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Development of an electronic device for protection from agricultural machinery hazards

Tarım makineleri tehlikelerinden korunmak için bir elektronik cihazın geliştirilmesi

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ABSTRACT

Objective: The objective of this study was to develop an electronic device capable of being connected to agricultural machinery to protect operators from mechanical hazards.

Material and Methods: The electronic device contains two electronic circuits for alarming and automatically shutting off. The device is equipped with a pair of passive infrared sensors with a daylight resistance to increase the devise sensitivity. The alarm circuit operates a siren that warns the operator when approaching dangerous objects such as rotors, knives, exposed gears, etc. The automatic disconnect circuit turns off the tractor's engine when the operator does not pay attention to the alarm. Four sensing distances of 0.25, 0.5, 0.75, and 1.00 m were tested with three delay periods of 30, 60, and 90 s at two levels for the interstitial distances between the sensors of 150 and 200 mm.

Results: The device was tested by simulating human hands to test the efficiency of the sensor response and the efficiency of the time delay. The addition of the day light resistance to the passive infrared sensor led to an increase in its response efficiency, from 90.67% to 95.83%.

Conclusion: The developed electronic device can be attached to agricultural equipment to protect operators from operating risks.

Keywords: Interstitial, operators, response, sensitivity, solenoid

ÖZ

Amaç: Bu çalışma, operatörleri mekanik tehlikelerden korumak için tarım makinelerine bağlanabilen bir elektronik cihaz geliştirmeyi amaçlamaktadır.

Materyal ve Yöntem: Elektronik cihaz, alarm vermek ve otomatik olarak kapatmak için iki elektronik devre içermektedir. Cihaz, cihaz hassasiyetini artırmak için gün ışığı direncine sahip bir çift pasif kızılötesi sensörle donatılmıştır. Alarm devresi rotorlar, bıçaklar, açıktaki dişliler vb. gibi tehlikeli nesnelere yaklaştığında operatörü uyaran bir siren çalıştırır. Otomatik bağlantı kesme devresi, operatör alarma dikkat etmediğinde traktörün motorunu kapatır. 0.25, 0.5, 0.75 ve 1.00 m'lik dört algılama mesafesi, 150 ve 200 mm'lik sensörler arasındaki boşluk mesafeleri için iki seviyede 30, 60 ve 90 s'lik üç gecikme periyoduyla test edildi.

Araştırma Bulguları: Cihaz, sensör yanıtının etkinliğini ve zaman gecikmesinin etkinliğini test etmek için insan elini simüle ederek test edildi. Pasif kızılötesi sensöre gün ışığı direncinin eklenmesi, tepki veriminde %90,67'den %95,83'e bir artışa yol açtı.

Sonuç: Geliştirilen elektronik cihaz, operatörleri işletme risklerinden korumak için tarım ekipmanlarına takılabilir.

Anahtar sözcükler: Geçiş reklamı, operatörler, yanıt, hassasiyet, solenoit

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INTRODUCTION

Occupational risks associated with operating agricultural machinery are one of the primary causes of accidents in the agricultural sector (Mucci et al., 2020). Accidents rise as a result of stressful conditions imposed by continuous labor strain and adverse weather conditions in some nations. The majority of accidents happen during harvest seasons and when preparing the soil following harvest, which results in an increase in accidents annually. Accidents are primarily caused by dissenting occupational safety protocols and recommendations to separate agricultural equipment during maintenance (Benos et al., 2020). Usually, the danger results from moving, rotating, and sharp parts found in agricultural machinery. The cutting parts, such as reciprocating mower knives and harvesting knives in harvesters and the grain transport augers, cause accidents resulting from the entanglement of clothes, hands, arms, and feet (Ngajilo & Jeebhay, 2019).

The rotating parts from the feeding rollers, rollers, and belts of the threshing and winnowing machines, as well as the contract device in the hay balers and the power takeoff of the tractor, cause painful accidents (Fargnoli et al., 2018). Hair and clothes can be pulled, causing cases of amputation and suffocation if not adhered to when wearing suitable, non-loose clothes. The components of hydraulic systems, such as winches, excavators, and dredgers, lead to serious injuries as a result of oil leakage or explosions. One of the most hazardous industries globally is the agricultural sector (Evangelakaki et al., 2020; Vigoroso et al., 2021). The use of agricultural equipment has increased due to the ability of tractors and harvesters to be controlled by satellites using global positioning systems. Despite the utilization of sensors and developed software, the development of the operator's work environment still needs to advance in its application of artificial intelligence to reduce potential dangers (Mirmahdi & Shirazi, 2021). The development of harvesters using laser range sensors can leverage laser application usage in the agricultural sector. The power take-off (PTO). for tractor was developed from a mechanical one to be electrically operated using a motor in order to avoid accidents for operators when connecting equipment manually (Prankl et al., 2011). The development of independent machines to perform various agricultural operations, from soil preparation to harvesting, requires the efforts of a few designers to replace traditional devices with electronic ones that can be monitored remotely using Internet applications, reducing agricultural accidents and raising operational safety rates (Shutske et al., 2022). The use of modern technology for agricultural machinery, such as robots and sensors, does not guarantee the safety of operators due to their ignorance of the sources of danger. Therefore, it is necessary to develop programmed systems to prevent accidents (Aby & Issa 2023).

The operator's safety was significantly impacted by the use of electronic sensors like infrared motion sensors, lasers, and gravity sensors attached to the agriculture machinery, which resulted in a decrease in accidents (Erdal & Jakob, 2004; Teng et al., 2016). A pressing issue is the global trend toward enacting tough legislation to lower workplace dangers, so using these electronic devices can solve safety problems. The expense of work accidents can be attributed to the advancement of technology in the environment in which the operators work (Ivascu & Cioca, 2019). Accidents are attributed to the management of the work team by 75% due to ignorance of the dangerous elements of agricultural machinery, while the percentage of accidents due to the workplace represents 50%. The deficiencies in the equipment, like agriculture machinery, in the work environment cause accidents by up to 56% (Ivascu et al., 2021). To lower the accident rate, occupational safety initiatives in agricultural professions must be developed using skilled labor and developed electronics to prevent accidents and injuries (Noman et al., 2021). Many workers, whose ages range from 30 to 59, suffer injuries as a result of accidents caused by the use of some agricultural equipment, including tree saws and other equipment, especially harvesters.

Manufacturers of agricultural equipment must support all forms of protection, including installing shields and other barriers (Lopez et al., 2021; Khorsandi et al., 2022). The modern tendency towards developing an operator alert and protection device employing sensors offers a perfect working environment free of hazards.

Harvesters and shredders cause many agricultural accidents. The application of smart devices increases the field efficiency of agricultural machinery by decreasing the time spent on maintenance and allowing the operators to save themselves from hazards. The use of automatic devices in precision farming applications using sensors and robots is entirely related to the safety of operators (Colantoni et al., 2018). This is due to the non-use of traditional devices, such as the use of complex mechanical connections with a lot of maintenance and malfunctions, which may affect operators when they do not pay attention to them as a result of repeated malfunctions, unlike the modern, developed systems that depend on remote sensing systems. Thus, the mission of developing such logic automatic control devices could participate in the development of artificial intelligence for agricultural equipment.

The developed electronic safety device is placed, for example, next to the knotter device in hay balers because it is very dangerous to protect the operators' hands from entanglement in the gears. The electronic safety device can also be inserted into mowers on the three-point hitch of the tractor to prevent their hands from being cut by knives. The device can also be used on all choppers and mincing machines at the manual feeding part to protect their hands. Also, this device can be installed on the tractor to suit the connections of all agricultural equipment, such as threshing machines, feed flaps, and so on. It is necessary to use electronic protective devices to protect agricultural workers from various potential risks. There is a fundamental difference between electronic protection devices and traditional ones, which are mostly mechanical. The electrical response time is instantaneous in a fraction of a second, which speeds up the insurance process significantly, unlike mechanical systems that are slow in response. Multiple features have been introduced to the developed electronic insurance device to give a warning first, and in the event that the operator does not pay attention, this device will forcefully stop the equipment, machine, or tractor to protect the operator before an injury occurs. The assembly and synthesis of motion sensors with this new insurance system and programming them by Arduino to secure the agricultural worker is considered new in electronic applications attached to modernizing traditional agricultural equipment. The electronic safety device was tested and evaluated in experiments that simulate different operating conditions of agricultural equipment by using a 12-volt DC current as a source of electrical supply and directing the movement of the human hand using the device to ensure that the device works with optimal efficiency.

Hence, a study was conducted and the objective of this study was to develop an electronic device to secure and protect the operators and workers of agricultural machinery and test the efficiency of the device's performance and operation under different operating conditions.

MATERIALS and METHODS

Experimental procedure

The tests were carried out in 2023 at the Al-Serw Agricultural Research Station in Damietta, Egypt, located at 31.24° N, 31.80° E. The smart electronic protection device was designed, developed, evaluated, and calibrated to fit several kinds of agricultural equipment. The device is suitable for installation on straw baler machines, mowers of all types, threshing machines, agricultural waste choppers, etc. Two laboratory experiments were conducted to test and calibrate the sensitivity of the PIR sensors, once using the passive infrared sensors and the other when installing an LDR light-day resistor (photoresistor), as shown in Figure 3. The experimental variables included four sensing distances of 0.25, 0.5, 0.75, and 1.00 m. The specified sensing distances are considered the standard range specified for passive motion sensors listed in the usage specifications, which can be adjusted using the potentiometer for each sensor individually. The sensing distance (SD) was adjusted by turning the potentiometer on the PIR sensor. Three delay periods (DP) of 30, 60, and 90 seconds for shutting off the tractor automatically were also tested. This time can be set using the countdown timer attached to the device, and this time is considered appropriate for operating agricultural equipment. The delaying periods were adjusted using the delay timer module. Also, two interstitial distances (SID) were tested between installing the sensors, which are 150 and 200 mm. The interstitial distances between the two used passive motion sensors were adjusted by moving the sensor fixation position on the movable slider on the sensor fixation shaft, as shown in Figure 1. The experiments were performed using a three-way completely randomized factorial design. The experiments included five replications for the experimental variables. The movement of the worker was simulated in front of the positive motion sensors of the electronic insurance device and installed on the tractor to suit the attachment of the various agricultural equipment with a risk factor. The device is suitable for working on most types of tractors, whose electrical devices depend on a direct current of 12 volts, and any agricultural machine. The device can be installed next to any rotating part, such as a knife, gear, belt, drums, or the power take-off (PTO) of the tractor, to act as a shield to protect from the dangers of moving parts.

General description

The electronic device was developed to protect operators from high-risk agricultural equipment. The device was intended to secure the equipment connected to the tractor, such as balers, mowers, choppers, etc. The device is secured electronically in two stages. First, the device warns the operator when approaching a dangerous place in the equipment. Secondly, the device automatically shuts off the tractor before reaching the dangerous part. The tractor is compulsorily stopped when the second motion sensor is reached, which is electrically connected to the tractor's stop solenoid. Every place near moving parts, such as gears, wheels, rollers, and knives, can be installed in the device, as the device has been configured to be easily installed in any place with complete flexibility. In general, the electronic device that protects workers from agricultural hazards consists of the following parts, as shown in Figures 1 and 2.

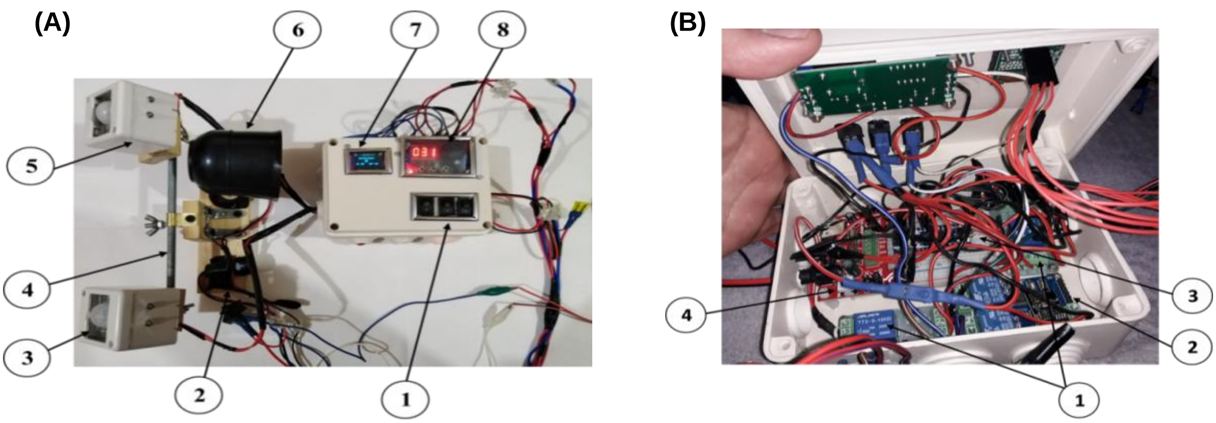


Figure 1. (A) *The smart electronic protection device components (1- the operating switches for the device, the Wi-Fi module, and the countdown timer; 2- the connecting plug for switching off the tractor fuel solenoid; 3- the PIR sensor for the warning circuit; 4- sensors interstitial distance slider shaft; 5- the PIR sensor for the automatic shutoff circuit; 6- the siren 12 V, 25 W, 110 dB; 7- the OLED LCD display 0.96 inch; 8- the countdown timer relay module;* ***(B)*** *The inlet components of the smart electronic protection device (1- 12V one-channel relay modules; 2- Wi-Fi two-channel relay modules; 3- Arduino Nano; 4- 12-5V power supply modules).*

Şekil 1. (A) *Akıllı elektronik korunma cihazının komponentleri (1-cihaz çalıştırma anahtarları, Wİ-Fİ modülü, geri sayım timer'ı 2- Traktör yakıt selenoidi kapatma için bağlantı fişi; 3- uyarı devresi için PIR sensörü; 4-Sensörün intertestiyal mesafesi için kaydırılabilir şaft; 5- PIR sensörünün otomatik kapatma devresi için PIR sensörü; 6- siren 12 V, 25 W, 110 db; 7_0.96 inç OLED LCD ekranı; (8) geriye doğru sayım için timer röle modülü;* ***(B)*** *akıllı elektronik koruma cihazındaki komponentler (1-12 V tek kanallı röle modülü; 2- İki kanallı Wİ_Fİ röle modülü; 3- arduino Nano; 4- 12-5V güç tedarik modülleri.*

The safety device (Figure 2B) consumed 30-35 W of 12 V direct current. The device is easy to install and connect. It is also possible to install the safety device inside the tractor cab, extend the sensor holder cables only outside the cab, and install it using a bracket next to any rotating part, such as power take-off (PTO) of the tractor, or next to the most dangerous moving parts in any equipment attached to working with the tractor. The device relies on the use of passive infrared sensors (PIR). A pair of PIR sensors are connected to the electronic safety device. Each PIR sensor contains a pair of adjustable potentiometers for distance and time delay. The adjustable potentiometers are controlled by turning them clockwise or anticlockwise, as shown in Figure 2A. The distance potentiometer controls the sensing distance range of 0.25-7 m. The second time delay potentiometer controls the response delay time of the sensor from 1 to 5 minutes. The time period for disconnecting the motion sensor is standard, but the time can be precisely controlled using the delay timer, which operates from a range of 1 second to 10 hours. The device contains two circuits, the first for warning and the second for shutting off the tractor's engine automatically by the tractor's stop solenoid, as shown in Figure 2 (A and B).

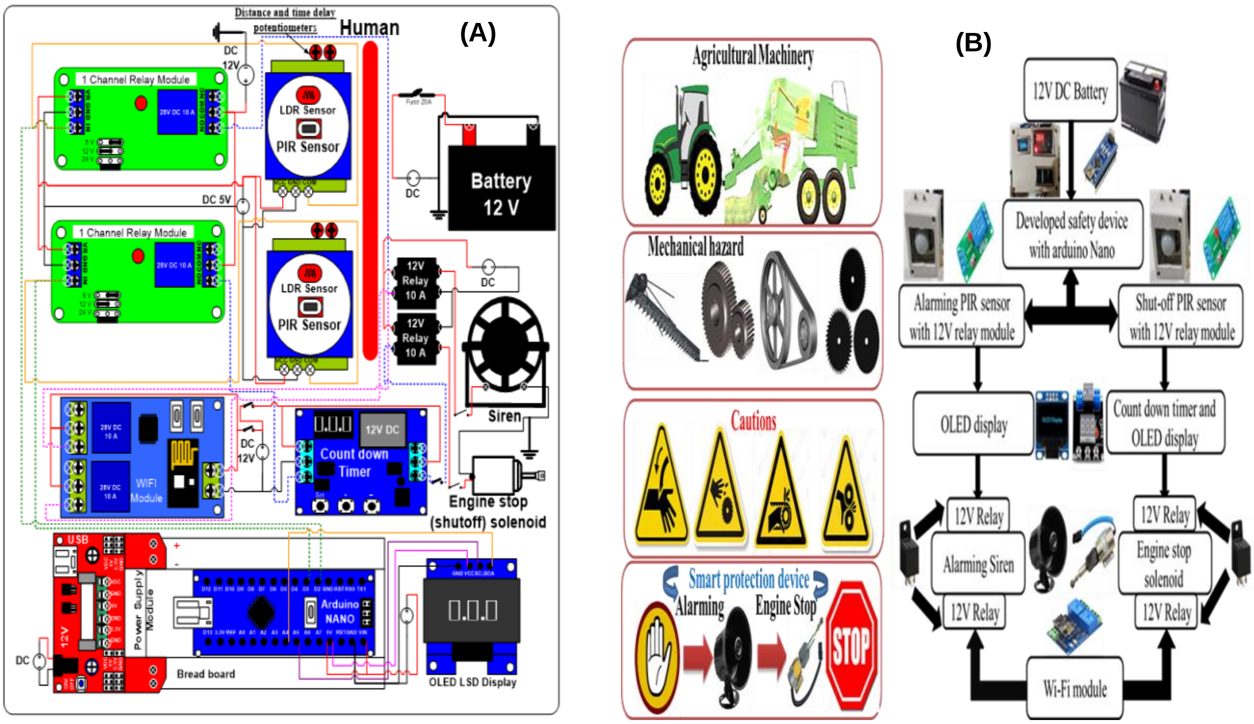
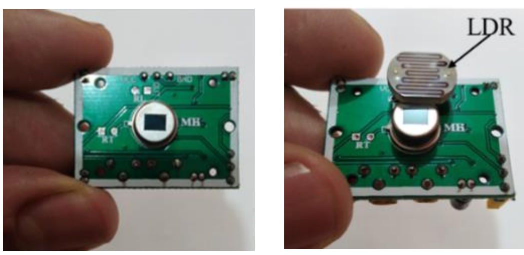


***Figure 2. (A)** The electronic circuit of the smart protection device; **(B)** The flowchart of the developed smart protection device's operation.*

***Şekil 2. (A)** Akıllı koruma sisteminin elektronik devresi; **(B)** Akıllı koruma cihazının akış şeması.*

First, the warning circuit consists of the following parts: The first PIR sensor, as shown in Figure 1A, No. 3, was connected to the warning circuit. The alarm circuit triggers a siren (Figure 1A, No. 6) when approaching the first sensor. The PIR sensor is powered with a 5 volt DC source via the power supply module (Figure 1B, No. 4). The power supply module converts the connected voltage from the tractor battery from 12 volts to 5 volts. When approaching the first PIR sensor of the warning circuit, the electrical outlet signal is transmitted to the Arduino Nano port (D2) (Figure 1B, No. 3) to display the number of coming signals from the relay on the OLED LCD display, as shown in Figure 1A, No. 7. When a person approaches, because his body contains infrared rays, it is sensed by positive motion sensors within the sensor's vision range from any direction when approaching its range, whether passing at an angle or straight, because the sensor lens is spherical in shape. Also, as the PIR warning sensor operates, it transmits a 12 V relay module with one channel (Figure 1B, No. 1). The relay module coil operates with 5 volt to connect its contacts, which are connected to a 12 volt power source, to its built-in relay. Then the electric current is transmitted again to an external relay (12 volts and 10 amps) connected directly to the siren, as shown in Figure 2B.

Secondly, the automatic shut-off circuit consists of the following parts: The second PIR sensor (Figure 1A, No. 5) connects the outlet voltage to another one-channel relay module (Figure 2A). The automatic cut-off circuit is built into the electronic device box and is connected to the device to stop the tractor and cut off the fuel from the tractor engine to stop its operation electrically. Also, the second PIR sensor is connected to port D3 on the Arduino Nano to display the number of signals on the OLED LCD display. The relay module connects the 12 V voltage to the 12 V LED automatic countdown timer relay module, as shown in Figure 1A, No. 8. The delay period for shutting off the tractor is set by the countdown timer instead of using the PIR time delay potentiometer due to its accuracy. The countdown timer is set by choosing between three time programs: seconds, minutes, or hours. There are three press switches to operate the countdown timer as shown in Figure 2A. The relay for the countdown timer connects the outlet voltage to an external 12-volt relay connected directly to the tractor fuel cutoff solenoid, as shown in Figure 2B. The number of response times from the two PIR sensors is counted by a programmable circuit that has been installed. The circuit consists of an Arduino Nano attached to a 0.96-inch OLED LCD display. The OLED LCD display shows the number of responses from the warning and shutting off circuits. Arduino is installed on a breadboard and connected to the power supply module to operate it, as shown in Figure 1B, No. 4. A two-channel Wi-Fi relay module (Figure 1B, No. 2) was used to be controlled directly by an application installed on the mobile smart phone, as shown in Figure 4. The Wi-Fi module connects directly to the pair of external relays connected to the siren and the fuel shutoff solenoid, as shown in Figure 2B. The Wi-Fi relay module was used to control the device directly in emergency cases to protect the operator remotely, as shown in Figure 2B.



(A) **(B)**

Figure 3. (A) *PIR sensor (passive infrared sensor) without LDR (light day resistance);* ***(B)*** *PIR sensor with LDR.*

Şekil 3. (A) *LDR (gün ışığı dirençli) olmayan PIR sensor (pasif infrared sensor);* ***(B)*** *LDR'ye sahip PIR sensor.*

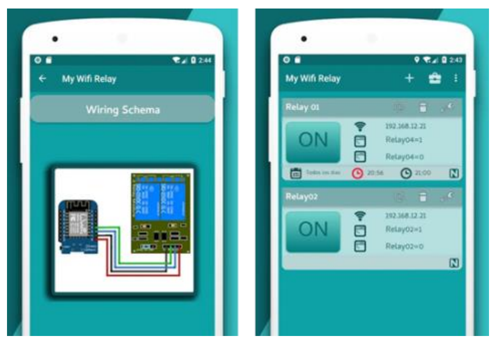


Figure 4. *The mobile application for controlling the smart electronic device using a Wi-Fi controller module.*

Şekil 4. *Wİ-Fİ control modülünü kullanan elektronik akıllı cihazın kontrolünde kullanılan mobil aplikasyon.*

The protection device evaluation

The electronic safety system's components were calibrated, tested, and evaluated. The performance of the electronic warning and tractor automatic shutdown circuits was also evaluated. A simulation was made to test the efficiency of passive infrared sensors. A human hand was passed at a constant speed (10 m s^{-1}), parallel to the direction of the sensors, 30 times per minute. A sensitive electronic piece connected to cables connected to a computer application was installed to measure the speed of the human hand, and the speed was fixed at the required limit for taking measurements. The electronic safety device records the average readings. There is an interval swipe time of 2 seconds between each attempt. The sensor's response efficiency (*SR η*, %) was measured using Equation No. 1. (Zappi et al., 2010)

$$SR\,\eta = \frac{SR_{ac}}{SR_{th}} \times 100, \% \qquad (1)$$

Where: $SR\ \eta$= the PIR sensors response efficiency, %; SR_{ac}= actual sensing responses recorded, once; SR_{th}= theoretical sensing responses trail, once (constant 30).

The efficiency of the electrical tractor's shut-off circuit was evaluated. A stopwatch was used to record the actual tractor shutoff delay time. The device can be installed next to any rotating or moving part using screws. The device automatically stops the tractor as the second motion sensor directs the electrical signal coming out of it when sensing any movement to the delay timer. The timer automatically operates via a cable connected to the Fuel solenoid valve, which cuts off fuel from the tractor engine, so that the tractor stops before an accident occurs. The device is suitable for all types of tractors, and its operation is not affected by the type of tractor. The theoretical delay periods are set using the insurance device's countdown timer. The time delay efficiency (*TDη*, %) was calculated using Equation 2. (Narayana et al., 2015)

$$TD\ \eta = \frac{\mathrm{DP}}{DP_{th}} \times 100, \% \tag{2}$$

Where: $TD\ \eta$= the time delaying efficiency, %; DP_{ac}= actual delaying periods, s; DP_{th}= theoretical delaying periods, s.

Statistical analysis

The statistical programs CoStat 2017 and Minitab 2019 were used to analyze the data. Variables were tested using analysis of variance (ANOVA) at a significant probability level of $P \leq 0.001$. The determination coefficient and the standard error were estimated. The least significant difference (LSD) was calculated at a level of 0.001 for the mean averages of the tested variables. Linear regression equations were estimated to measure the interaction between variable levels.

RESULTS and DISCUSSION

Factors affecting the sensor's response efficiency

Figure 5a shows an inverse relationship between the sensing distances and the sensor's response efficiency at the different delay times. The greater the sensing distance levels from 0.25 to 1.00 m, the less efficient the sensors' response. Figure 5a, shows that there is a significant increase in the response efficiency of the sensors when the LDR is installed compared to when it is not installed. As shown in Figure 5A, the highest recorded values of *SR η* were 90.67% and 95.83% for the PIR sensors without and with LDR, respectively. The maximum values of *SR η* were gained for 30 s delay periods (DP) and a sensing distance (SD) of 0.25 m. As shown in Figure 5 B, the effect of sensing distances (SD) on *SR η* values at the sensors interstitial distances (SID). The *SR η* values were increased from 84.56 to 90.78% at a SID of 150 mm, from 1.00 to 0.25 m of SD, respectively, for the PIR sensors without LDR. At the PIR with LDR, the *SR η* values were increased from 85.67% to 95% at a SID of 150 mm, from 1.00 to 0.25 m of SD, respectively. The minimum values of *SR η* were 84.33 and 85.33% at 200mm of SID and 1.00 of SD, as shown in Figure 5B.

Figure 5C demonstrates the interaction between the DP and SID levels on the *SRη* values. The maximum *SR η* values were increased from 88 to 88.42% at the lowest DP of 30 s and at SID levels of 200 and 150 mm, respectively, for the PIR sensors without LDR. The minimum and maximum values of *SR η* were 88.42 and 90.75%, respectively, for DP of 90 and 30 S. The increment ratio for the maximum value for *SR η* at PIR sensors with LDR over it but without LDR was 2.57%. As tabulated in Table 1, the mean and standard errors for the studied factor levels were highly significant at $P \leq 0.001$.

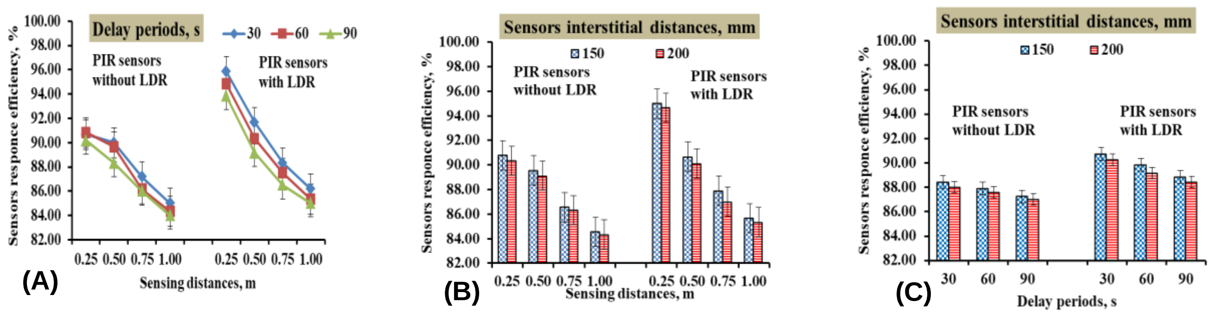


Figure 5. *(**A**) The effect of sensing distances on the sensor's response efficiency at the delay periods; (**B**) The effect of sensing distances on the sensor's response efficiency at the sensor's interstitial distances; and (**C**) The effect of delay periods on the sensor's response efficiency at the sensor's interstitial distances for the PIR sensors without and with LDR.*

Şekil 5. ***(A)*** *Gecikme periyotlarında sensörlerin tepki verimlliliğine algılama mesafesinin etkisi;* ***(B)*** *Gecikme periyotlarında sensörün intertestiyal mesafesinde algılama mesafesinin etkisi ve (C) LDR ve LDR olmaması durumunde PIR sensörleri için gecikme periyotlarında PIR sensörün intertisyal mesafelerinde sensörün tepki etkinliği.*

Table 1. *The mean values and standard errors for the PIR sensor without LDR*

Çizelge 1. *LDR ye sahip olmayan PIR sensörünün ortalama değerleri ve standart hataları*

Factors		SR_{ac}, once	$SR\ \eta$, %	DP_{ac}, S	$TD\eta$, %
SD, m	**0.25**	27.00 ± 0.01^{a}	90.56±0.15^{a}	61.44±6.04^{a}	97.61±0.12^{a}
	0.50	26.83 ±0.09^{b}	89.33±0.20^{b}	62.33±6.24^{b}	96.33±0.11^{b}
	0.75	26.00±0.01^{c}	86.44±0.15^{c}	63.28±6.42^{c}	94.83±0.17^{c}
	1.00	25.22±0.10^{d}	84.44±0.12^{d}	64.33±6.44^{d}	92.89±0.11^{d}
	LSD 0.001	0.138	0.389	0.195	0.195
	P value	0.00***	0.00***	0.00***	0.00***
DP, S	**30.00**	26.42±0.13^{a}	88.21±0.48^{a}	31.25±0.09^{a}	95.92±0.39^{a}
	60.00	26.25±0.17^{b}	87.75±0.55^{b}	62.58±0.22^{b}	95.46±0.37^{b}
	90.00	26.13±0.16^{c}	87.13±0.49^{c}	94.71±0.40^{c}	94.88±0.37^{c}
	LSD 0.001	0.119	0.337	0.167	0.169
	P value	0.00***	0.00***	0.00***	0.00***
SID, mm	**150.00**	26.33±0.13^{a}	87.86±0.43^{a}	62.81±4.38^{a}	95.53±0.30^{a}
	200.00	26.19±0.13^{b}	87.53±0.41^{b}	62.89±4.39^{b}	95.31±0.32^{b}
	LSD 0.001	0.097	0.275	0.138	0.138
	P value	0.00***	0.00***	0.0391*	0.00***
	R^2	0.884	0.888	0.899	0.895

Where: *SD*= sensing distances, m; *DP*= delay periods, s; *SID*= sensors interstitial distances, mm; SR_{ac}= actual sensing responses recorded, once; $SR\ \eta$= the PIR sensors response efficiency, %; DP_{ac}= actual delaying periods, s; $TD\ \eta$= the time delaying efficiency, %.

$^{a\text{-}d}$ the means with no common subscript within each column differed significantly ($P \leq 0.001$).

The interaction between the variables levels was significant for $SR\ \eta$ values for the PIR sensors without and with LDR. The linear regression equations for $SR\ \eta$ values at the PIR sensors without and with LDR were estimated as follows:

$SR\ \eta$, % = 95.25 - 8.489 SD – 0.0181 DP – 0.0067 SID R^2 =0.888 (PIR sensors without LDR)

(Where: SD: sensing distances, m; DP: delay periods, s; SID: sensors interstitial distances, mm)

$SR\ \eta$, % = 101 – 12.378 SD – 0.0313 DP – 0.0106 SID R^2= 0.894   (PIR sensors with LDR)

The efficiency of the response of the sensors is significantly higher when the LDR is installed than when it is not, due to maximizing the PIR sensors sensitivities. By affecting the light, supplying passive infrared sensors with LDR daylight resistance increases the degree of response and sensitivity of the sensors. The shorter the sensors' distance, the greater the infrared spectrum reflected from the human body, which increases the efficiency of the sensor's response. The results are in agreement with the results obtained by Zappi et al. (2010). When the interference between PIR sensors is shortened, the efficiency of the sensor's response is maximizing significantly, and vice versa, in agreement with the results of Narayana et al. (2015). According to Furgale et al. (2013), using the shortest time period to adjust the sensors in order to disconnect the electrical current significantly increases the efficiency of the sensors' responses due to the lack of standard error for calibrating the timing devices and the shorter the time period of their adjustment.

Factors affecting the time-delaying efficiency

Figure 6A displays an inverse relationship between the sensing distances (SD) and the time delaying efficiency (*TDη*) for the various delay periods (DP). The maximum values of *TDη* were 98 and 98.2% for the PIR sensors without and with LDR, respectively, at the lowest DP of 30s and 0.25m of SD. The minimum values of *TDη* were 92.50 and 93.17% for the PIR sensors without and with LDR, respectively, at the highest DP of 90 s and 1.00 m of SD. As shown in Figure 6 B, the SID level of 150 mm was more significant than the highest level of 200 mm for the *TD η* values. The increment ratios of (*TDη*) values at the descending SD from 1.00 to 0.25 m were 4.66 and 4.09 % for the PIR sensors without and with LDR, respectively, at a SID of 150 mm.

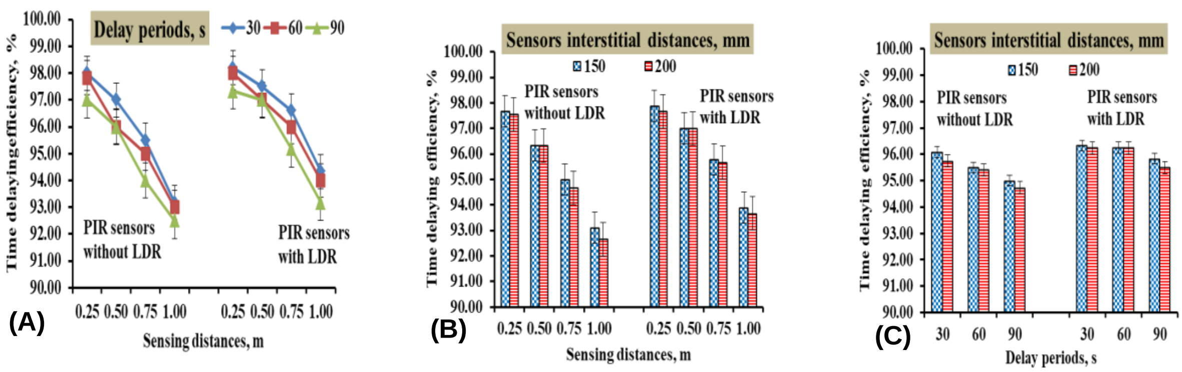


Figure 6. (A) *The effect of sensing distances on the time delaying efficiency at the delay periods; (B) The effect of sensing distances on the time delaying efficiency at the sensor's interstitial distances; and (C) The effect of delay periods on the time delaying efficiency at the sensor's interstitial distances for the PIR sensor's without and with LDR.*

Şekil 6. (A) Gecikme periyotlarında zaman gecikme etkinliğinin algılama mesafesinde etkisi; (B) Gecikme periyotlarında zaman gecikme etkinliğinin sensörün intertisyal mesafelerinde etkisi ve (C) LDR ve LDR olmaması durumunde Gecikme periyotlarında zaman gecikme etkinliğinin sensörün intertisyal mesafelerinde etkisi.

At a SID of 200 mm, the *TDη* values decreased from 97.56 to 92.67% at 0.25 and 1.00m of SD, respectively, for PIR sensors without LDR. For PIR sensors with LDR, the *TDη* values decreased from 97.67% to 93.67% at 0.25 and 1.00m of SD, respectively, at a SID of 200 mm. Figure 6C demonstrates the effect of DP on *TDη* values at the various SID levels. The lowest value of *TDη* was recorded for the PIR sensors without LDR, which was 94.75% at the maximal DP of 90s and 200 mm of SID. The maximum value of *TDη* was 96.33 % at the lowest DP of 30 s and 150 mm of SID for the PIR sensors with LDR. The increment ratio was 0.26 % of the highest value of (*TDη*) for PIR sensors with LDR over the PIR sensors without LDR.

The interaction between the variable levels was significant for the *TDη* values for the PIR sensors without and with LDR, as listed in Table 2. The means and standard errors for the studied factor levels were highly significant at a probability of $P \leq 0.001$. At the PIR sensors without and with LDR, the linear regression equations for TDη values were estimated as follows:

$TD\eta, \% = 101.153 - 6.267\ SD - 0.0174\ DP - 0.0044\ SID$ $R^2 = 0.895$ (PIR sensors without LDR)

$TD\eta, \% = 100.5 - 5.311\ SD - 0.0104\ DP - 0.0028\ SID$ $R^2 = 0.885$ (PIR sensors with LDR)

The time-delaying efficiency was significantly improved when using the smaller sense distances of 0.25 to 0.5 m instead of the larger sense distances of 0.75 to 1.00 m. The significant increment in sensor response efficiency ultimately caused the time-delaying efficiency to increase significantly, in accordance with the results of Yang et al. (2017). The effect of the installation of daylight-resistant LDR was significant and resulted in a large increase in the time-delaying efficiency. The significant correlation between the sensors time delay and the sensing distances had a significant effect on the time delaying efficiency. According to Yue et al. (2010), the greater the sensitivity of the insurance device, the greater the significance of the time-delaying efficiency, and vice versa. According to Ai et al. (2014), the shorter the time delaying efficiency, the lower the standard error for the electronic timing circuit is.

Table 2. The mean values and standard errors for the PIR sensor with LDR

Çizelge 2. *LDR ye sahip PIR sensörünün ortalama değerleri ve standart hataları*

Factors		***SR** $_{ac}$**, once***	***SR η, %***	***DP** $_{ac}$**, S***	***TDη, %***
***SD*, m**	**0.25**	28.50±0.12[a]	94.83±0.22[a]	61.33±6.04[a]	97.78±0.10[a]
	0.50	27.17±0.09[b]	90.39±0.27[b]	62.00±6.14[b]	97.00±0.00[b]
	0.75	26.22±0.10[c]	87.44±0.22[c]	62.33±6.24[c]	95.72±0.11[c]
	1.00	25.67±0.11[d]	85.50±0.15[d]	64.00±6.34[d]	93.78±0.13[d]
	LSD 0.001	0.138	0.413	0.241	0.275
	P value	0.00***	0.00***	0.00***	0.00***
***DP*, S**	**30.00**	27.29±0.24[a]	90.50±0.77[a]	31.25±0.09[a]	96.29±0.30[a]
	60.00	26.88±0.22[b]	89.50±0.75[b]	62.25±0.23[b]	96.25±0.31[b]
	90.00	26.50±0.23[c]	88.63±0.70[c]	93.75±0.31[c]	95.67±0.35[c]
	LSD 0.001	0.119	0.358	0.209	0.238
	P value	0.00***	0.00***	0.00***	0.00***
***SID*, mm**	**150.00**	27.00±0.21[a]	89.81±0.61[a]	62.42±4.32[a]	96.14±0.26[a]
	200.00	26.78±0.18[b]	89.28±0.62[b]	62.42±4.32[b]	96.00±0.27[b]
	LSD 0.001	0.097	0.292	0.17	0.195
	P value	0.00***	0.00***	0.0158*	0.0159*
	R^2	0.893	0.894	0.899	0.885

Where: *SD*= sensing distances, m; *DP*= delay periods, s; *SID*= sensors interstitial distances, mm; SR_{ac} = actual sensing responses recorded, once; *SR η*= the PIR sensors response efficiency, %; DP_{ac}= actual delaying periods, s; *TD η*= the time delaying efficiency, %.

[a-d] the means with no common subscript within each column differed significantly ($P \leq 0.001$)

SD: algılama mesafesi, m; gecikme periyotları, s; SID: sensörlerin intertesyal mesafesi, mm: SRac : kaydedilen gerçek algılama mesafesi, bir kez; *SR: PIR sensörlerinin tepki etkinliği, %;* DP_{ac}= gerçek gecikme periyotları, s; *TD η*= zaman gecikme etkinliği, %.

CONCLUSIONS

The automatic warning and shutoff circuits' use of passive infrared sensors demonstrated extremely high efficiency. Providing the daylight resistance to the passive infrared sensors led to an increase in the efficiency of the sensors responses to 95.83%. The best levels for adjusting the sensitivity of the electronic insurance device for operators and agricultural machinery are when setting the sensing level at 0.25 m, the delay period at 30 s, and the interstitial distance between the sensors at 150 mm. The highest value of time-delaying efficiency was 98.20% when calibrating the device at the most accurate levels. It can be recommended to rely on the developed electronic insurance device to protect operators of agricultural equipment with a high risk factor after the tests. It can be recommended to conduct tests on the electronic safety device and attach it to various agricultural equipment such as hay balers, mowers, cutters, and threshing machines to maximize the benefit of the electronic safety device during agricultural machinery operations.

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