Iraqi Journal of Agricultural Research (IJAR)
Ministry of Agriculture
ISSN Print: 2790-5306 – ISSN Online: 2790-5314
http://ijarmoa.gov.iq – OPEN ACCESS
VOL. 30 NO. (1) 2026

DOI: https://doi.org/10.65814/ijar.30.1.202

EVALUATING OF SOME PERFORMANCE INDICATORS OF THE MACHINERY UNIT BY EMPLOYING A SMART ELECTRONIC SYSTEM POWERED BY INTERNET OF THINGS TECHNOLOGIES*

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ABSTRACT

A smart electronic system utilizing Internet of Things (IoT) technologies was developed to measure real-time performance indicators of a machinery unit (tractor and implement) and display the results directly on a phone or computer screen. An experiment was conducted to evaluate the system's performance using a Massey Ferguson 470 Xtra tractor integrated with a moldboard plow. The evaluated indicators included traction force, tractor wheel slip ratio, and tractor driver's seat vibration. These performance indicators were measured at three operating speeds: 2.86, 3.84, and 4.81 km. hr^{-1}. The fieldwork was carried out in silty clay soil within the Abu Ghraib region in 2024.

The results obtained from the developed smart system were then compared with the traditional measurement methods to determine the performance efficiency of the developed system. The results demonstrated a high efficiency of the developed method in measuring the performance indicators of the machinery unit when compared to traditional measurement methods, reaching 96.82%, 97.35%, and 95.29% for traction force, slip ratio, and vibration, respectively.

Keywords: IoT technologies, machinery unit performance, seat vibration, slip ratio, traction force.

INTRODUCTION

The agricultural tractor is recognized as a mobile power unit employed to run stationary farm machinery like pumps, saws, generators, and mobile implements such as plows, seed drills, and more. Regarding mobile farming machinery, the best use of tractor power results from enhanced traction force during forward movement. Efficient operation of agricultural tractors involves selecting the appropriate operating speed for the machinery unit, thereby maintaining the tractor wheel slip ratio within the permissible limits of 10-15% [15] and [22] This, in turn, enhances tractive and fuel efficiency of the tractor engine [20].

* A part of Ph.D. Dissertation for the first author.

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- **Received:** October 8, 2025.
- **Accepted**: December 7, 2025.
- **Available online**: June 30, 2026.

Traction force is the most influential factor in tractor performance and it is affected by several factors such as the load on the traction, type of implement used, tractor speed, and soil conditions like texture and moisture [16, 18, 26]. Many researchers have found that the value of traction force depends on a range of factors including tractor speed, soil moisture, and tillage depth [5, 17, 23].

In the field of intelligent control and management of tractor operations, reducing the tractor wheel slip has become a primary focus for farmers, researchers, engineers and designers, due to its essential and efficient influence on fuel consumption and traction efficiency [24].

The main challenge for individuals interested above is obtaining real-time wheel slip data during various field operations, and even off field [15]. On both road and field soil surfaces, vibration is one of the factors that negatively impact tractor drivers' health [14] as confirmed by Singh *et al.* [29]. Tractor vibration arises mainly from multiple factors, such as the tractor's forward speed, engine vibration, tire shape, the implement used, and field conditions such as roughness of the ground surface. Then the vibration subsequently transferred to the driver's seat and then to the driver's body. For the tractor driver, high-level vibrations or prolonged exposure to low or medium vibrations can cause numerous health issues [9, 33]. Several studies, such as Langer *et al.* [21] and Qiu & Yin [25] have indicated that prolonged exposure to high-level vibrations can lead to lower back injuries, gastrointestinal disorders, cardiovascular problems, and other ailments. It was confirmed that agricultural tractor operators are exposed to whole-body vibrations which can have very severe effects depending on the tractor's forward speed, the type of the used agricultural implement, and field conditions [30]. Consequently, tractor seats require appropriate attention since the driver utilizes them for about eight hours daily, which is the standard working period and can occasionally exceed that time [4, 14].

Several systems have been developed to measure tractor and implement performance parameters, relying on data collected from a range of sensors. The systems were designed to measure various performance indicators such as forward speed, wheel slip, traction force, and fuel consumption. The developed systems were tested in laboratory and field conditions. Data measured by the developed systems were compared with traditional measurements. It was found that the accuracy of measuring the studied indicators in the field exceeded 90% compared to traditional methods. The developed systems were characterized by being compact, portable, user-friendly, and efficient in terms of energy, time, and cost, with the capability of installing on various types of agricultural tractors [1, 28, 32]. Electronic systems mainly rely on sensors and microcontrollers to measure the tractor wheel slip ratio, making them dependable for automatically assessing driver wheel slip during different field operations. These systems can record and transmit slip data during field operation [13, 27].

Computational intelligence-based methods for measuring the performance indicators of the machinery unit (tractor and implement) serve as a vital alternative to traditional measurement techniques, as they enable us to measure, record, send, and process of diverse data types [6].

Internet of Things (IoT) technologies can be applied in smart monitoring systems that are connected to a data logger which is linked to a computer, which wirelessly sends data to a cloud platform to enable the visualization of recorded data. The smart system operates to r record, send, and display various tractors and implement performance data, including forward speed, tractor wheel slip ratio, traction force, and fuel consumption wirelessly through different sensors and electronic control units (ECUs). To obtain accurate measurements, the system’s sensors need to be calibrated and evaluated in both laboratory and field environments [8, 29, 31] conducted a study aimed to provide a smart solution for monitoring and analyzing vibration at the driver's seat using IoT technologies via Thing Speak technology to provide continuous

vibration monitoring and provide warning alerts to the tractor operator when the vibration value exceeds the permissible limits. The scarcity of studies in this area prompted us to conduct this experiment. This study aimed to:

1- Develop a smart electronic system using Internet of Things (IoT) technology to measure some machinery unit (tractor and implement) performance indicators in real-time.
2- Display the measured indicators directly to the tractor operator during field work, enabling him to control them if it exceeds permissible limits.
3- Increase the accuracy of recorded measurements by obtaining a very large number of readings for each performance indicator.
4- Reduce field hazards associated with traditional measurement methods.

MATERIALS AND METHODS

A smart electronic system for measuring tractor-implement performance indicators was assembled and tested. The smart system collected and processed the measured data. The processed data was sent to a cloud platform using IoT technologies (https://blynk.cloud). The cloud platform was utilized to display the measured data via a custom-designed display interface. The smart electronic system mainly consisted of three subsystems including electronic system for measuring 1) traction force, 2) slip ratio, and 3) operator's seat vibration.

Electronic System for Measuring Traction Force

Figure 1 illustrates the components of the electronic system for measuring traction force. A hydraulic cylinder was used to measure traction force by measuring the pressure exerted on the cylinder's hydraulic oil during various traction operations and converting the measured pressure values from pressure units in bar to force units in kilonewtons. A pressure sensor model T12C was used to measure the hydraulic oil pressure which was connected to an ESP32 microcontroller which also was programmed with custom code to convert pressure values measured by the sensor to force values. The electronic system was equipped with a 3.3V rechargeable battery to supply it with electrical power during. An on/off button was installed on the electronic system to control its operation (turning it on/off). All assembled system parts were enclosed in a custom plastic casing, created with a 3D printer to protect the system parts from damage caused by external influences.

To measure the hydraulic oil pressure within the cylinder, a pressure sensor was installed on the hydraulic cylinder's oil front port which was calibrated after the electronic circuit components were installed on the hydraulic cylinder. Pressure sensor calibration was done by suspending known weights and comparing them against the pressure sensor readings. The pressure sensor reads the hydraulic oil pressure and sends electrical signals representing the pressure values to the microcontroller that using the programmed code, converts these electrical signals to numerical data representing traction force values. Then, traction force data send from the microcontroller to the tractor operator's computer or mobile phone via Wi-Fi which in turn relays these force data to the Blynk.cloud platform (https://Blynk.cloud). Finally, the traction force data is then displayed on the designed interface of the cloud platform which is accessible on computer and/or mobile phone (figure2).

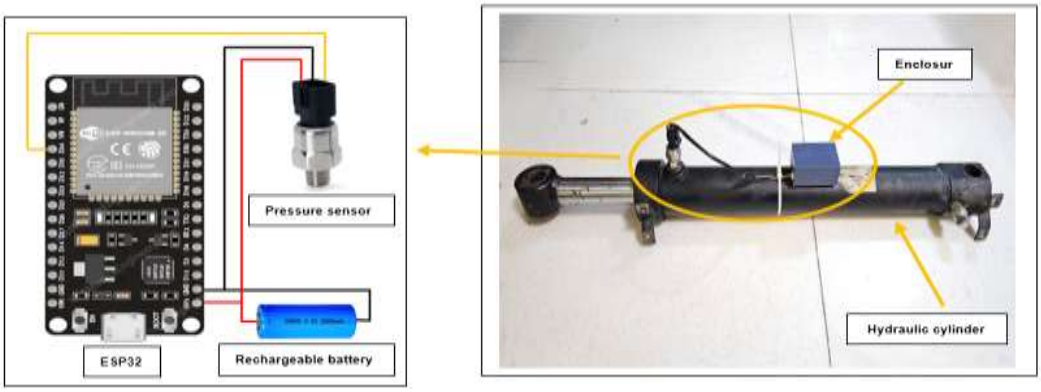


Figure 1: Smart system for measuring traction force.



Figure 2: The interface of the program used at the Internet of Things (IoT) cloud service on the website platform: https://blynk.cloud.

Electronic System for Measuring Slip Ratio and Operator's Seat Vibration:

Figure 3 illustrates the electronic system's components for measuring slip ratio and operator's seat vibration. A three-axis gyroscope and accelerometer sensor (MPU6050 GY-521) were used to measure the tractor's forward speed and operator's seat vibration. The MPU6050 GY-521 sensor was connected to an ESP32 microcontroller which was programmed with custom code to measure the tractor's forward speed (theoretical and practical speeds) and seat vibration. The electronic system had a 3.3V rechargeable battery to provide electrical power while functioning. All assembled system components were housed in a custom plastic enclosure, fabricated using a 3D printer, to protect system components from damage due to external factors. The ESP32 microcontroller receives electrical signals from the sensor and converts them into numerical data representing the tractor's forward speed and the seat vibration and then sends them to the tractor operator's computer or mobile phone via Wi-Fi technology. The computer or phone subsequently sends this information to the Blynk cloud platform (https://Blynk.cloud), which is pre-loaded with the theoretical speed value and equation for calculating slip ratio (figure 2).

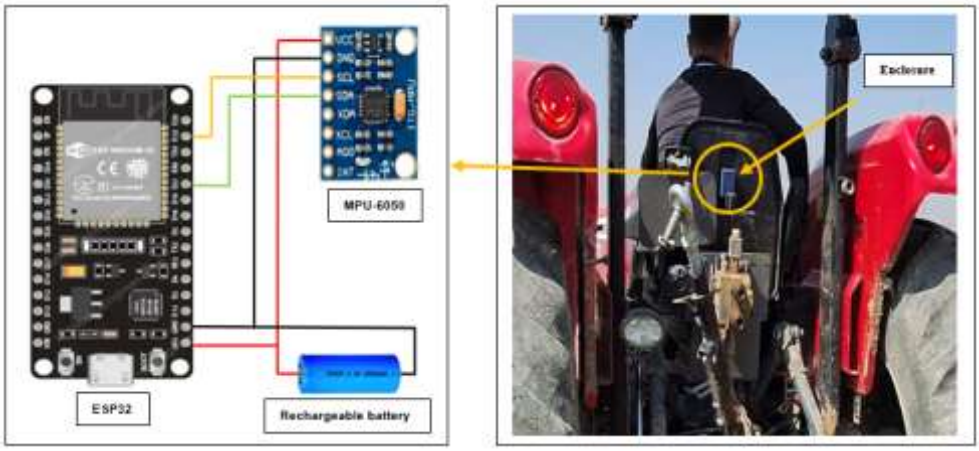


Figure 3: Smart system for measuring slip ratio and vibration.

Field Experiment Procedure:

The field experiment was conducted in Abu Ghraib region (33.326848, 44.224294) a silty clay soil using a Massey Ferguson *Xtra470* tractor and a moldboard plow. The field was divided into plots, each 100m in length. Care was taken to leave a 20m at the beginning of each working line to allow for the stabilization of tractor speed and implement depth. The operations were performed at a soil moisture content of 18-20% The experiment was conducted according to the following steps:

Measuring Traction Force: The hydraulic cylinder, equipped with the electronic system, was connected between the ahead tractor and the driven tractor MF *Xtra470* (figure 4). The ahead driver tractor towed the neutral driven tractor with the moldboard plow, which were its bottoms' blades nearly touched the ground at the selected speed. Researchers measured the motion resistance force of the tractor and implement using the ESP32 microcontroller, which was programmed to calculate traction force. This process was repeated three times to ensure measurement accuracy. The motion resistance force value was then established and displayed on the interface designed on the Blynk.cloud platform. Subsequently, the earlier procedure was repeated while the moldboard bottoms' blades penetrated the soil Traction force was calculated and displayed in real-time during operation on the display interface of the Blynk.cloud platform (figure 2).Traction force was also measured using the traditional method with a mechanical dynamometer (Dillon dynamometer). The following equation was used to calculate traction force for the traditional method [16]:

$$F\,T\,(KN) = FTT - FRM \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where:

FT= Traction force (KN),

FTT= Total traction force (KN),

FRM= Motion resistance force (KN)



Figure 4: Measuring traction force in field by the smart method.

Measuring Tractor Slip Ratio and Operator Seat Vibration: The electronic system for measuring slip ratio and vibration was positioned at the rear of the tractor driver's seat. The moldboard plow was attached to the rear of the tractor. The tractor with the attached moldboard plow operated at the chosen speed along the plot's length while moldboard plow's bottoms shares almost touch the ground surface, to calculate the theoretical speed using the program code on the ESP32 microcontroller set for speed calculation. The smart electronic system was activated at the beginning of the plot and deactivated at the end of the plot using the On/Off switch. This process was repeated three times to ensure the accuracy of the recorded readings.

The theoretical speed value was then established on the Blynk.cloud platform and displayed on the electronic display interface. Then, the machinery unit was driven again at the same speed as the moldboard plow blades penetrating the soil at the required depth. The smart electronic system was activated at the beginning of the plot and deactivated at the end of plot. The tractor wheel slip ratio and the operator seat vibration were calculated during implement operation and displayed immediately on the display interface. The tractor wheel slip ratio was also measured using the traditional method using a regular stopwatch, at the same time calculating the slip ratio by the smart electronic method. This process was repeated three times to ensure the accuracy of the calculated readings. The following equations were used to calculate the slip ratio for the traditional method [3]:

$$S\ (\%)\ = \frac{Vt-Vp}{Vt} * 100 \quad \text{-----} \quad \text{…….(2)}$$

Where:

Vt= Theoretical velocity (km.hr^{-1}),

V*p*= Practical velocity (km.hr^{-1})

Also, the operator seat vibration was measured using the traditional method using the vibration meter, type VM-6360. The experiment was conducted using a split-split plot design within a randomized complete block design (RCBD). After the experiment was completed, the obtained data were tabulated and analyzed according to the chosen design, and the differences between the means were compared using the least significant difference test under probability level of 5%.

RESULTS AND DISCUSSIONS

Traction force (kN): Figure 5 shows the effect of smart and traditional measurement methods and operating speed on traction force. The statistical analysis showed no significant difference under the probability level of 5% when measuring traction force using smart and traditional methods. While the results showed that increasing the plowing speed from 2.86 to 3.84 and then to 4.81 km.hr^{-1} led to a significant increase in traction force from 18.74 to 19.74 and then to 21.54 kN when measured using the smart method and from 18.22 to 20.31 and then to 22.44 kN when measured using the traditional method. The reason for the increase in traction

force is due to increased soil resistance to blade penetration and an increased rate of soil particle collision with the plow blade per unit time, thus increasing the load on the plow, as indicated by [7, 12]. The results also showed that the efficiency of measuring traction force using the smart method compared to the traditional method reached 96.82%, [32].

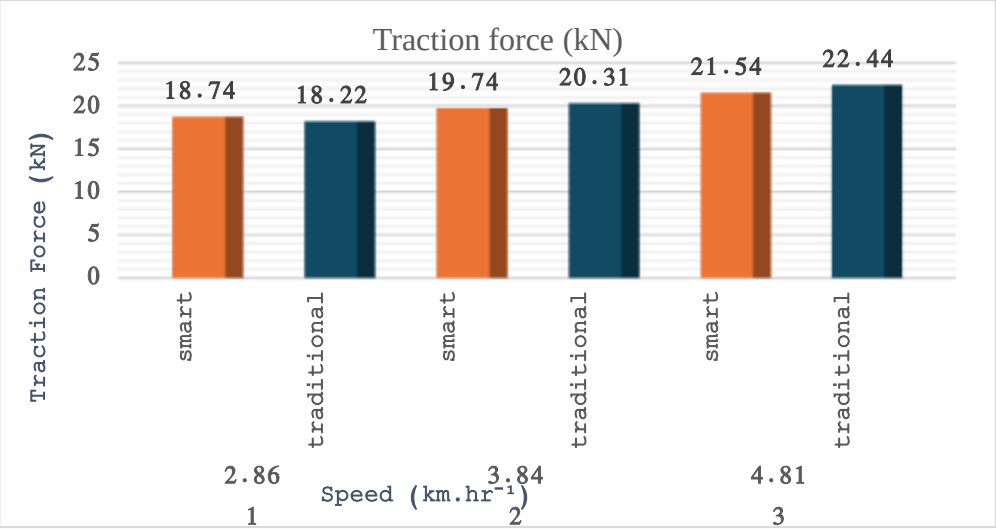


Figure 5: Effect of measuring method and operating speed on traction force for moldboard plow.

Slip ratio (%): Figure 6 shows the effect of both smart and traditional measurement methods and operating speed on the slip ratio. The statistical analysis showed no significant difference under probability level of 5% when measuring the slip ratio using the smart and traditional methods. However, the results showed a significant difference in the slip ratio when increasing the working speed. Increasing the plowing speed from 2.86 to 3.84 and then to 4.81 km/hr^{-1} led to an increase in the slip ratio from 7.37 to 11.34 and then to 14.31% when measured using the smart method and from 7.20 to 11.09 and then to 14.82% when measured using the traditional method. The reason is due to the decrease in the practical speed compared to the theoretical speed due to the increased force required to penetrate the soil, which consequently increases the traction force and this, in turn, increases the difference between practical speed and theoretical speed, leading to an increased slip ratio. This is consistent with both Azzawi *et al.* [2] and de Melo *et al.* [11]. The results showed that the efficiency of measuring the slip ratio using the smart method compared to the traditional method reached 97.35% [10].

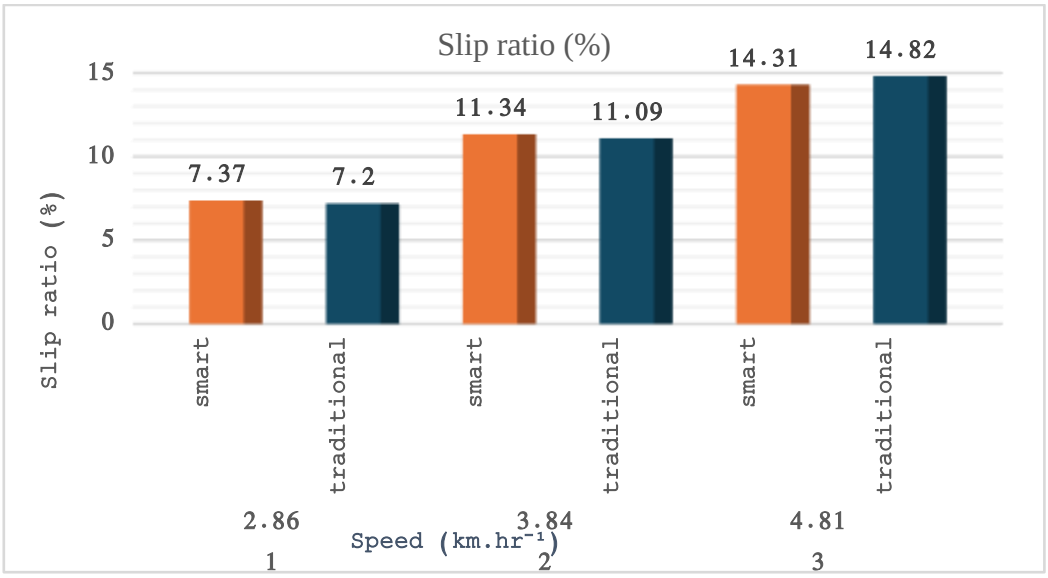


Figure 6: Effect of measuring method and practical speed on slip ratio for moldboard plow.

Driver's seat vibration (m.s^{-2}): Figure 7 shows the effect of both the smart and traditional measurement method and tractor speed on driver's seat vibration. The statistical analysis showed no significant difference under probability level of 5% when measuring vibration using the smart and traditional methods.

However, the results showed a significant difference in vibration when increasing the working speed, as increasing the plowing speed from 2.86 to 3.84 and then to 4.81km.hr^{-1} led to an increase in vibration from 2.13 to 3.54 and then to 4.98 m.s^{-2} when measured using the smart method and from 2.23 to 3.37 and then to 4.73 m.s^{-2} when measured using the traditional method. The rise in vibration at high working speed is attributed to the higher collision rate of the wheels and plowing tool with soil irregularities resulting in a higher vibration frequency of the tractor mass and, therefore, an increase in tractor seat vibration, which is consistent with Cvetanovic *et al.* [9] and Alin *et al.* [4].

The results showed that the efficiency of measuring vibration using the smart method compared to the traditional method reached 95.29%, [19]

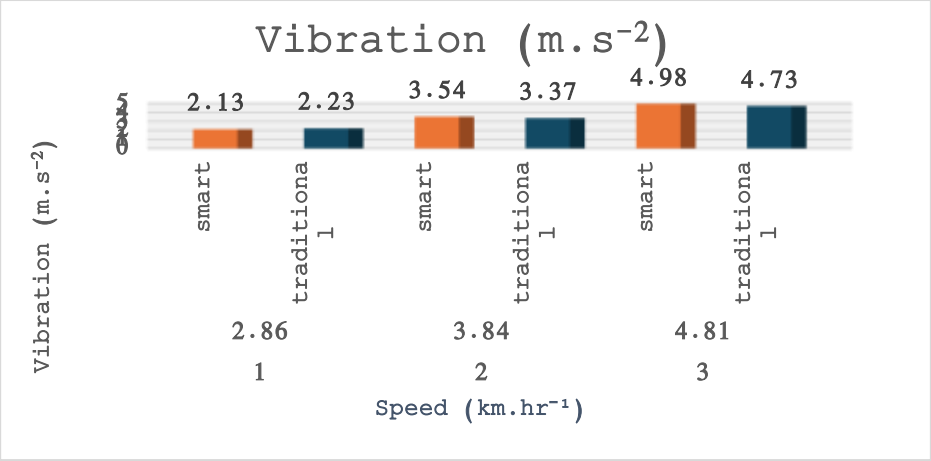


Figure 7: Effect of measuring method and practical speed on driver seat vibration.

Conclusion

The results obtained from the experiment indicated that the use of the smart electronic system in measuring the machinery unit (tractor and implement) performance indicators was highly effective. It can also be relied upon to obtain real-time performance indicator measurements during operation, which helps the tractor operator to make immediate decisions in the field. Within the experiment condition, the 4.8 km. hr^{-1} was the optimum operating speed for plowing with the moldboard plow where the traction force, slip ratio, and vibration were within permissible limits. I recommend conducting experiments on other types of implements and tractors, and in different soil types and conditions.

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وزارة الزراعة
ISSN Print: 2790-5306 – ISSN Online: 2790-5314
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2026 (1) العدد 30 مجلد

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تقييم بعض مؤشرات أداء الوحدة المكنية باستخدام نظام إلكتروني ذكي يعمل بتقنيات إنترنت الأشياء *

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الملخص

تم تطوير نظام إلكتروني ذكي باستخدام تقنيات إنترنت الأشياء (IoT) لقياس مؤشرات الأداء في الوقت الفعلي للجرار والآلة وعرض النتائج مباشرة عبر الهاتف أو شاشة الحاسوب. أجريت تجربة لتقييم أداء النظام المطَور باستخدام جرار *Massey Ferguson 470 Xtra* ومحراث مطرحي قلاب. المؤشرات التي تم دراستها في تقييم النظام المطَور هي قوة الجر ونسبة انزلاق عجلة الجرار واهتزاز مقعد سائق الجرار. تم قياس مؤشرات الأداء عند ثلاث سرع تشغيل بلغت 2.86 و3.84 و4.81 كم.ساعة$^{-1}$.

أجريت التجربة في تربة طينية غرينية في منطقة أبو غريب في عام 2024. ثم قورنت النتائج التي تم الحصول عليها من النظام الذكي المطَور بطرق القياس التقليدية لتحديد كفاءة النظام المطَور.

وأظهرت النتائج كفاءة عالية للنظام المطور في قياس مؤشرات أداء الوحدة المكينة مقارنة بطرق القياس التقليدية حيث بلغت كفاءة النظام 96.82، 97.35، و95.29% عند قياس قوة الجر، ونسبة الانزلاق، والاهتزاز على التوالي.

الكلمات الدالة: انترنت الأشياء، أداء الوحدة المكنية، اهتزاز مقعد الجرار، نسبة الانزلاق، قوة الجر.

* جزء من أطروحة دكتوراه للباحث الاول

[1] جامعة بغداد، كلية علوم الهندسة الزراعية، بغداد، العراق.

- **تاريخ تسلم البحث:** 8/تشرين اول/2025
- **تاريخ قبول البحث:** 7/ كانون اول/2025
- **متاح على الانترنت:** 30/حزيران/2026.