.9%, reinforcing the need for adjustments, especially with ballasts, to avoid power loss through the wheels and to keep the tractor moving. The essential information, fuel consumption, and slippage can be read in real-time by the operator, on the box display on the tractor panel, and later, by the technical area, as they are recorded in the microcomputer memory to analyze the operations.

Keywords: agricultural mechanization, electronic instrumentation, automatic data acquisition, embedded systems, operational evaluation.

SISTEMA AUTOMÁTICO DE AQUISIÇÃO DE DADOS-ADAS PARA OTIMIZAÇÃO DE ENERGIA EM TRATORES E IMPLEMENTOS

RESUMO - O dimensionamento técnico do conjunto trator e implementos para cada cultura e respectivas áreas que serão explorados, estabelece a largura do implemento, potência do trator e características do manejo, a ser utilizado. O consumo de combustível (l/h), o desempenho operacional de trabalho (ha/h) e a qualidade do trabalho são os indicadores de desempenho operacional mais importantes do conjunto. O Sistema Automático de Aquisição de Dados – SIAD, desenvolvido em 2018, foi aperfeiçoado em 2020, de fácil manuseio, gerenciamento as operações de campo do conjunto trator+implemento, com um módulo de aquisição programável, com registros em tempo real, georreferenciados e armazenados na memória, em intervalos de um segundo. O SIAD foi testado em bancada e a validação, por um conjunto trator+implemento arando um solo Aluvial, em 12 ciclos de coleta de dados, para uma avaliação operacional. Comparando a eficiência de tração de 43,07 obtido pelo conjunto trator+arado, para um deslizamento de 17,3%, com valores aquém dos apresentados por Janulevičius et al. (2019). Além disso, a Tabela 4 indica que o trator está trabalhando com um faixa de valores de patinagem, variando de 17,3 a 41,9%, reforçando a necessidade de ajuste regulagens, principalmente com lastro, para evitar perda de potência pelas rodas, para manter o trator em movimento. As informações mais importantes, consumo de combustível e patinagem, podem ser lidas em tempo real, tanto pelo operador, no visor da caixa no painel do trator, como também posteriormente, pela área técnica pois estão gravados na memória do microcomputador, para análise das operações de campo.

Palavras-chave: mecanização agrícola, instrumentação eletrônica, aquisição automática de dados, avaliação operacional.

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Farmers can count on a large amount of agricultural machinery and equipment available on the national market to meet the different agricultural production systems. The choice of tractor and implement is defined according to the size of the property, calendar, and type of crop being exploited to optimize its use within the allowed operational capacity. Therefore, the operational work performance (ha/h) and the quality of the work are the most important indicators of the tractor+implement set. Various studies showed that the ideal tractor wheel slip in the upper soil layer should be 8-16% (Damanauskas & Janulevičius, 2015; Battiato & Diserens, 2017). However, Leite et al. (2020) separate these ideal slip values for maximum traction efficiency between two tire types: diagonal tires, between 8% and 12%, and radial tires, 10% and 15%.

Even before being used, any agricultural implement has its operational capacity (ha/h or t/h) known and its respective power demand for choosing the tractor. However, even knowing that the agricultural implements can work within a range of operational capacities, the farmer is only concerned with the performance of the work and is pressured against the clock to give time to his schedule. Furthermore, fuel consumption in various field operations depends on many factors, such as soil texture and structure, tractor size and configuration, tractor and implement ratio, tillage speed, and others (Lee et al., 2016). Therefore, before starting field operations, it is necessary to establish operating conditions that balance the high work capacity provided by agricultural mechanization and the sustainability of the production area. In this case, if the tractor operator can count on an indicator on the tractor panel, showing mainly the specific consumption (l/h), and percentage of slippage of the driving wheels (%), he could interrupt a work operation when the values are outside acceptable levels, avoiding thus excessive energy consumption without producing good work. Increasingly, production systems will have to optimize their production costs, reducing energy waste and increasing the productivity of their crops to meet the growing demand for food and other raw materials and make a profit. The data presented by the production cost spreadsheets for the second harvest of corn and conventional and transgenic soybean crops from the Institute for the Strengthening of Agriculture of Goiás (2021) and the Secretariat of Agriculture and Supply of Paraná (Paraná, 2021) show that operations with agricultural machinery have varied from 14.8 to 18.6% of the total cost.

However, due to the lack of field data, these percentage values have been estimated, in most cases, due to the difficulty in obtaining operational data, in real-time, of agricultural machine operation variables that make up production costs. For this purpose, automatic acquisition systems have been developed using the most diverse platforms, as shown by Garcia et al. (2015). Furthermore, the growing technological evolution of microcontrollers and embedded computers has led to several solutions aimed at agribusiness and other sectors of the economy (Lamborelle & Álvarez, 2017). For this reason, in work developed by Santos et al. (2018), the indication was to program embedded systems as compactly as possible, with alternative solutions to improve the algorithms.

With the popularization of microelectronics applied to agricultural systems, process automation, and data acquisition, agriculture has tools to optimize the use of machines. It implements and, at the same time, monitors field operations by the operator or remotely using wireless systems.

This work aimed to develop/improve a more interactive data acquisition system-ADAS/SIAD with a low-cost operator embedded in a set to reduce energy consumption during field operations.

Material and methods

The development/improvement of the ADAS/SIAD was carried out at the Mechanization Laboratory, at Embrapa Maize and Sorghum, with field tests in the experimental area, in an alluvial, eutrophic soil with a sandy loam texture, with the water content in the soil being monitored, in all tests, with composite samples, of the cut profile. It is essential to mention that the improvement work for a more user-friendly operation required developing an embedded system for data collection that is easy for people who are not specialists in electronics or information technology. It is an easy-to-use system for data acquisition programming of the tractor+implement set in field activities.

Next, a construction sequence of the new ADAS/SIAD will be presented, with details of the acquisition box components, sensors, and field test procedures to monitor field operations.

System Description

The Automatic Data Acquisition System (ADAS/SIAD) was developed in 2018 and improved in 2020 for a more user-friendly and easy-to-handle system aimed at managing field operations. Several sensors were installed in a tractor+implement set and connected to a programmable acquisition module, which performed records displayed in real-time, georeferenced, and stored in memory at regular intervals of approximately one second to monitor field operations. The information collected by ADAS/SIAD is made available in real-time during the operation, which is being carried out in the field and is composed of the following data:

1. Date and time:
2. Geographic positioning, latitude, longitude, and altitude;
3. Fuel consumption, l/h;
4. Power demanded by the implement, kW;
5. Working speed, km/h;
6. Slippage of drive wheels, %;
7. Implement working depth, cm.

In real-time, this information generated by the acquisition system allows the operator of the tractor+implement set, when initiating field operations, to check whether the implement

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adjustments are adequate, assessing whether the tractor's ballast, in terms of weight, as well as the tractor tire. Two pieces of information can be evaluated initially for this regulation adjustment, fuel consumption, and slippage percentage, which indirectly indicate loss of power in the wheels, due to excessive slippage, with low tractor efficiency (TE). At the same time, the slipping percentage and the fuel consumption indicated on the acquisition box display on the tractor panel allow the operator to adjust the set, aiming to work according to the manufacturer's recommendations.

System Development

Technologies associated with microelectronics have become increasingly accessible to the general public, and evidence of this is the popularization of microcontrollers, development platforms, and small computers. These microprocessed devices, with the help of appropriate programming, allow the development of applications that flexibly meet the specific demands of each user.

The system was developed based on a single-board computer, in which several sensors were connected. To manage data collection, each of these sensors associated with algorithms was implemented in C and C++, observing the characteristics of each connected device. According to Santos et al. (2018), the C and C++ languages are good alternatives for developing embedded systems, given the possibility of accessing low-level abstraction resources such as access to processor registers and bit manipulation, as well as the assembly language. Also, programming is reasonably easy compared to high-level languages since they are multipurpose, have many libraries, and are compatible with most system architectures.

The system has an AM3358x processor that integrates a 32-bit, 200 MHz ARM Cortex-A8 microcontroller, which was used to read the digital signals accurately. This controller, also called a Programmable Real-Time Unit (PRU), processes the signals from flow and inductive sensors at a very high speed. In this way, the latency in reading the signals is practically non-existent, which gives the system high reliability in measuring fuel consumption and slippage.

Figure 1 displays the overview of the developed ADAS/SIAD, indicating the connection of the sensors and components of the user interface (buttons and display).

Validation of the Automatic Data Acquisition System – ADAS/SIAD

The ADAS/SIAD was tested on the bench with the aid of a function generator, making it possible to carry out an initial validation of the system. Once the bench tests were successful, a new validation was carried out through field tests. Considering that the system's operating conditions embedded in the tractor are severe, adjustments were necessary, both in the hardware and in the firmware, to carry out a test data collection aiming to evaluate the general functionalities of the system.

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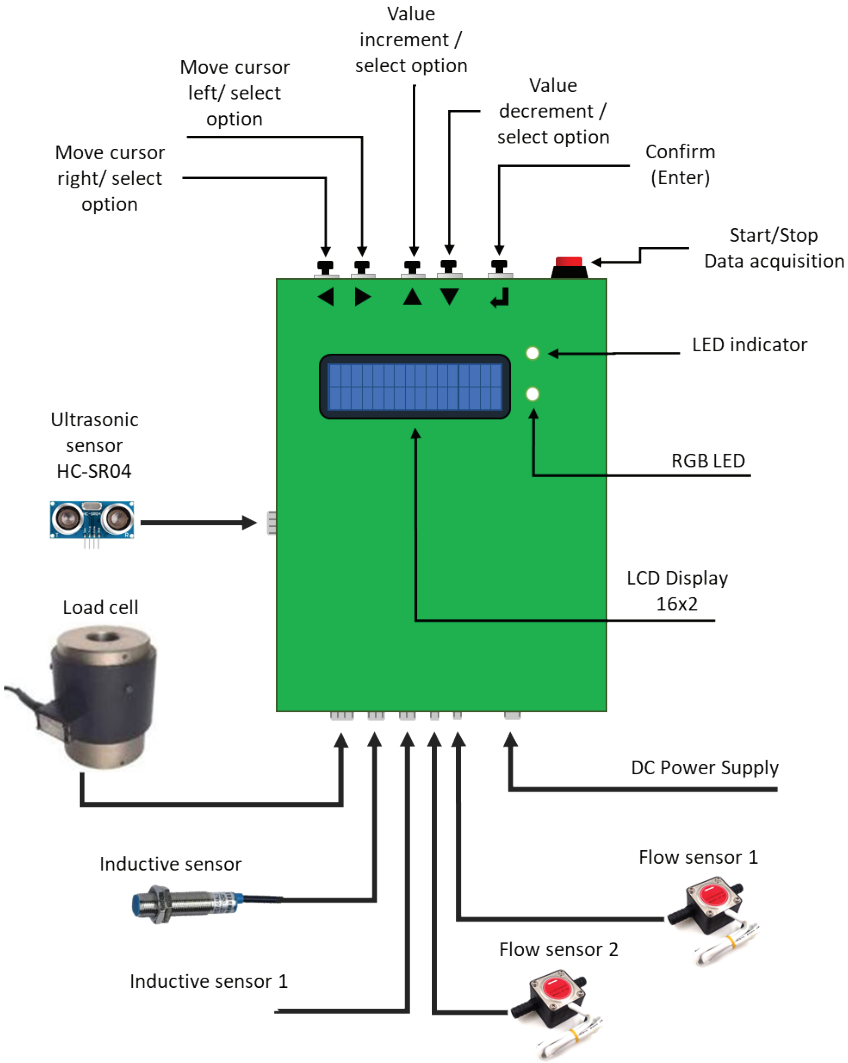

Figure 1. Overview of the developed ADAS/SIAD, with the respective sensors and user interface components (buttons and display).

The ADAS/SIAD was loaded onto a TL-95E New Holland tractor (2012), 4x4, FPT engine, 72 kW of power, pulling a plow of 3 moldboards of 28” (Figure 3) for plowing an experimental area, of a eutrophic alluvial soil, with a sandy loam texture, for 15 minutes, with the collection of all seven information simultaneously, every second, during 12 cycles of data collection, corresponding to the turns of the set, at the end of the line of work.

Since ADAS/SIAD collects field data during a given operation, the operator can know if the fuel consumption data shown on the screen are consistent for the tractor+implement set in which he works. Fuel consumption is obtained by the difference between the instantaneous measurements of the two fuel sensors installed on

Figure 2. Automatic data acquisition system-ADAS/SIAD (data collector) and tests in the Mechanization Laboratory of the tractor-implement set (TL-95E New Holland and moldboard plow, 3x28"), of adjustments/calibration of the signals of each sensor, prior to field testing.

the tractor, the first on the engine inlet line and the second on the return line to the tank. Over time, under similar conditions, with engine rotation of 2100 rpm and working speed (km/h) by the Ublox NEO-6M GPS module with exact information transmitted from the module to the onboard computer through serial communication (UART).

Once the ADAS/SIAD screen indicates the instantaneous consumption, the operator can use the indicated values to evaluate the need for inadequate adjustment of the implement or to verify if the tractor is adequately ballasted for the type of work. According to Piacentini (2012), fuel consumption varies according to working conditions, characteristics and state of the machine, and operator skill and can be obtained using existing data or estimates. The data collected in the field are considered references for better control of fuel consumption, and currently, continuous notes are recorded manually in notebooks of the operations carried out. In order to have an estimate of the specific fuel consumption in tractors powered by gasoline, diesel, and natural gas, in tractors with a load greater than 17 to 20%, the ASABE (American Society of Agricultural and Biological Engineers, 2003) proposes a methodology where the ratio between the power required by the implement at the power take-off and that available by the engine at the power take-off (PTO) is used in an equation to obtain the specific fuel consumption.

$$CCH = CEC * PRTDT,$$

On what:

- CCH = Hourly fuel consumption (L/h)
- CEC = Specific fuel consumption (L/kWh)
- PRTDP = Required power at PTO (kW)

The working depth was measured by an ultrasonic sensor HC-SR04, by the emission of ultrasonic waves, 12 cycles at 40 kHz, during plowing with the moldboard plow as described by Santos et al. (2018). This ultrasonic sensor is precise and can be used in other activities, in addition to this activity under test, to evaluate, for example, the sowing depth, which is extremely useful for specific crops.

Schoenbuch IBCT 1812 inductive proximity sensors were installed on the tractor's rear wheels to measure its angular velocity, aiming to measure the slip of the driving wheels. These devices can detect metallic masses through the emission of a magnetic field produced by an oscillator and a coil. Thus, knowing the number of metallic points distributed along the wheel capable of sensitizing the inductive sensor, it is possible to use the equations described by Liljedahl et al. (1989) to determine the angular velocity and, consequently, the slippage that occurred during plowing, which demands traction force transmitted by the wheels.

The power provided by the engine was indirectly determined by the methodology performed by Mantovani et al. (1999). The use of indirect power in PTO was due to the difficulty of obtaining instrumentation to measure it at the wheels, which would be more appropriate.

The manufacturer provided the consumption and power curves of the TL-95E New Holland Tractor (2012), with fuel consumption in l/h and power at the Power Take-Off (PTO) in kW. In this way, the indirect power value was obtained at different engine speeds through the fuel consumption values in liters per hour. The equations obtained from the calibration curves were inserted into the program to calculate the power supplied by the engine at 1900 and 2100 rpm.

Results and discussion

The field evaluation tests of the ADAS/SIAD, embarked on the tractor+implement set, shown in Figure 3, were carried out in an experimental area in the municipality of Sete

Figure 3. Automatic data collection system-ADAS/SIAD embedded in the tractor + implement set (TL-95E New Holland and moldboard plow, 3x28”) in field tests.

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Lagoas-MG, whose latitude and longitude are, respectively, 19° 28' S and 44° 15' W. The altitude is 732 meters, in alluvial, eutrophic soil with a sandy loam texture, with the results shown in Table 1.

Test site: Várzea (Pivozinho), Embrapa Maize and Sorghum;

- Type of soil: Eutrophic alluvial, sandy loam texture;
- Soil sampling: five locations throughout the work area;
- Implement under test: Moldboard plow, 3 x 28";
- Collection date: 10/30/2020.

Next, reading files obtained by ADAS/SIAD for about 15 minutes are presented, including the turns at the end of the field, resulting in 845 georeferenced samples and presented in Table 2, with the following pattern of data acquisition:

The data obtained by ADAS/SIAD, during the work of the set, tractor + moldboard plow, in the field, were distributed in twelve cycles of collection times, resulting in 845 georeferenced samples of work speed, slippage of driving wheels, fuel consumption, working depth and power demanded by the implement. The average test time, operating speed, slippage of the driving wheels, fuel consumption, the power demanded by the implement, and cutting depth, for each cycle, are shown in Table 3.

The results presented graphically in Figures 4 to 9 are from the twelve collection cycles obtained during the soil preparation operation, with moldboard plow, for an operational evaluation of each monitored variable.

The tests consisted of recording consumption over time, under similar conditions, and an engine speed of 2100 rpm. The tractor+implement set, TL-95E New Holland, and moldboard plow, 3x28", are in alluvial soil. The results obtained in the field tests are shown in Figure 4. The spatial

Table 1. Results of soil water content (%), from five sampling sites, from the ADAS/SIAD test area, and the tractor + moldboard plow set.

depth (cm)	sampling site	wet weight (g)	dry weight (g)	tare (g)	Moisture content (%)
0 - 20	1	326.07	278.97	61.67	21.7
	2	385.02	327.61	66.32	22.0
	3	385.07	324.19	58.68	22.9
	4	361.28	303.21	67.48	24.6
	5	377.39	317.58	61.98	23.4

• Obs. The five soil sampling sites were taken along the test area of the tractor+implement set to find out the water content of the soil.

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Table 2. An example of a standard data sheet generated by ADAS/SIAD, during field tests, for the operational evaluation of the tractor+implement set.

```
            Data acquisition System - AgroMec 2.0
 time |   latitude   |  longitude   | alt |speed| ptg |cnsm|depth|power
hhmmss|  (deg/min)   |  (deg/min)   |  m  |km/h| n/a |l/h | mm |   kW    |
13:02:06,19°26.70377'S,44°10.05993'W,701.5,5.7,0.55,14.5,694,55.9
13:02:07,19°26.70369'S,44°10.05964'W,701.5,2.6,0.446,7.1,728,27.6
13:02:08,19°26.70354'S,44°10.05907'W,701.6,8.9,0.017,11.1,740,43.0
13:02:09,19°26.70336'S,44°10.05837'W,701.7,7.5,0.435,16.9,740,65.4
13:02:11,19°26.70322'S,44°10.05788'W,701.7,6.4,0.404,16.7,766,64.5
13:02:12,19°26.70312'S,44°10.05738'W,701.7,4.2,0.080,11.7,737,45.2
13:02:13,19°26.70297'S,44°10.05702'W,701.7,4.4,0.132,8.2,659,31.7
         .                                         .
         .                                         .
         .                                         .
13:19:04,19°26.70604'S,44°10.05198'W,696,6.2,0.654,19.9,744,76.8
13:19:05,19°26.70622'S,44°10.05248'W,696,6.2,0.287,17.9,608,69.0
13:19:06,19°26.70642'S,44°10.05306'W,696.1,7.8,0.450,12.3,806,47.7
13:19:07,19°26.70671'S,44°10.05372'W,696.1,8.8,0.225,7.7,814,29.8
13:19:08,19°26.70698'S,44°10.05446'W,696,9.3,0.175,10.7,1306,41.3
13:19:09,19°26.70726'S,44°10.05521'W,696.1,9.7,0.100,4.5,798,17.4
13:19:10,19°26.70754'S,44°10.05595'W,696,9.4,0.144,4.2,748,16.3
13:19:11,19°26.70781'S,44°10.05667'W,695.9,9.2,0.183,4.6,824,17.7
13:19:12,19°26.70800'S,44°10.05744'W,695.6,9.3,0.151,16.2,800,62.7
13:19:13,19°26.70827'S,44°10.05822'W,695.5,9.6,0.025,9.4,1546,36.2
13:19:14,19°26.70854'S,44°10.05896'W,695.5,8.6,0.029,2.7,801,10.3
13:19:15,19°26.70864'S,44°10.05929'W,695.6,1.3,0.310,4.9,819,19.1
13:19:16,19°26.70866'S,44°10.05936'W,695.5,0.2,0.038,6.2,768,23.9
13:19:17,19°26.70866'S,44°10.05938'W,695.4,0.3,0.036,2.8,854,10.7
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Table 3. Summary of data obtained with ADAS/SIAD and organized with statistics of measures of Working speed, slippage of driving wheels, Fuel Consumption, Power demanded by the implement, and Depth of cut of the moldboard plow, of the twelve cycles of data collection, during field tests, for operational evaluation of the tractor+implement set.

Cycle	Statistics	Speed [km/h]	Slippage [%]	Fuel consumption [l/h]	Power [kw]	Depth [cm]
1	Min	6,0	0,1	7,2	24,1	10,7
1	Max	8,6	0,4	15,0	57,9	24,9
1	Average	7,7	0,2	11,0	40,8	16,5
1	CV	7,2	29,5	20,7	24,2	21,3
2	Min	7,2	0,1	7,7	21,8	10,2
2	Max	8,9	0,3	12,8	49,5	19,4
2	Average	8,3	0,2	9,7	32,3	13,9
2	CV	5,9	31,8	16,3	25,6	18,3
3	Min	7,2	0,1	7,5	30,0	10,3
3	Max	9,3	0,4	15,1	58,4	26,4
3	Average	8,3	0,3	12,0	47,1	15,9
3	CV	6,1	26,3	17,8	16,0	27,3
4	Min	7,1	0,1	7,3	20,7	11,3
4	Max	9,2	0,4	17,0	65,5	28,5
4	Average	8,2	0,3	12,5	45,1	16,9
4	CV	6,1	25,8	22,5	29,7	26,2
5	Min	6,9	0,1	7,7	23,4	10,2
5	Max	9,5	0,4	17,5	67,7	24,9
5	Average	8,5	0,3	11,6	40,7	15,4
5	CV	7,5	31,9	24,2	30,9	25,5
6	Min	7,8	0,1	7,3	20,4	10,9
6	Max	9,9	0,3	18,6	71,8	26,2
6	Average	9,1	0,2	12,3	43,3	15,7
6	CV	5,5	29,5	32,9	39,2	22,6
7	Min	5,7	0,1	7,4	28,4	10,8
7	Max	9,3	0,4	19,4	74,9	21,0
7	Average	7,9	0,2	12,4	47,8	16,9
7	CV	12,4	39,7	28,6	28,6	18,1
8	Min	5,0	0,1	7,5	24,1	10,2
8	Max	9,1	0,4	16,7	64,6	26,5
8	Average	8,0	0,3	12,5	47,6	17,7
8	CV	9,0	23,7	21,0	23,1	23,6
9	Min	7,5	0,2	7,0	23,6	11,1
9	Max	9,3	0,4	16,9	65,3	28,7
9	Average	8,5	0,3	12,1	43,5	16,5
9	CV	7,2	26,6	20,9	27,6	28,8
10	Min	6,1	0,2	7,4	24,9	10,4
10	Max	9,3	0,4	17,8	68,8	28,3
10	Média	8,0	0,3	13,3	50,7	19,3
10	CV	10,0	22,1	24,6	26,1	28,2
11	Min	7,0	0,2	6,3	24,4	10,8
11	Max	9,3	0,4	16,3	63,0	25,8
11	Average	8,5	0,3	13,0	50,3	15,7
11	CV	7,6	26,9	18,5	18,6	25,1
12	Min	6,2	0,2	7,0	23,9	10,1
12	Max	9,7	0,4	17,0	77,9	29,2
12	Average	8,1	0,3	12,7	49,2	17,7
12	CV	11,7	27,9	26,1	33,6	28,9

distribution of the average fuel consumption (l/h) in Figure 5 is from the twelve data collection cycles. It varies by an average of 10 l/h, with alteration according to the hardness of the soil and with values below five l/h, during maneuvers at the head of the set when the hydraulic system raises the plow.

These values of average fuel consumption, in l/h, in Figure 4, vary according to the values indicated by the manufacturer and oscillate around the average for greater or lesser demand for power in the traction of the implement throughout the plowing. Considering that the soil is not homogeneous in its constitution and degree of compaction, its resistance may require a greater or lesser force to pull the plow, especially when there is a significant variation in the water content of the soil. In this context, the use of GPS, marking the geographical positioning of the measurements, allows the creation of georeferenced maps of fuel consumption or even another measured variable such as Depth of cut, Figure 6, where it will make it possible to evaluate places of greater consumption, with analysis texture and soil compaction problems, aiming at reducing fuel consumption during soil preparation.

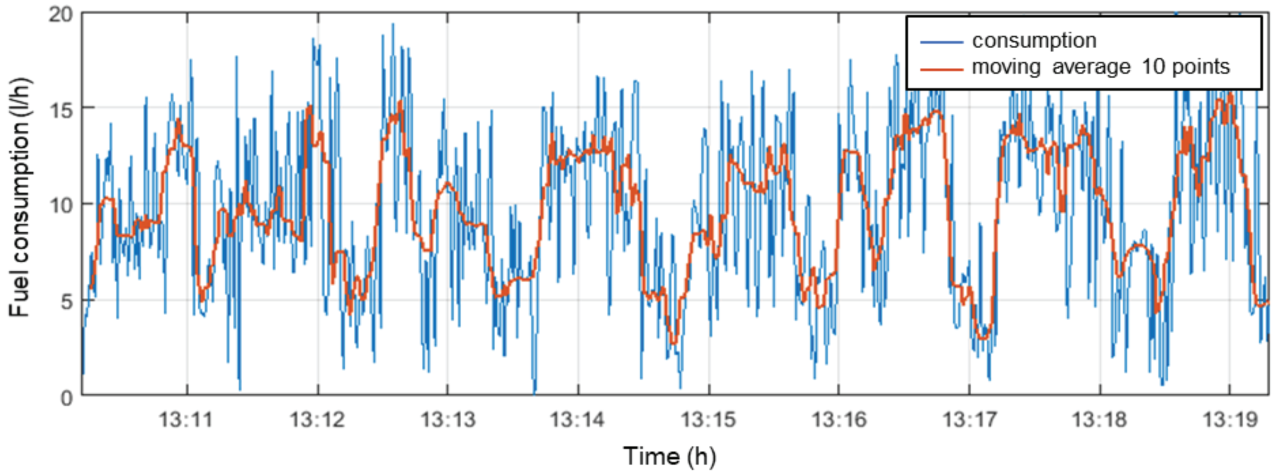

Figure 4. Tractor fuel consumption values (l/h), collected over time.

The use of a GPS along with the other ADAS/SIAD sensors allows the georeferencing of the collected measurements, for the preparation of the two maps shown in Figures 5 and 6, with the spatial distribution of fuel consumption represented by the different colors in l/h, the cutting depth in mm, and the individual variability indicated by the color differences, in the 12 collection cycles, during soil preparation. For example, in Figure 6, when evaluating the spatial distribution of plowing depth, it is possible to visualize a uniformity of soil cutting depth, during plowing, with a slight variation from 139 to 177 mm of depth, indicating that the demands of power and consumption of fuel are being altered during data collection, mainly due to the difference in soil texture, hardness, and water

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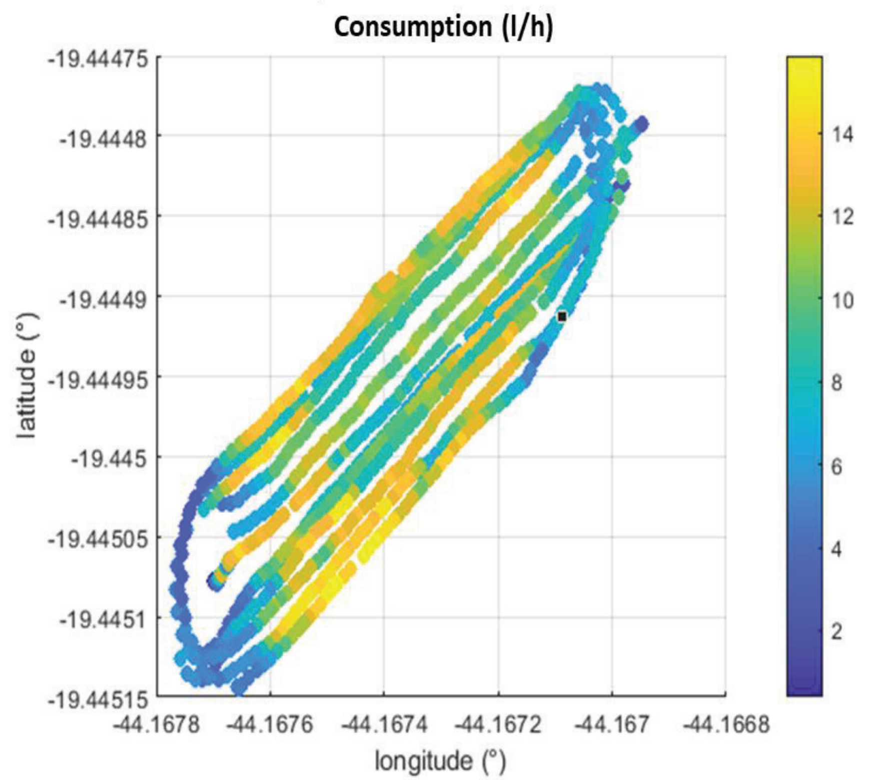

Figure 5. Spatial distribution moldboard (mm).

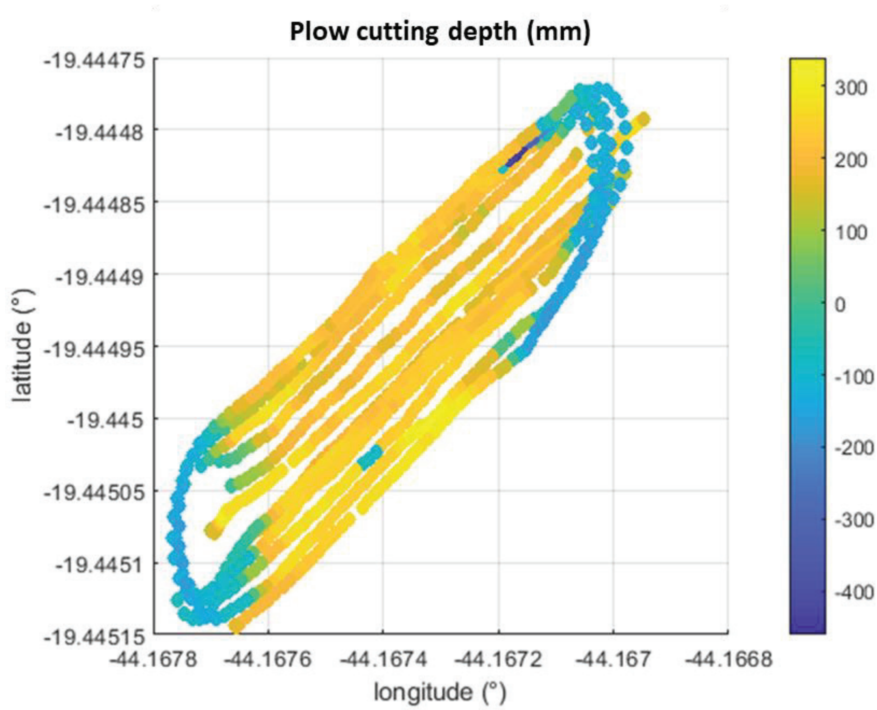

Figure 6. Spatial distribution moldboard (mm).

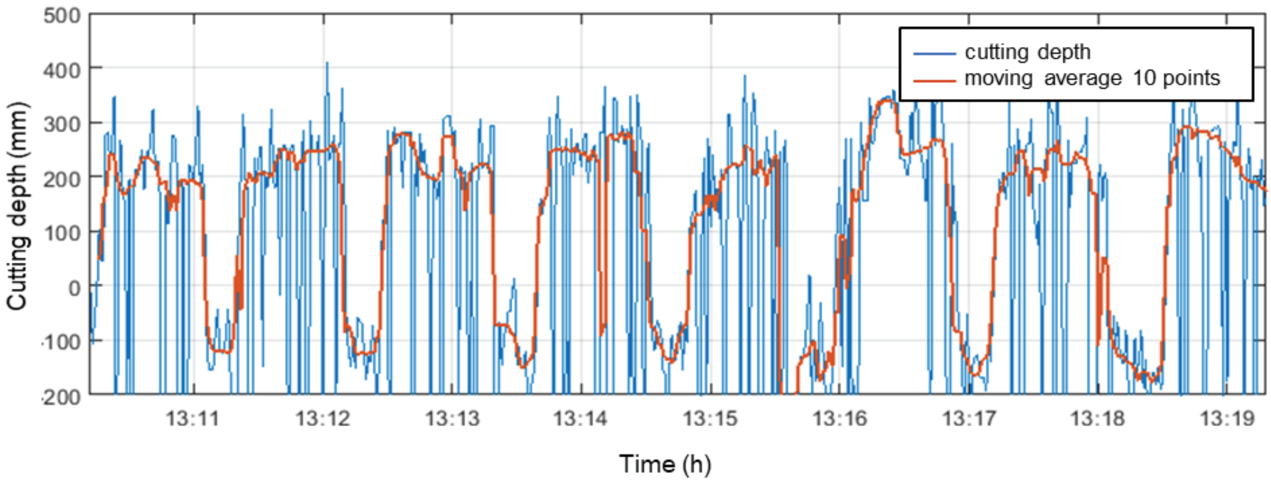

Figure 7. Moldboard plow cutting depth (mm) over time.

content. The spatialization of the production area is possible due to the increased precision of GNSS devices ("Global Navigation Satellite Systems"), which allows sensors to measure the quantities of interest in real-time during field operations (Grego et al., 2014). The georeferenced mapping allows viewing the spatial variability of the energy consumed in the field during the execution of the work and, at the same time, evaluating whether the values are following the recommended technical values. Thus, for agricultural property, whether of small or large extensions of areas, these georeferenced maps of the measured variables will allow an analysis of areas with higher energy consumption (kWh/l) to reduce the cost of agricultural mechanization in the production cost.

The working depth measured by the ultrasonic sensor promotes the triggering of the signal that, when hitting an obstacle, the emitted ultrasonic waves are echoed back to the sensor that records the information and, employing an equation, calculates the distance between the sensor and the obstacle, in millimeters.

The average values of soil cutting depth, shown in Figure 7, vary from 155.07 to 177.1 mm, with an average water content of 22.92%, collected in five locations along the path and according to the plan for the field tests. The variability of the measurements along the route in the 12 collection cycles indicates that the tractor+plow set maintained a very uniform soil preparation, with slight variation in depth, maintaining an average of 160 mm in most measurements collected (Figure 7).

Monitoring the working depth with georeferenced maps may also be helpful for sowing areas, where the farmer will have control over the depth of placement of the seed in the soil, according to the technical recommendation for each crop and type of soil. ADAS/SIAD will also be able to monitor both the sowing depth in real-time on the acquisition module display and send the information through wireless data transmission to a server or remote station in the future. This information will allow adjustments to the seeders during fieldwork to avoid plant stand losses due to the irregular distribution of seeds per line.

Currently, this monitoring can already be carried out in commercial seeders-fertilizers with sensors in the sowing lines to control the number of seeds distributed in the soil. In these two cases, of depth control and seed quantity, the recurrent problems of playability are solved, for the establishment of the recommended technical stands, mainly for the corn crop, which is different from what was planned due to the difficulty of monitoring during planting, in real-time.

The slipping of the driving wheels (%) was measured using inductive sensors installed on the tractor's drive wheels, reading the presence of metallic masses (wheel bolts) or contact points through the emission of a magnetic field produced by an oscillator and a coil, which can measure the number of turns of the wheel. In the case in question, there are eight screws that, when read, are equivalent to one turn of the wheel. The data obtained indicated that the greater the number of contact points, the greater the measurement accuracy since the distance traveled necessary for the emission of a pulse will be smaller, thus reducing the possibility that a cycle is not completed during the reading. With the tractor on firm ground and without load, the signals from the inductive sensors were recorded over a 100-meter course to evaluate the displacement using the GPS module. To calculate the average velocity, the methodology described by Santos et al. (2018) used the diameter of the wheels to which the sensors were installed and the duration of the journey. Figure 8 shows the results of the slippage of the driving wheels in the 12 test cycles:

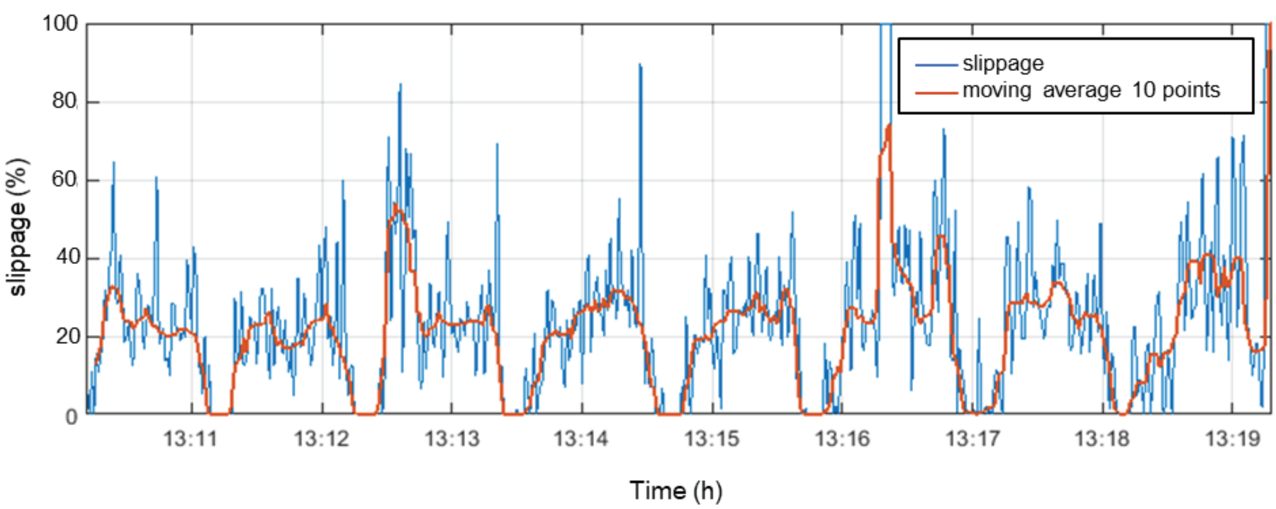

Figure 8. Tractor drive wheel slippage (%) over time.

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The average values of slippage during the twelve cycles of the course varied from 17 to 42%, with the vast majority of values between 27 and 29%, indicating a slight average variation of 2% but above the 16% recommended by (Damanauskas & Janulevičius, 2015). The oscillation of slipping points, shown in Figure 8, during plowing, reflects the heterogeneity of the soil, apparently uniform, but with places of greater hardness, perhaps compacted, and with difficulty in cutting, to maintain the depth of plowing, according to results of Figure 7.

To evaluate the average power demanded by the implement (kW) in the ADAS/SIAD, the methodology described by Mantovani et al. (1999), indirectly in TDP, through consumption and power curves of the TL-95E New Holland Tractor (2012), at different engine speeds through fuel consumption values, in liters per hour. The equations obtained from the tractor calibration curves were inserted into the program to calculate the power supplied by the engine at 1900 and 2100 rpm. Figure 9 shows the values obtained by the ADAS/SIAD over the plowing time for the 12 cycles of the route to demonstrate the oscillation during work in the field.

The values obtained during the field tests for the different variables, presented graphically and georeferenced maps, Figures 4 to 9, show the spatial variability of the results that occurred in an operation of the TL-95E New Holland tractor, pulling a plow with three moldboards of 28".

The results indicate that the variations are due to the power demand of the set plowing the soil and the heterogeneity of the soils in terms of texture, organic matter and water content in the soil. In addition, the power values obtained at the headlands of the areas reflect the significant drop in the curves in the graphs due to the need for the implement to be lifted by the tractor's hydraulics to make the return and restart the activity.

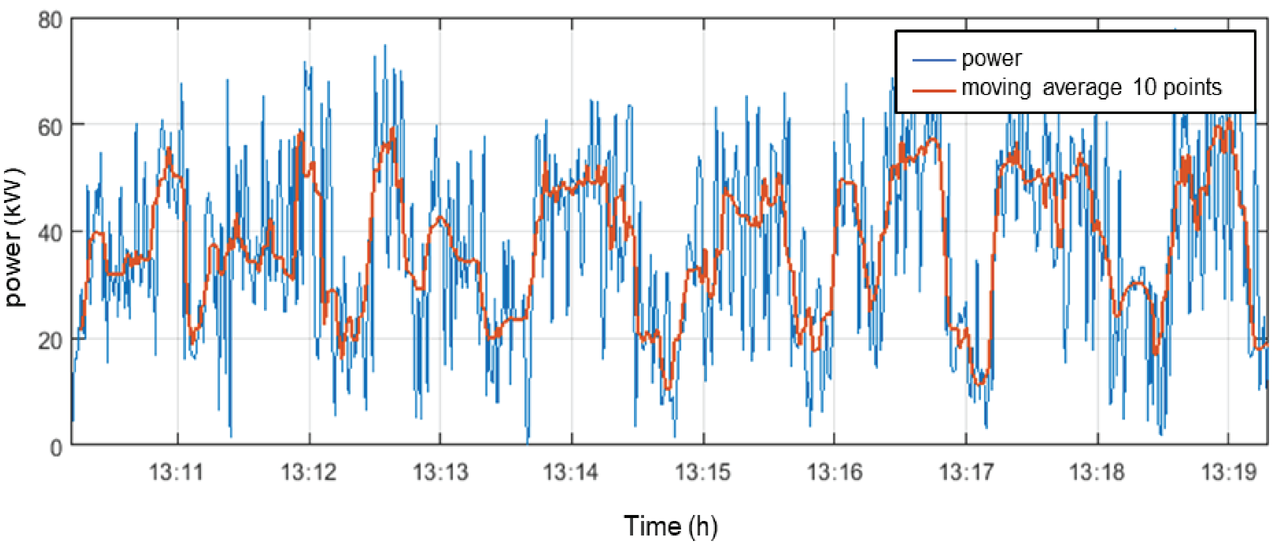

Figure 9. Power (kW) demanded by the implement, over time.

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Table 4. Spreadsheet of the average data generated by ADAS/SIAD, during the field tests, with the values calculated for the operational evaluation of the tractor+implement set.

	Tractor speed	*Wheel slippage*	*Fuel consumption*	*Demanded power*	*Depth*
Cycles	*[km/h]*	*[%]*	*[l/h]*	*[kw]*	*[mm]*
Cycle 1	7.7	27.7	10.4	40.2	165.0
Cycle 2	8.2	17.3	8.0	31.0	139.0
Cycle 3	8.3	27.5	11.5	44.6	158.6
Cycle 4	8.2	28.3	11.5	44.2	166.3
Cycle 5	8.5	29.0	10.3	39.7	150.7
Cycle 6	9.1	20.3	10.7	41.4	156.5
Cycle 7	7.9	34.9	12.1	46.9	169.5
Cycle 8	8.0	29.1	11.9	45.9	177.1
Cycle 9	8.5	27.4	10.6	41.0	164.9
Cycle 10	6.6	41.9	12.2	47.2	173.8
Cycle 11	8.6	29.7	12.7	49.1	173.8
Cycle 12	7.9	39.3	11.9	45.8	173.8
Standard Deviation	0.4	5.2	1,23	4.72	11.21
Maximum Value	9.1	41,9	12,7	49.1	177.2
Minimum Value	6.6	17,3	8,0	31.0	139.0

For a better evaluation of ADAS/SIAD's work, Table 4 summarizes the information generated during the operation of the set+implement in the field, with the values of the studied variables.

Furthermore, when the slipping range of the driving wheels is within the recommended range of 8 to 16%, the tractor is making good use of the power released by the engine to pull the implement and obtain the best Traction Efficiency, i.e., the ratio between the power used by the implement and provided by the tractor engine, Liljedahl et al. (1989) calculating the traction efficiency of 43.07%, obtained by the tractor+plow set, for a slippage of 17.3%, in Cycle 2, in Table 4, and comparing with the values of 72% in a slippage of 16% presented by Janulevičius et al. (2019), it is noticed that the waste of power is high and below what is desirable. Table 4 indicates that the TL-95E New Holland tractor worked with a very high range of slipping values, ranging from 17.3 to 41.9%, reinforcing the need for adjustments in adjustments, mainly with ballasts, avoiding loss of power through the wheels, keeping the tractor+implement moving.

The operational evaluation of the tractor+implement set, with data obtained in real-time and monitored by the operator on the acquisition module display, is essential for adjustment adjustments. This procedure

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is necessary due to the high percentage of slippage in this plowing; two situations are happening: the first, with energy wasted by the drive wheel tire on the soil, to keep the plowing at the same depth, and the tractor+plow in the current operation, compacting the soil; second is the amount of power demanded by the implement, with a large part being lost in the ground and with a low Traction Efficiency (%).

The advantage of obtaining data during operation with the ADAS/SIAD is that the most critical information, fuel consumption and slippage, can be read in real-time, both by the operator, on the display of the box on the tractor panel, and also later, by the technical area because they are recorded in the microcomputer memory, for analysis of field operations.

Conclusions

1. The Automatic Data Acquisition System-ADAS/SIAD presented in this document was improved from a previous version, with changes made to algorithms, hardware, and user interface to facilitate system operation;

2. This system allows data acquisition at regular intervals of approximately one second, with records displayed in real-time, georeferenced, and stored in memory.

3. The use of ADAS/SIAD makes it possible to evaluate the operational efficiency of the tractor+implement set in real time, which is extremely important for optimizing the costs of field operations;

4. The set of variables being evaluated simultaneously and in real-time allows the operator, or the monitoring center for mechanized activities on the property, to know whether fuel consumption (l/h), slippage (%), and cutting depth (mm) are within acceptable limits for the same work area, annually.

5. The results obtained in the operational evaluation of the tractor+implement set follow the expected technical values, indicating that the ADAS/SIAD meets the proposed requirements and can be used to evaluate mechanized operations in digitalized maps, mainly for tractors with low and medium power.

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