MISR JOURNAL OF AGRICULTURAL ENGINEERING ISSN-Print: 1687-384X
https://mjae.journals.ekb.eg/ ISSN-Online: 2636-3062

Misr J. Ag. Eng., 41 (---): ….. - ….. **DOI:** 10.21608/mjae.2024.283120.1136

INTELLIGENT CONTROL SYSTEM FOR MONITORING THE MAINTENANCE OF THE CENTER PIVOT IRRIGATION SYSTEM

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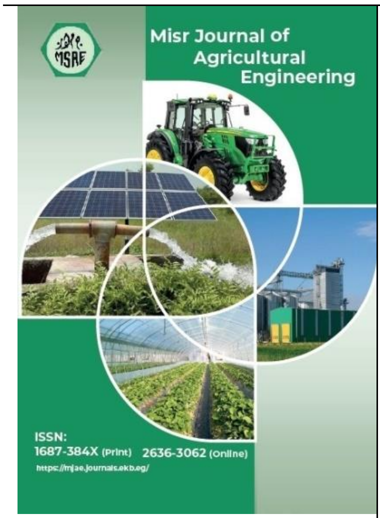


Keywords:

Central pivot irrigation system; Monitoring systems; Early error detection; Maintenance.

ABSTRACT

The national Egypt strategy for sustainable agricultural development (SADS-2030),focuses on increasing agricultural area by approximately 1.5 million feddan to address the food gap. The central pivot irrigation system is one of the most effective ways to achieve this goal. Maintaining a center pivot device is hard. Moreover, repairing the damage that happens after the malfunction of the device will be time-consuming and costly. So, the main goal of this study was to monitor, detect early error and warn the operator before starting any irrigation process, which prevents a malfunction or crash of the center pivot. The developed monitoring systems use NTC thermistors and an oil level sensor to monitor oil temperature and leaks in the gear box and motor. Tire pressure monitoring sensor (TPMS) was used to monitor towers' tires pressure. These sensors were installed in a unit known as "Tower/central node board" which consists of two ESP32 microcontrollers installed inside the main control panel. The main control panel of the device collects all the vital readings from all towers and communicates them with the cloud server using the internet, which allows the remote control of the device. Field tests were performed by using a "Valley" center Pivot System at the Egyptian Ismailia governorate's conditions, for detecting the sensitivity and accuracy of the system. Data was collected from two towers of the center pivot system and analyzed in a simple digital model that was used to process and decide on possible maintenance instructions.

INTRODUCTION

Center pivot irrigation systems have helped revolutionize agricultural irrigation and increase crop yields since 1940, when inventor Frank Zybach created his first design. It is considered an efficient way to evenly irrigate large scales, and since their inception, it has improved dramatically in reliability and preventing water loss. The center pivot irrigation system is the most popular sprinkler system in the world (**Waller and Yitayew, 2016; Dong et al., 2023**). Center pivot irrigation systems have been used in corn, soybean, potato, alfalfa, wheat, cotton, vegetables, and sugar beet fields (**Grassini et al., 2011; Hines, and Neilbling, 2013; Grassini et al., 2015 and Alptekin, Y., 2011**). It serves agricultural land in a circular pattern or semicircular if it uses an end gun sprinkler. The center pivot consists of groups of sprinklers with specific discharge suspended in a series of tubes carried on the towers that move on wheels driven by electric motors through the transmission of movement from the gearbox. Although the most common length of a basic machine is about 400 m, which serv es an area of more than 120 fed. This irrigation system is one of the best irrigation systems used in the newly reclaimed desert; it can serve areas of over 150 fed and is suitable for most field crops such as wheat, corn, and beans, saving water up to 40% (**Devan et al., 2021**). Recently, with better access to high-speed Internet, the proliferation of cellular networks, and IoT-powered precision agriculture, the next frontier for center pivot irrigation systems is remote monitoring and control.

Drive Units of Center Pivot Irrigation System:

The electric power drive of center-pivot irrigation systems has two gear reductions. One gear reduction exists in the drive shafts that connect the electric motor to a gear box at each of the two tower wheels **(Nguyen et al., 2022).** The second gear reduction is the gear box driving each wheel. So, center pivot travel speed is determined by the speed of the electric motor, the speed reduction ratios in both the center drive shafts and gear boxes, and wheel size **(Gillespie, 2021).** Consequently, the drive unit is composed of an electric motor, a center gearbox, wheel gearboxes, drive wheels, and a tower box, which gets and sends the orders of movement from the alignment system or control panel **(Brar et al., 2017)**.

Gear Motor:

The three-phase center pivot motor had a power range of 0.5 to 1.5 HP and operated at 480 V (60 Hz) or 380 V (50 Hz), with a gearbox reduction ratio of 20:1 to 60:1 **(Fipps and New, 2005).** These induction motors provide the required power efficiently and proper component selection and maintenance helps ensure reliable performance despite harsh field conditions.

Gearbox:

Gear box stiffening is crucial in steep terrain and heavy soils with traction issues. Special oil is needed to make gear movement smoother and lubricate them. The optimum temperature range for gearbox oil in industrial applications, including center pivot irrigation systems, is between 40°C (104°F) and 60°C (140°F). This temperature maintains viscosity, essential for proper lubrication. Low temperatures can cause inadequate lubrication and increased friction, while high temperatures can cause oil thinning, reduced lubricating properties, and accelerated wear. Maintenance depends on manual oil level measurement and regular changes. If oil leakage occurs, gears may grind against each other, causing damage, noise, and inefficiency. The gearbox may fail completely, requiring costly repairs or replacements. Regular monitoring of oil level and quality is essential, especially in harsh conditions (**Dong et al., 2020**).

One possible solution is to use sensors and wireless communication to detect and report any changes in the gearbox oil status in real time (**Dong et al., 2020**). Therefore, it is crucial to have a monitoring system that discovers the change in gearbox oil and alerts the workers before it is too late.

Tires:

The center pivot travel speed is influenced by water application, determined by wheel size and power drive mechanism. Mismatched tires sizes will cause to thermal overload, alignment fault and early drive train failure (**Nguyen et al., 2022**). Certainly, maintaining optimal tire pressure is crucial of the irrigation system operation, as it prevents thermal overload and early drive train failure.

Center Pivot irrigation system Maintenance:

Maintaining a center pivot device on farm is hard, especially with multiple devices, as it becomes time-consuming and costly. Detecting errors before they happen is hard due to checking every part (gearbox, gearmotor, tires, and more) of each device, leaving only after - effects. Moreover, fixing damage after malfunction or crashes can be costly, potentially leading to overspend or unplanned costs **(Ouazaa et al., 2015; Buono et al., 2020)**.

Agricultural output losses result from operating failures during crucial stages of crop growth, lack of qualified maintenance crew, and expensive maintenance procedures (**Debauche Olivier et al., 2020; Aaron et al., 2021**). Therefore, proper maintenance requires expert detection by expert system, speedy failure location discovery, decision making to stop machine movement, and manual problem-solving methods to prevent system and crop.

Important of Internet of Things (IoT):

Internet of things technologies available today made it an opportunity to innovate the regular center pivot irrigation systems into the evolution of smart pivot irrigation systems that would help farms and operators to manage their devices more efficiently and assist them with diagnosing errors and remotely controlling the devices anywhere and anytime. (**Matilla et al., 2022**).

IoT Application on Center Pivot Irrigation System:

Several studies have explored the use of IoT for monitoring malfunctions in center pivot irrigation systems. This technology uses smart sensors and cloud computing services to collect and transmit data, notifying farmers when a problem arises (**Zyrianoff el at., 2018**). IoT is used to reduce the manual labor involved in collecting the crucial agriculture data (**Brar et al., 2017**), as it can send collected data directly to a central server in real time. The data integrity is ensured, and advanced analytical software tools to draw most accurate predictions (**Kumar et al., 2023**).

Paparao et al., 2017 proposed an automation system based on IoT, Geographic Information System (GIS), and quasi real-time in the cloud of water requirements to improve the efficiency of water use. The system controls each pivot-center segment individually to optimize irrigation yield. Therefore, integrating factors such as stage of crops' development, soil heterogeneity, runoff, drainage, soil components, nutrients, and moisture content will integrate to improve system efficiency. A complete system integrating sensors, GIS, IoT, and cloud computing was developed, allowing fine-grained automation of water consumption without decreasing yield.

From all of the previous, the intelligent maintenance system with smart sensors will assist to keep an eye on the machine. Key operations include monitoring in the gearboxes. Oil levels and temperature and tires pressure along the pivot machine. It ensures that the machine operator’s goal is achieved without any problems.

The research work aims to develop an intelligent maintenance system (IMS) that uses functional monitoring to identify and address practical issues, such as failures, by stopping the machine until maintenance is completed. The regular transportation of the combined data to the maintenance control panel, which is programmed for data analysis and decision-making (alarm or shutdown) did this according to failure reports. The IMS uses a microcontroller connected to the server to monitor sensors and remotely control the system, detecting failures quickly. This system achieves immediate maintenance for the machine, reduces human errors, saves time during operation, offers cost-effective maintenance and repairs. It, also, provides pivot operation regulatory monitoring reports and extends the machine 's life, ensuring the stability of the crop productivity.

From the abovementioned, the aims of this study were to:

- Design, build, verify, and validate a smart real-time system for monitoring the factors that affect the operation of the mechanical parts of a center pivot irrigation system.
- Investigate the developed real-time smart system under field conditions.
- Build, verify, and validate an IoT program for monitoring the efficiency of the mechanical parts of a center pivot irrigation system.

MATERIALS AND METHODS

The center pivot irrigation system 's monitoring system design prioritized several critical aspects. Firstly, ESP32 Node-MCU, a low-cost open-source development board with programmable Wi-Fi module, was chosen for IoT applications. secondly, sensors selection and placement were pivotal, aiming to detect malfunctions preemptively. Durable sensors capable of operating in the challenging environment of high temperatures and moist dust were sought for easy maintenance or replacement. Finally, Compatibility was for easy as the system needed to be easily installed on various center Pivot devices without requiring farm replacements. The system was designed to be easily plugged into most center pivot devices and control panels.

System components

- Temperature sensor

The purpose of utilizing a temperature sensor is to monitor and collect data from either the gear motor or the gear box of each center pivot irrigation system tower.

The NTC thermistor sensor was used to measure the oil temperature because these sensors are accurate (± 0.2 °C), cheap, robust, and work at high temperatures (primarily used in 3D printer heaters that reach 230 degrees Celsius). this type of thermistor’s resistance decreases by increasing the temperature around it (Figure (1)).

- Oil level sensor.

Figure (2) shows an oil level sensor in which the prism functions as a mirror, reflecting light onto the phototransistor and sending a high signal. when the sensor isn’t submerged in any oil, the transistor on the receiver side turns on, producing an output that approximately equals the sensor power voltage, which reads "1". When the sensor is submerged in oil, the transistor is switched off, resulting in an output of "0". Furthermore, the technical specification of the employed oil level sensor may be summarized as follows:

- Rating Voltage: 5 ~ 24V.
- Liquid detection Sensitivity: ± 1mm.
- Signal: Digital signal.
- Product lifetime: 50,000 Hrs

- Tire Pressure Sensor

The tire pressure monitoring sensor (TPMS) is mainly used for real-time monitoring of vehicle tire pressure. When the pressure is exceeds or below the standard value range, the system will generate an alarm signal, as shown in Figure (3). These sensors are installed inserted within the tire, and continuously monitor the pressure and broadcast the results via Bluetooth.

- Tower Node Board

Installing the tower node board for each tower is mandatory to be able to collect the vital readings for the gearmotor, gearboxes, and tire pressure for each tower. Each node board consists of two ESP32 microcontrollers Fig. (4). one of these microcontrollers is responsible for collecting data from the wired sensors and transmitting it between towers via the ESP NOW protocol, while the other manages the Bluetooth connection with the tire pressure sensors. The main components tower node board are shown in Figure (5).

Figure (1): Temperature sensor

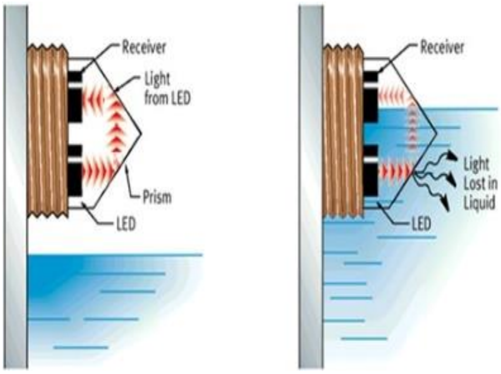


Figure (2): Oil level sensor

Figure (3): Tire Pressure Sensor

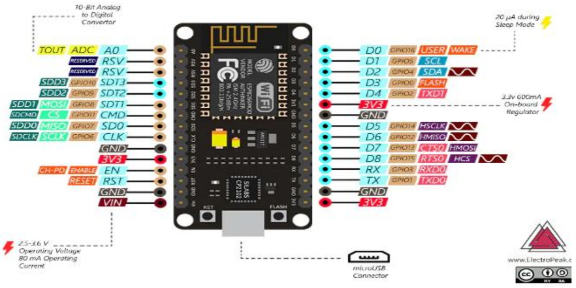


Figure (4): ESP32

- **Central Node Boards**

The components of a central node board are identical to those of a tower node board, but they serve different purposes and are positioned differently. A central node board is mounted next to the center Pivot's control panel (Figure 5), and it gathers and transfers all of the crucial data from all tower node boards to the cloud server via the internet. It can also be used to control the gadget remotely.

Figure (5): Components and position of Tower and central Node Board

The flowchart in Figure (6) shows the data flow and control, as well as data transfer between node boards and sensors. Figure (7) depicts a flowchart of data transit within the central node board.

- **Software**

The communication system is based on data distribution via tower node boards, with the last board sending data to the one after it until it reaches the center node board. the data delivery's methodology could be shown in Figure (8). a problem occurs if one of the boards is disconnected for whatever reason, the data transmission chain to the central board will be cut. So, when such an issue happens, the system alerts the user, and once the board is connected again, the system immediately resumes its activities.

ESP-NOW is a protocol developed by “Espressif” that allows multiple devices to communicate with one another with using Wi-Fi. The protocol is similar to the low-power 2.4GHz wireless communication that is often deployed in a wireless mouse. As a result, before the devices can communicate, they must first pair. C++ is suitable for programming ESP boards due to its speed and efficiency. Additionally, the Arduino IDE is used to develop and upload code to the boards. Figure 9 depicts the computer program interface.

In addition to the program's main function of gathering data from the aforementioned sensors, it also sends warnings in the event of operational errors such as decline in gearbox and gear motor efficiency (due to decline of oil levels in them) and decline of tire pressure.

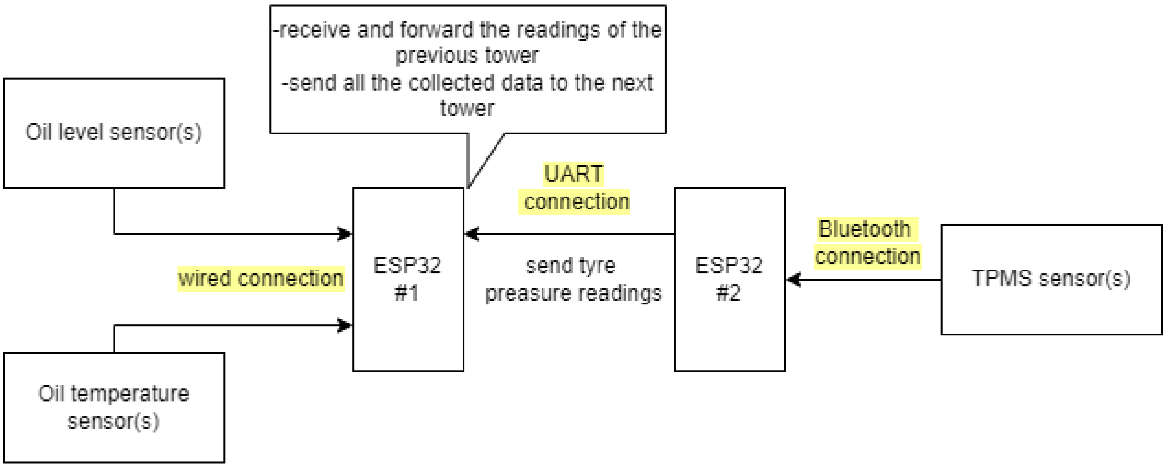


Figure (6): Flowchart of data collection and recorded of each tower node boards

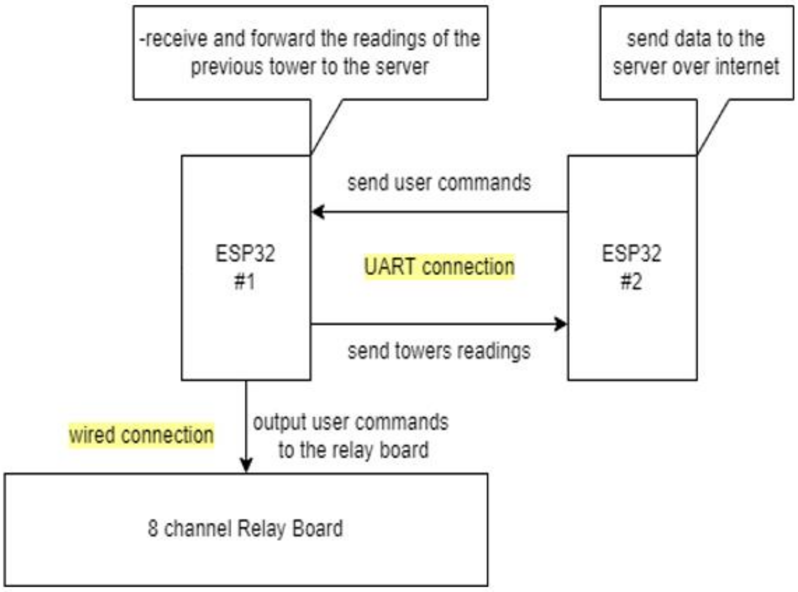


Figure (7): Flowchart of data transfer within the central node board

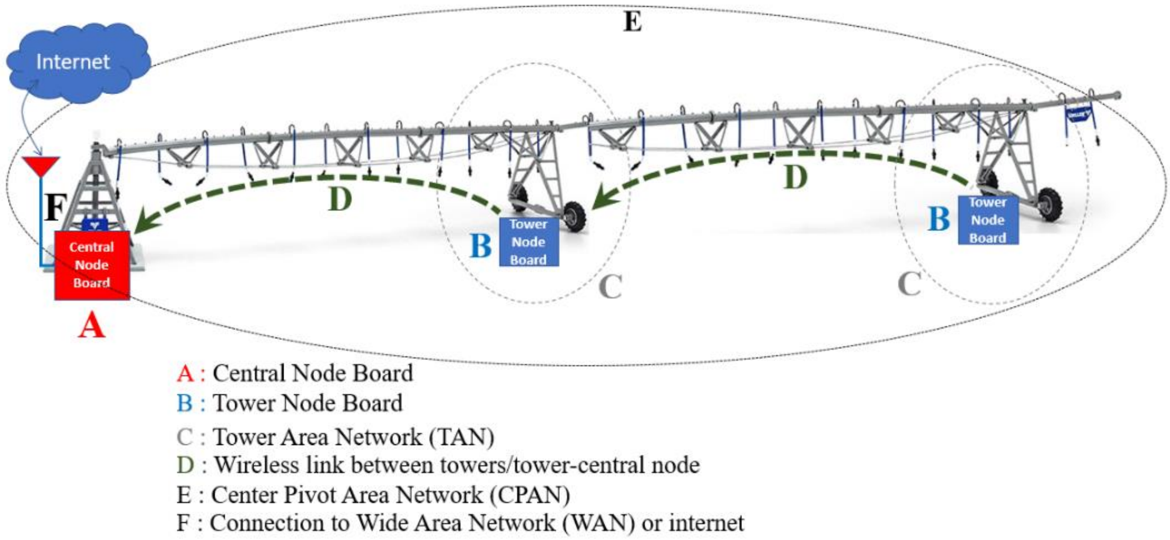
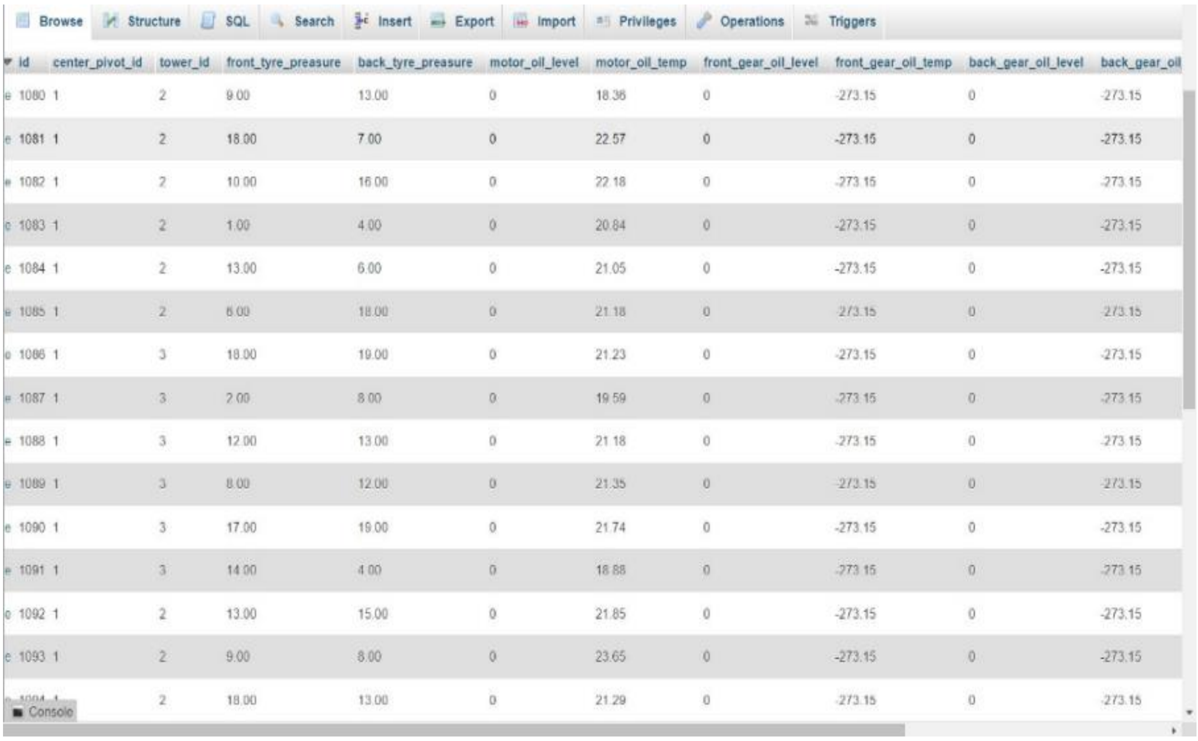


Figure 8: The data delivery's methodology.



id	center_pivot_id	tower_id	front_tyre_preasure	back_tyre_preasure	motor_oil_level	motor_oil_temp	front_gear_oil_level	front_gear_oil_temp	back_gear_oil_level	back_gear_oil
1080	1	2	9.00	13.00	0	18.36	0	-273.15	0	-273.15
1081	1	2	18.00	7.00	0	22.57	0	-273.15	0	-273.15
1082	1	2	10.00	16.00	0	22.18	0	-273.15	0	-273.15
1083	1	2	1.00	4.00	0	20.84	0	-273.15	0	-273.15
1084	1	2	13.00	6.00	0	21.05	0	-273.15	0	-273.15
1085	1	2	6.00	18.00	0	21.18	0	-273.15	0	-273.15
1086	1	3	18.00	19.00	0	21.23	0	-273.15	0	-273.15
1087	1	3	2.00	8.00	0	19.59	0	-273.15	0	-273.15
1088	1	3	12.00	13.00	0	21.18	0	-273.15	0	-273.15
1089	1	3	8.00	12.00	0	21.35	0	-273.15	0	-273.15
1090	1	3	17.00	19.00	0	21.74	0	-273.15	0	-273.15
1091	1	3	14.00	4.00	0	18.88	0	-273.15	0	-273.15
1092	1	2	13.00	15.00	0	21.85	0	-273.15	0	-273.15
1093	1	2	9.00	8.00	0	23.65	0	-273.15	0	-273.15
1094	1	2	18.00	13.00	0	21.29	0	-273.15	0	-273.15

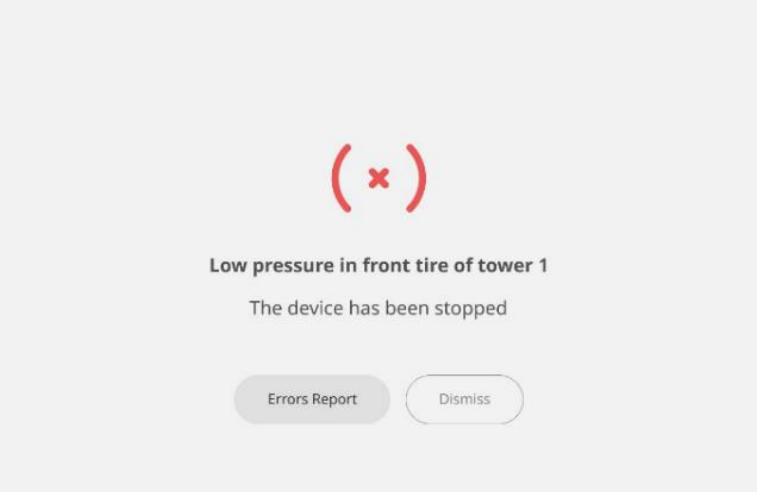
Figure 9: The computer program interface.

Thus, the alerts are conveyed to the decision-maker via Wi-Fi, allowing for different feedback and remote-control actions to be made in the device (if the device requires stopping for maintenance or continuing the device's operation if the condition is not serious).

For example: If the Tire pressure is optimal, the device will work normally; otherwise, if it is below optimal, the system will display a warning on the screen, giving the operator two options: stop the device remotely or keep it working as it is Figure (10). In the final case, if the tire has a critical pressure reading, the device will display an error and will automatically stop running Figure (11) to help prevent major issues with the center pivot.


Medium pressure in Tower 1 front tire

Figure (10): System warning of decline of tire pressure



Low pressure in front tire of tower 1

The device has been stopped

Figure (11): System stopped because of critical tire pressure.

The developed monitoring system evaluation

Therefore, in order to achieve the main goal of monitoring the factors that affect the performance analysis of the center pivot irrigation systems to have the opportunity to detect the problem in a real-time by using IoT technology based on sensors technique, field experiments were conducted on a private farm equipped with a central pivot irrigation system that was located in Ismailia Governorate and the experiments were conducted during July 2023.

However, the technical specification of the investigated center pivot irrigation system may be summarized as following: Center Pivot System Type: Valley; Number of Span: 5 Span (the field experiments had been carried out on two towers of the center pivot); Length of Span: 48 meters; Pivot Length: 240 meters; Pivot Description: Used; and Pipes Type: Galvanized. However, the location of the investigated center pivot could be described as Latitude: 30°26'51.94"N; and Longitude: 31°50'16.71"E, as shown in Figure (12).

Figure (12): Field experiments of center pivot irrigation system location.

Installation the developed monitoring system in the field experimental site

Installation of all equipment and sensors on the center pivot was done after the oils in the gearboxes and motors were changed, making sure that the oil level was correct. The tire pressure was also set to the correct level, and a local network was setup to be able to collect the data instantly on the laptop device. The central node board was connected wirelessly to a network router to be able to send the data to the server and store the reading in the database. The sensors were installed as follows:

- one Tire pressure sensor was used in each tower (one at the front tire) as shown in Figure (13) and (14).
- Two temperature sensors were used in each tower (one at the gearbox and one at the gearmotor) as shown in Figure (13) and (15 a, b).
- Two Oil level sensors were used in each tower (one at the gearbox and one at the gearmotor) as shown in Figure (13) and (16 a, b).
- Two Node Board were used in each tower (one at the center and one at each tower) as shown in Figure (13) and (17 a, b).

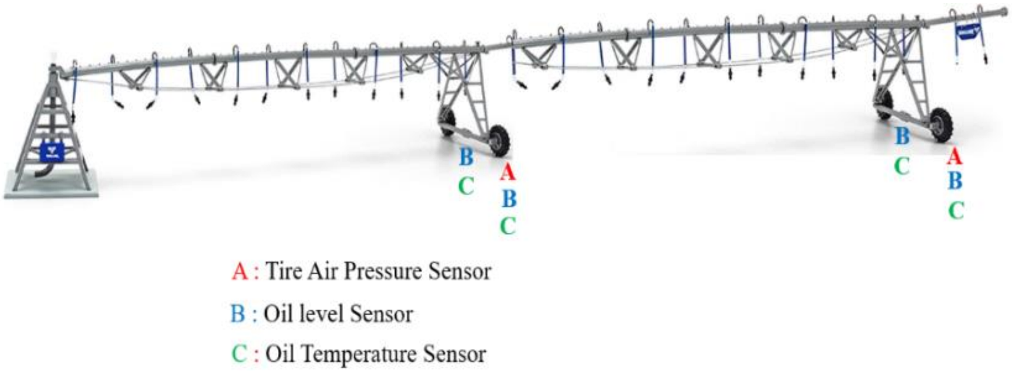


Figure (13): Allocation of sensors on a center pivot irrigation system.

Figure (14): The tire pressure sensor installation.

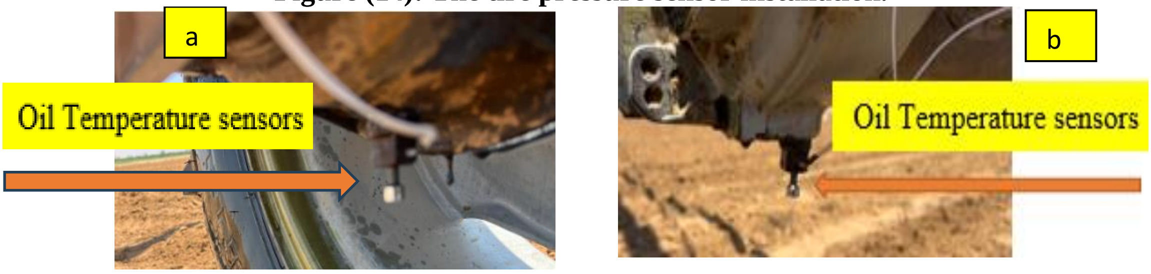


Figure (15): a- The temperature sensor of gear box installation, b-The temperature sensor of gear motor installation.

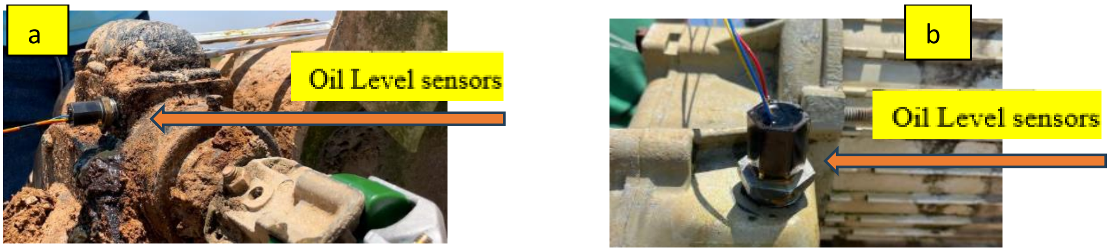


Figure (16): a- The oil level sensor of gear box installation, b-The oil level sensor of gear motor installation.

Figure (17): a-The tower node boards installation, b-The Central node board installation

Data acquisition; and statistical analysis

Data from the field was gathered, refined, and analysed to achieve the objectives of this study. However, data of each affected parameter at each tower and central were mathematically evaluated and presented in the appropriate way of presentation. Furthermore, the data were statistically analysed by using Excel and SPSS 26 software and using the appropriate statistical methods, that could be described as followings:

- **Arithmetic mean**

  $\bar{x}$: it is an indicator to determine the relative importance of each question element and the relative weights that have been assigned to the sample vocabulary responses to the survey questions using the following mathematical equation:

$$\bar{X} = \frac{\sum_{i=1}^{n} x}{n}$$

where:

- $\bar{x}$: The arithmetic means of the relative weights.
- $\sum_{i=1}^{n} x$: The sum of the relative weights determined by the responses.
- n: the sample size.

- **Standard deviation(σ)**

It is one of the measures of dispersion. It is used as an indicator to determine the deviations of the values from their arithmetic mean, and it is calculated as follows:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x - \bar{x})^2}{n}}$$

- **Coefficient of variation**

It measures the percentage of respondents differing from them about the mean, and it calculated by dividing the standard deviation by the arithmetic mean. The smaller the coefficient of variation, the better it indicates the homogeneity of the sample.

- **Percentages**

It measures the percentages of the target group out of the total sample.

- **Analytical statistics**

To compare the two towers (tower 1 and tower 2) according to the three recording variables, the parametric t test had been used according to the study hypothesis. the test consists of two tests:

- Levene's Test for Equality of Variances:
  Levene's test is used to test if two samples have equal variances (homogeneity of variance), assume that variances are equal across groups or samples. The Levene test is defined as:

H0: $\sigma 1 = \sigma 2$ (variance1= variance2)

H1: $\sigma 1 \neq \sigma 2$ (variance1 ≠ variance2) for two groups (1,2).

According to the result of equality variance the value of t test had to be calculated.

- t test for Equality of means:
  After the test of variance, the following null and alternative hypotheses for the independent t-test. The hypotheses are null hypothesis (H0) and alternative hypothesis (H1) of the one sample T test can be expressed as:

$H_{0:}$ Gear Motor Temperature for tower 1 = Gear Motor Temperature for tower 2.

$H_{1:}$ Gear Motor Temperature for tower 1 ≠ Gear Motor Temperature for tower 2.

RESULTS AND DISCUSSIO

Regarding the accuracy of the data acquired utilizing the developed real-time monitoring system. The total number of readings exceeded 9000. Despite this, 96% of the data is a total percentage of approved. The amount of data errors in is 3%, while the number of missing values is 1%. Thus, it can be concluded that the real-time monitoring system has the greatest number of applications for monitoring the engineering factors influencing mechanical parts efficiency.

Validation of different equipment sensitivity in the developed real-time monitoring system

The gear motor and gearbox evaluation are the most important factor, followed by the tower number. Oil level and tire pressure measurements are also factors to consider. To monitor the gear box, gear motor, and tire components of the irrigation system in Ismailia Governorate. Temperature monitoring aided in the evaluation of the gearbox, gear motor, and tire components' performance under Ismailia Governorate field circumstances. The observed measurements and description of the gear motor performance analysis are provided below:

- **Gear Motor Performance Analysis.**

Monitoring of the performance analysis of the gear motor of the center pivot irrigation system. Which could be determined as a reflection of the change in oil temperature degrees within the time of the experiment and operating event. It may be considered an effective parameter of judgment and can help in taking a right decision for maintenance and real-time solving-problem.

The temperature data suggest that tower 1 and 2 differ slightly from one another, as seen in Figure (18). The maximum temperature of the gear motor is 51^{o} c and the lowest temperature is 29^{o} c. Meanwhile, the average range is around 37.23 and 35.4^{o} c, respectively. Although the average temperature in the first tower differs from the second, however the gear motor temperature of tower 1 and 2 in the nominal range of operation under field conditions.

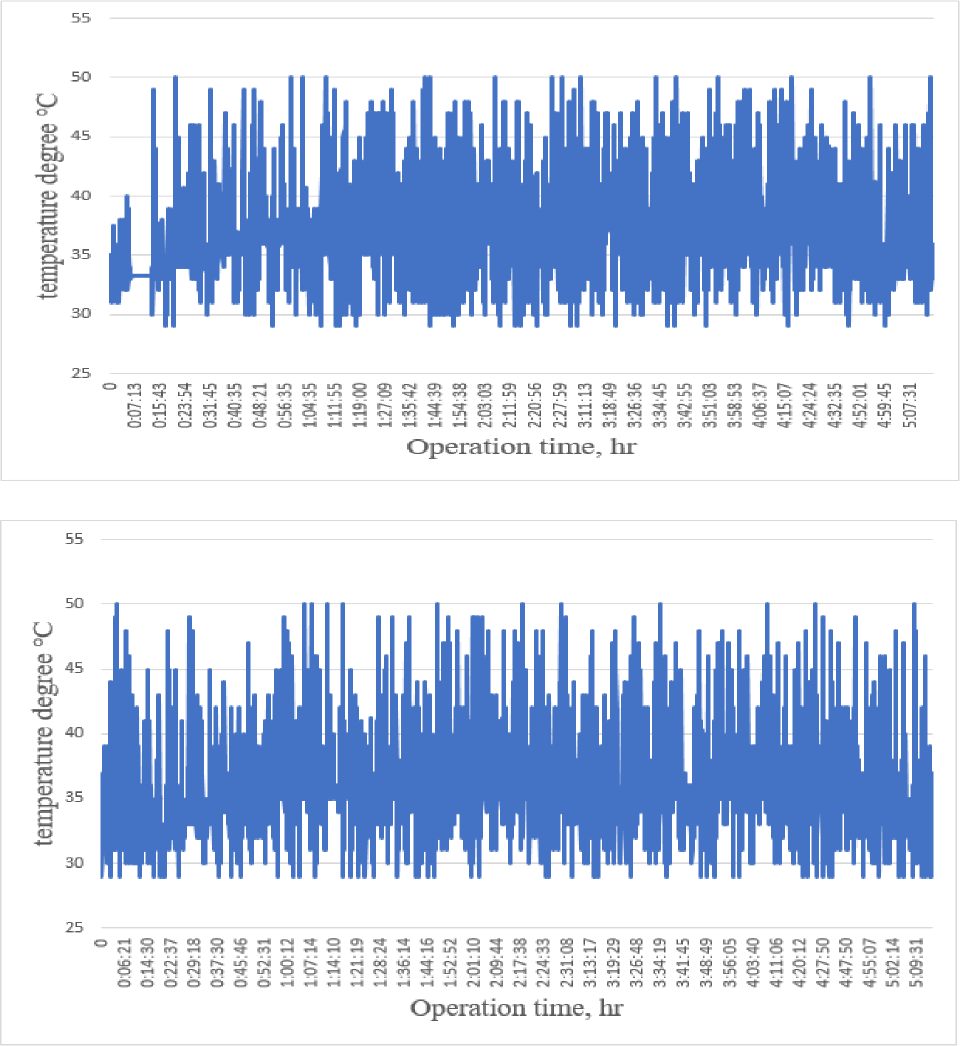


Figure (18): Gear motor Temperature Monitoring of Tower 1&2.

According to the oil-level change data of the gear motor of tower 1 and 2 as shown in table (1), the oil level decreased in the tower 1, while there was no notable change in tower 2. This could explain the temperatures difference observed between the tower 1 and 2.

Regarding the time consume for data transfer, data analysis indicates that the time of recognise of all measurements (oil temperature, oil level) had been ranged from 3 up to 7 seconds with an average of 4 seconds, with except in one reading that time of transfer reaching 9 seconds.

Table (1): Compare of the gear motor oil level between tower 1 and tower 2

Gear Motor Oil level	Data of Tower 1	Data of Tower 2
0	93.3%	100%
1	6.7%	0%
Total Reading	4082	4069

- **Gear Box Performance Analysis**

Gear box temperature data show that there is a difference between tower 1 and 2 which the maximum temperature of gear box is 50 and 61° c and the lowest temperature is 29 and 33° c, meanwhile, the average range is around 33.9 and 36.8° c, respectively.

It can be noted that the gearbox of tower 2 has experienced significantly higher temperatures in comparison to the gearbox of tower 1. These observations agree with the logic thinking of centre pivot irrigation systems operation. However, its movement is beginning from the last tower up to the first one. This means that high loading on gear box No.2 higher than is appearing with gear box No1. However, the loading in operations had been reflected as high-temperature degrees. Despite the above, the gear motor temperature of tower 1 and 2 in the nominal range of operation under field conditions as shown in Figure (19).

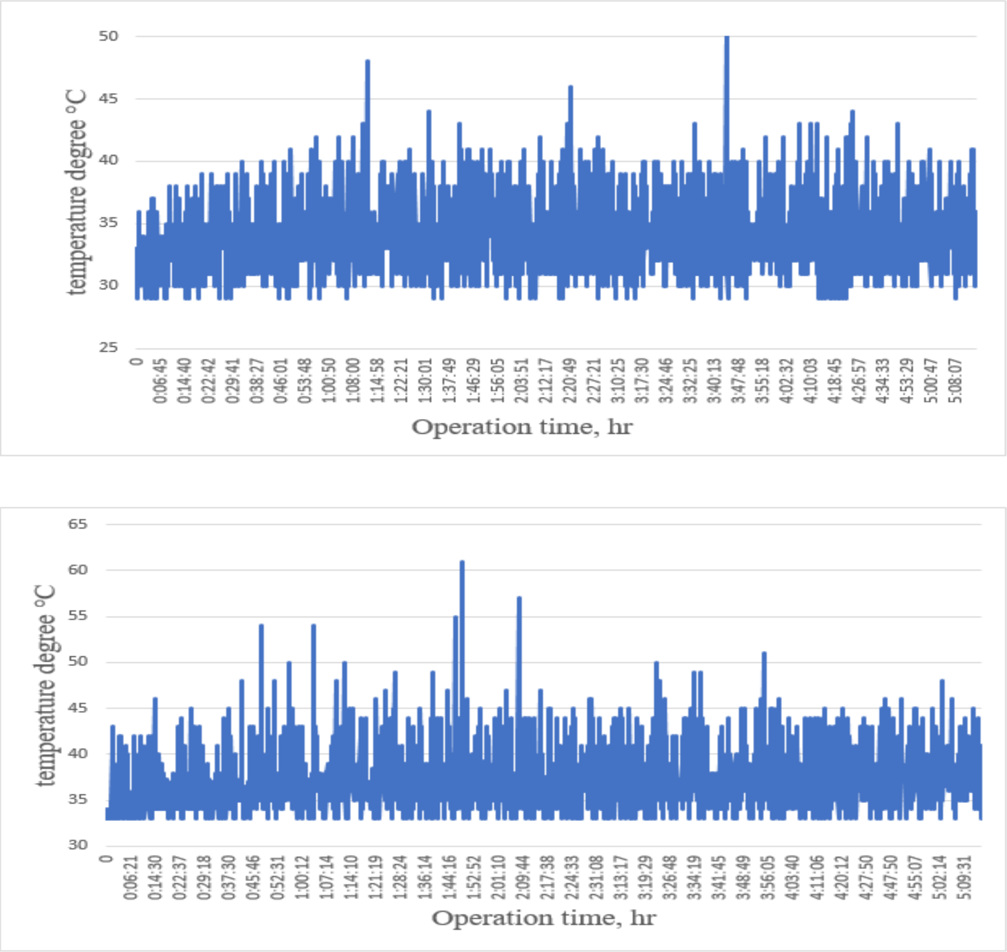


Figure (19): Gear Box Temperature Monitoring of Tower 1&2.

Following prior findings, the oil-level change data of the gear motor in towers 1 and 2, as given in table (2), revealed that there was no discernible change in oil-level in tower 1, but a drop in gear box oil tower 2. This is another reason for the temperatures differential measured between the tower 1 and 2.

Table (2): Compare of the gearbox oil level between tower 1 and tower 2

Gear Box Oil level	Data of Tower 1	Data of Tower 2
0	100.0%	91.3%
1	0.0%	8.7%
Total	4082	4069

- **Monitoring of Tire Pressure**

In consideration of the performance evaluation of the sensor for monitoring tire pressure at tower 1 and 2, the data depicted in Figure (20) reveal that the maximum tire pressure recorded was 174 kPi and 182 kPi, respectively, while the minimum tire pressure recorded was 169 kPi and 177 kPi, respectively. Nevertheless, the tire pressure fluctuated to up and down over the duration of the inquiry. This phenomenon could potentially be attributed to the interplay between boundary climate conditions and tire life expectancy.

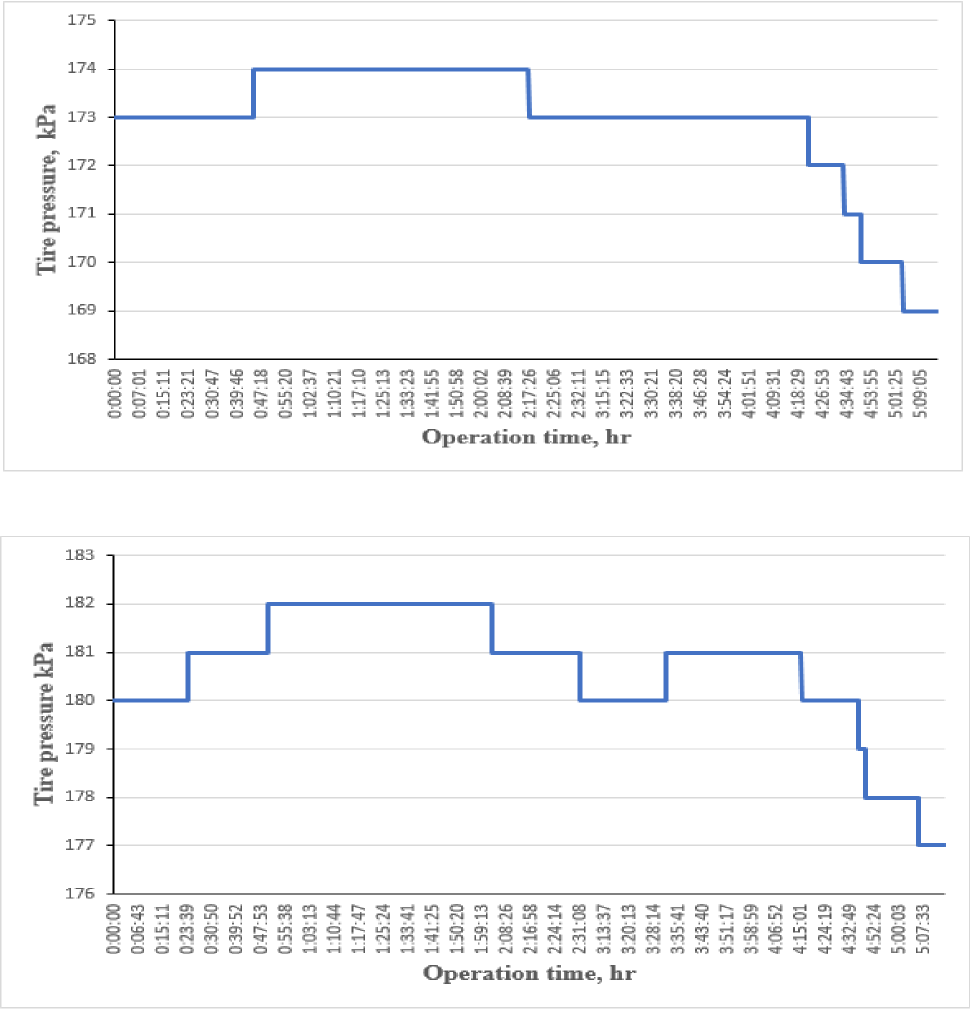


Figure (20): Tire Pressure Monitoring of Tower 1&2.

Statistics analysis of the Developed Real-Time Monitoring System in Field Conditions

- **Data Distribution**

The descriptive statistics shown in table (3) for the variables of the study samples in Tower 1 and Tower 2 provide useful information about the operational conditions. The gear motor temperatures exhibit moderate variability, as indicated by standard deviations of 3.307 and 3.3293 for Tower 1 and Tower 2, respectively. The median values of 38 and 35 degrees suggest central tendencies, while the coefficient of variation (C.V.) at 8.9% and 9.3% indicates a reasonable level of stability.

Similarly, the gear box temperatures show a slightly less variability with standard deviations of 2.176 and 2.471 for Tower 1 and Tower 2. The median values of 34 and 37 degrees and C.V. of 6.4% and 6.7% suggest a relatively stable temperature distribution.

The tire pressure, with low standard deviations of 1.266 and 1.252, and C.V. of 0.7%, demonstrates consistent and stable readings for both towers. Overall, these results suggest that the operational conditions in both towers are stable, with acceptable levels of variability in the measured parameters."

Table (3): The descriptive statistics of the study variables in the two towers

Tower id		N	Min.	Max.	Mean	Std. Deviation	Median	c.v.
Tower 1	Gear Motor Temperature	4082	29	51	37.23	3.307	38	8.9%
	Gear Box Temperature	4082	29	50	33.9	2.176	34	6.4%
	Pressure	4082	169	174	172.9	1.266	173	0.70%
Tower 2	Gear Motor Temperature	4069	29	51	35.4	3.293	35	9.3%
	Gear Box Temperature	4069	33	61	36.8	2.471	37	6.7%
	Pressure	4069	177	182	180.7	1.252	181	0.70%

- **Analytical statistics**
  - **Compare the Gear Motor Temperature**

    Table (4) shows that the Levene's and T-Test results do not have variance equality. The F test has a significance level of 1%, and the test statistic t = 53.09 indicates that the test is significant at that level. By rejecting H0 and accepting H1, the alternative hypothesis "Gear Motor Temperature for tower 1 > Gear Motor Temperature for tower 2" is proven to be true

    This result was because of the leakage of oil from the gear motor shafts oil seal and that led to higher temperature in the gear motor of tower 1.

Table (4): Comparing the Mean of Gear Motor Temperature between Tower 1 and Tower 2.

Two Independent Samples T-Test	Levene's Test for Equality of Variances		T-Test for Equality of Means				
	F	Sig.	T	Df	Sig.	Mean Difference	Std. Error Difference
Gear Motor Temperature	53.48	0.001	53.09	8149	0.001	1.83	0.038

  - **Compare the Gear Box Temperature**

    Table (5) illustrates that Levene's test does not establish equality of variances, since the F test demonstrates significance at the 1% level and the statistical t = 53.857 with (df=8149) testifies significance at the same level. i.e., reject H0 and accept H1, which proves that the validity of the alternative hypothesis “Gear Box Temperature for tower 1 < Gear Box Temperature for tower 2.”

This result is according to the leakage of oil from the gearbox in tower no.2 during the field test, but the temperature did not reach a critical reading that would trigger a warning or an emergency stop for the device to be stopped.

Table (5): Comparing the Mean of Gear Box Temperature between Tower 1 and Tower 2.

Two Independent Samples T-Test	Levene's Test for Equality of Variances		T-Test for Equality of Means				
	F	Sig.	T	Df	Sig.	Mean Difference	Std. Error Difference
Gear Box Temperature	27.630	0.001	-53.857	8149	0.001	-2.77	0.023

- **Compare the Tire Pressure**
  In Table (6) shown, that the Levene’s test has no equality of variances according to F test is significant at 1%, and the test of statistical t = -273.382 with (df=8149) is significant at 1% level. i.e. reject H0 and accept H1, which proves that the validity of the alternative hypothesis “Tire pressure for tower 1 < Tire pressure for tower 2.”

The tire pressure sensor readings were optimal during all time of testing and the differences in the tire pressure between tower 1 and tower 2 was because of the pressure set at the beginning of the field study because the tire pressure was adjusted with a manual air compressor.

Table (6): Comparing the Mean of The Tire Pressure between Tower 1 and Tower 2.

Two Independent Samples T-Test	Levene's Test for Equality of Variances		T-Test for Equality of Means				
	F	Sig.	T	df	Sig.	Mean Difference	Std. Error Difference
The Tire Pressure	68.011	0.001	-273.382	8149	0.001	-7.74	0.028

CONCLUSION

The study had been focused on developing a model, framework, and a proof of concept for a digitally monitored, analyzed, and technically assisted center Pivot irrigation system. In terms of a digital transformation of existing irrigation services, this is called digital twining or rather digital shadowing. Digital shadows mainly rely on acquiring the data from a physical center pivot and create a digital replica of this center pivot, namely the digital center pivot. Moreover, the digital shadow system does not produce commends to remotely control and manage the operation of a physical thing (center pivot irrigation system). However, data collected from the physical center pivot irrigation system and analyzed in a simple digital model that was used to process and decides for possible maintenance instructions and request with few options for remotely controlling the operation of the center pivot, e.g., switching-off the center pivot in unsuitable running conditions.

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نظام تحكم ذكي لمراقبة صيانة نظام الري بالرش المحوري

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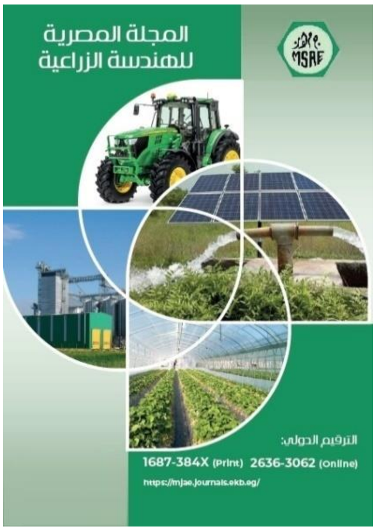

الكلمات المفتاحية:
نظام الري المحوري المركزي؛ أنظمة المراقبة؛ الكشف المبكر عن الأخطاء؛ صيانة.

الملخص العربى

تركز الإستراتيجية الوطنية المصرية للتنمية الزراعية المستدامة (SADS-2030) على إضافة حوالي ١,٥ مليون فدان إلى المساحة الزراعية لمواجهة الفجوة الغذائية. ويعتبر نظام الري المحوري المركزي من أنسب الأنظمة لتحقيق هذا الهدف. من الصعب صيانة جهاز المحور المركزي. علاوة على ذلك، فإن إصلاح الضرر الذي يحدث بعد عطل الجهاز سيكلف الوقت والمال. لذلك، كان الهدف الرئيسي من هذه الدراسة هو المراقبة والكشف المبكر عن الأخطاء وتحذير المشغل قبل البدء بأي عملية ري، مما يمنع حدوث أي خلل أو تعطل للمحور المركزي. تتكون أنظمة المراقبة المطورة من ثرمستورات NTC وجهاز استشعار لمستوى الزيت لمراقبة درجة حرارة الزيت وتسرب الزيت في علبة التروس ومحرك التروس. تم استخدام جهاز استشعار مراقبة ضغط الإطارات (TPMS) لمراقبة ضغط إطارات الأبراج. تم تركيب جميع هذه المستشعرات في وحدة تعرف باسم "اللوحة العقدة البرجية/المركزية" والتي تتكون من وحدتي تحكم ESP32 مثبتتين داخل لوحة التحكم الرئيسية. تقوم لوحة التحكم الرئيسية بالجهاز بجمع كافة القراءات الحيوية من كافة الأبراج وربطها بالخادم السحابي باستخدام الإنترنت مما يتيح التحكم بالجهاز عن بعد.

تم إجراء الاختبارات الميدانية باستخدام النظام المحوري المركزي "Valley" بظروف محافظة الإسماعيلية المصرية للكشف عن دقة حساسية النظام. تم جمع البيانات من برجين لنظام المحور المركزي وتحليلها في نموذج رقمي بسيط تم استخدامه لمعالجة وتحديد تعليمات الصيانة المحتملة.