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PEST-WATCH

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Abstract

Egypt faces crucial environmental and agricultural challenges that hinder its development. One of them is pests and fungal activities that account for more than 40% of crop losses. The purpose of the study is to implement a sustainable farming system that treats pest and fungal activities and eliminates the use of chemical pesticides. The solution depends on detecting pests and fungal growth conditions inside a soilless farming medium and automatically spraying eco-friendly pesticides if the system detects pests or fungal growth conditions. Through the test plan, the results were found to surpass the expectations for fast detection and response, accurately detecting fungal growth conditions, and the soilless farming system shows great sustainability by saving water. Many negative results also were found, but overall, if this project is applied on a large scale with the government's support, it will contribute to solving the pests and fungal activities challenges in Egypt.

Introduction

Egypt has been suffering from various challenges that interrupt its progress, such as the underdevelopment of the scientific and technological environment, arid areas, and climate change. This semester's capstone challenge is to develop a technological farming and adopt modern technological infrastructure in the agricultural sector. Thus, pests and fungal activities and the risks of chemical pesticides were the scope problem of the project. According to Food and Agriculture Organization (FAO), in 2019, it was estimated that global crop losses due to pests and fungal activities exceeded more than 40% of the total crop production and caused much crop losses from various crops, as shown in figure 1. According to an FAO report, solving this challenge can increase sustainability by up to 30% and reduce the reliance on harmful pesticides by 50%. Many prior solutions were conducted to solve this challenge. One of them is the Semios project which manages and controls pests by detecting pheromones released by pests to communicate with each other; then, it treats them. The project has high accuracy with detection and their types; conversely, it is expensive and requires expert human resources. Another project is Robhortic, a short-distance robot that detects pests using camera and GPS sensors, then automatically responds by spraying chemical pesticides. It has high efficiency in removing pests, but its detection range is limited to small scales. From these priors, many design requirements were established for the project that must be met to consider its success, such as being sustainable with saving water and eliminate the use of chemical pesticides, fast detection and response with pests and fungi, and accurate detection of fungal growth conditions.

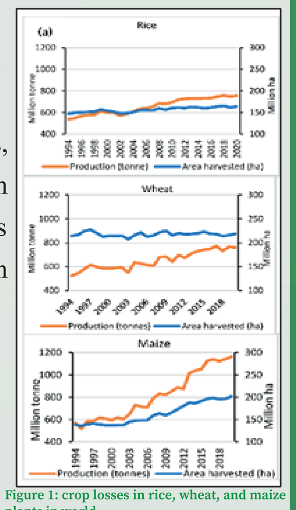
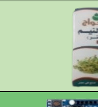
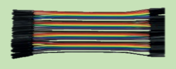
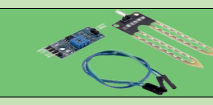
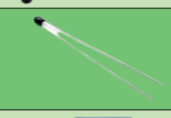
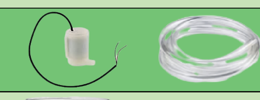
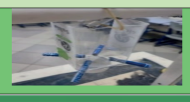


Figure 1: crop losses in rice, wheat, and maize plants in world.

Based on these requirements, the solution implemented is an autonomous system that detects pests using three parameters: pest motion, soil moisture, and temperature. Based on certain implemented conditions (moisture > 80%, temperature in the range of 15 °C – 20 °C), it would run an electrical switch connected with a pump to deliver eco-friendly pesticide and fungicide of neem oil solution. This system was established on a soilless farming system with lettuce crops, to sustain water resources used.

The solution succeeded in being sustainable by saving more than 60% of the water used in the soilless medium compared to traditional farming. It also has shown a fast detection process of fewer than 5 seconds and accuracy of detecting fungi conditions greater than 80%, all of that indicates its success in solving the specific problem chosen. Materials and methods play the greatest rule with understanding the solution therefore, they will be discussed in the following section.

Materials

Item	Quantity	Description	Picture
Rectangular Flowerpot	1 container	It was used to carry the soilless mixture and hold lettuce plants. It also contains drainage holes to allow excess water to drain out and prevent root rot.	
Sphagnum Peat Moss & Perlite	25,700 $cm^3 \pm 10$ cm^3 of peat moss, 11,000 $cm^3 \pm 10$ cm^3 of perlite	They are used to make the soilless mixture for the farming system by the ratio 7:3 respectively.	
Neem Oil	2 ml ± 0.2 ml of neem oil / 1 L of water	Natural plant-based oil is used as a pesticide and fungicide. It is diluted with water before using it.	
Arduino UNO R3	1 board	It is a microcontroller that is programmed to read input and give certain actions based on the received data.	
Jumper wires	2 packets	They are used to connect electronic components with each other or with the Arduino.	
Soil Moisture Sensor	1 sensor	It was installed in the roots to measure its moisture to maintain if there were fungal activities.	
PIR Sensors	2 PIRs	An electronic device that detects motion by sensing changes in infrared radiation. It was used to detect pests' motion in the plant's leaves.	
NTC Thermistor	1 Thermistor	semiconductor component used to measure temperature in terms of the change of its resistance.	
Relay Module	2 Relays	It was used to control high voltage devices (6V water pump) with low voltage devices (Arduino)	
6 Volt Pump / pipes	2 pumps 1 meter of pipe	It is a small-scale pump that is used to deliver neem oil to the sprayers through pipe connected with it.	
Jar	2 Jars	It is used to store neem oil, in which the motor pump will be put in; to deliver neem oil to the sprayers.	
Recycled Drip Emitters	2 Sprayers	It was used to drip the neem oil solution on the leaves of the lettuce plant. It receives neem oil from the pump with	

Methods

Methods for Constructing the Prototype

1. First, a 2D sketch, illustrated in figure 2, was made to outline the prototype design that would be followed.
2. After that, the soilless farming system was built by mixing peat moss and perlite in a ratio of 7:3, respectively, inside a large container.
3. Then, 8 lettuce crops were planted, four on each side of the container.
4. Next, 2 PIRs (motion detection sensors) were connected to the Arduino. They were set on the sides of the container, as shown in Figure 3.
5. Afterwards, the moisture sensor was connected to the Arduino and submerged inside the soilless mixture (peatmoss and perlite) in the container to read moisture levels.
6. Next, a thermistor was connected in a closed circuit with Arduino to read the temperature.
7. Then, the 6V water pump and 6V battery were connected to the relay module, which acts as a switch to control the running of the water pump, as shown in Figure 4.
8. Next, each pump was put inside a jar filled with neem oil, and a pipe was connected to each pump to deliver neem oil to the sprayers.
9. Then, a wooden holder was set; to hold the two recycled sprayers made. Each sprayer receives neem oil from the pipe connected to the motor.
10. Finally, The Arduino code was programmed using Arduino IDE to control the pump when the system detects pest or fungal growth conditions.

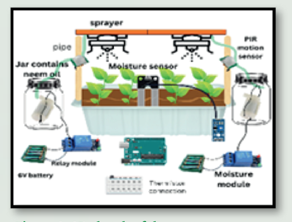


Figure 2: 2D sketch of the prototype.

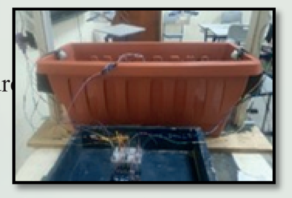


Figure 3: PIR sensors' connections.


Figure 4: Connections made with the relay.

Test Plan

The prototype was subjected to several experiments and tests to ensure it accomplishes the chosen design requirements of Conserving more than 50% of water used, fast running of the feedback detection and response in less than 5 seconds, accurate detection of fungal growth conditions (moisture) greater than 75%, and high efficiency of eliminating pests with natural pesticide greater than 70%. The tests are as follows.

1. First, The amount of water consumed with soilless farming is calculated with a graduated cylinder and compared with traditional farming to estimate the water-saving ratio.
2. Second, a timer was used to measure the speed of detection of pests and fungal conditions in 6 trials. Then the average speed was calculated.
3. Third, four samples of peat moss with different moisture levels were added on each sample. The moisture sensor was submerged on each one to measure its moisture percentage.
4. Forth, readings got were compared with more accurate moisture readings from the same samples using the soil moisture equation:
Moisture (percentage) = [(wet sample mass – dry sample mass) / dry sample mass] *100,
5. Fifth, to estimate the accuracy percentage, the sensor reading is compared with the accurate readings from the equation above.
6. Finally, five trials were made; each trial contains five pests. The number of pests eliminated by the neem oil is measured in each trial, to estimate the elimination pests efficiency in the system.

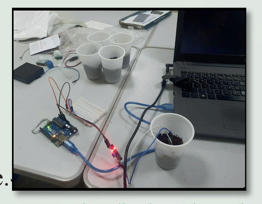


Figure 5: measuring soil moistures in samples.


Figure 6: Jars contain 25 pests from different kinds.

Results

Negative Results

Many negative results appeared while testing the prototype represented in:

- The high sensitivity of the PIR (motion sensor) leads to undesirable detections other than pests. This forced us to adjust its sensitivity and add on the code to make the system run when three continuous motions are detected.
- Using a high voltage power supply of 9V at first to control the 6V water pump led to the burning of the pump, which required us to replace it with another one and change the 9V battery to a 6V one.
- Poor soldering methods used while making the sprayer led to the leakage of neem oil solution of its dedicated path, which required us to strengthen it to prevent unintended pores.

Positive Results

• Conserving water resources used:

The system could pass the 50% conserving water in sustainability with conserving reached 64% ±2%. As it could reduce water consumed in each plant from about 500 ml/day in traditional farming to just 180 ± 20 ml /day for each plant.

• Fast detection of pests and fungal growth conditions:

The system could successfully perform detection and feedback within fast duration, with an average time taken of 2.3 ± 0.1 and 4.2 ± 0.1 seconds for fungal growth and pest feedback times respectively. The average values were taken from three trials made for each criterion, which is shown in figure 7.

• High efficiency of eliminating pests using neem oil pesticide:

Five trials were made with a total number of pests of 25 were tested on the neem oil feedback. The system could remove 21 out of the 25, with an estimated removing efficiency of 84%. The result of each trial is recorded in table 1.

• High accuracy for detecting fungal growth conditions (moisture):

By comparing the moisture values got from the moisture sensor with the more accurate values got from moisture equation, which is mentioned in the test plan. The accuracy was estimated to be on average 81.12. ± 2% The conducted table is shown in table 2.

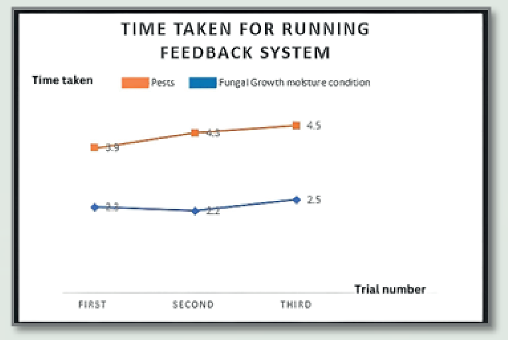


Figure 7: Line chart of time taken to run the feedback in each detection criteria.

Trial	Pests numbers	Eliminated pests
First	5	4
Second	5	3
Third	5	5
Fourth	5	4
Fifth	5	5
Total	25	21

Table 1: Pests eliminated by the neem oil

Trial	Dry sample mass (g)	Water mass added (g)	Real moisture value	Moisture sensor value	Error	Accuracy
First	40	5	12.5%	17.14%	4.64%	62.88%
Second	40	15	37.5%	30.08%	7.42%	80.21%
Third	40	25	62.5%	69.37%	6.87%	89.01%
Fourth	40	30	75%	80.73%	5.73%	92.36%

Table 2: Accuracy of the detecting fungal growth moisture conditions.

Analysis

Soilless farming with Peat Moss & Perlite

Peat moss is a soilless medium with high porosity and water-holding capacity, formed from the slow decomposition of wetland biomass. It has a low pH and high-water buffering capacity, which can help to buffer soil against pH fluctuations. Perlite, a volcanic glass, is lightweight and porous, improving soil drainage and aeration. It is often mixed with organic substrates like peat moss to maintain them for long periods and prevent compaction.
The 7:3 peat moss to perlite ratio provides a balance of water retention and drainage suitable for many types of plants. Peat moss provides water-holding capacity, while perlite provides pore space for aeration and drainage. The prototype, tested with this ratio, was found to conserve over 50% more water than traditional farming.

Nutrient Solution

The nutrient solution used is a carefully formulated mixture of essential micronutrients, composed of two main solutions, A and B. Solution A contains various fertilizers such as zinc, magnesium, high phosphorus, copper, and magnesium sulfate, while solution B contains iron and calcium nitrates. Also, The solutions contain components like potassium, nitrogen, and phosphorus, which are necessary for plant growth and productivity.
Nutrients uptake occurs through the process of osmosis, as shown in figure 8, in this process plants absorb nutrients using its root hairs, this method has shown great efficiency in the fast growth rate of the plants.

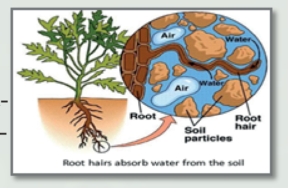


Figure 8: The uptake process by osmosis phenomenon.

Neem Oil

Neem tree is a semi-tropical plant distributed in climate zones like Africa, and South Asia. As it is studied in (BI.2.11), binomial nomenclature that is used to specify the ancestry of plants. Neem tree came from (Azadirachta indica A. Juss) ancestor. The most common way for extracting neem oil is through cold pressing the seeds of the neem tree. This involves crushing the seed to release oil, which is then filtered and collected.
Neem oil contains Azardirachtin compound, as shown in figure 9, which is known for its antifeedant activity on pests and fungi. Azardirachtin works blocking the release of molting hormone (ecdysteroids) from the prothoracic gland, leading to incomplete ecdysis in immature insects. In adult female, a similar mechanism of action leads to sterility. One of the key features of neem oil is being eco-friendly and having no harms on the nature compared to chemical pesticides.

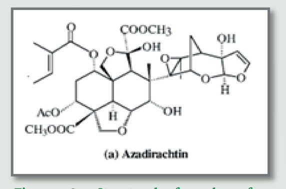


Figure 9: Structural formula of Azardirachtin.

The Feedback system, Arduino microcontroller and IDE

Feedback revealed its importance as a monitoring and controlling system, which helps manage the farming process to improve crop yields and maintain its sustainability. The project's feedback system was created to detect pests and fungal activities, as shown in the following flowchart. Arduino UNO microcontroller is used to manage information given by motion, moisture, and temperature sensors. Thus, managing the flow between inputs and outputs by using certain programming conditionals in the Arduino IDE, as shown in the flowchart. The conditions focus on the detection of motion and fungal growth conditions (moisture > 80%, temperature > 15°C and < 20°C). Based on these conditions, the Arduino automatically runs the feedback process to spray neem oil to protect the plant. A waiting period of three hours is required after neem oil spray to allow it to affect pests and subsequently impede the motion detection controller from reactivating the feedback loop.

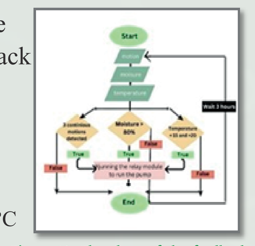


Figure 10: Flowchart of the feedback system process


Figure 11: A snipping of the Arduino code used.

Gathering inputs process, Passive infrared motion detection

A passive infrared motion sensor was used to monitor pest motion in the system. It consists mainly of two metals of ceramic substrate surrounded with a filter window to increase the range of detection angles, as shown in Figure 12. The sensor can detect the infrared rays emitted from any living organism passing within the two metallic poles. Once a motion is detected, it sends signals to the Arduino board to confirm pests' presence. The sensor also contains two adjusting screws for controlling the sensitivity of detection and the delay time between each detection. Both values should be well adjusted to prevent motion detection errors.
The PIR sensor is connected to the Arduino using the following connections shown in figure 13. The output PIN is connected with PIN number 2 of the Arduino; the results while testing the PIR sensor overpassed the expectations for detection with a wide range can reach 1.5 meter compared to its low price, which matches the design requirements implemented for fast and accurate detection.

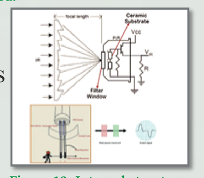


Figure 12: Internal structure of the PIR sensor.

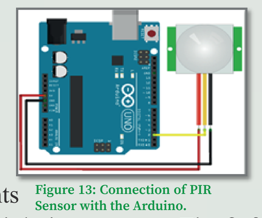


Figure 13: Connection of PIR Sensor with the Arduino.

Measuring soil moisture

Monitoring moisture levels in the soil is a crucial part, which can help in detecting if the plants are at risk of fungal activities. A soil moisture sensor is used to perform this task. It works mainly in two parts. The first one is the pope, which acts as a variable resistor that vary according to soil moisture. The second part is the module, which generates an output voltage based on the resistance of the probe. The voltage value is ranged from 0 (wettest level) to 1023 (driest level). To convert it into analog reading and get the moisture percentage, equations 1 and 2 are used.

$$AnalogOutput = \frac{ADCValue}{1023}$$

Equation 1: Calculating analog output from the voltage readings.

$$\text{Moisture in percentage} = 100 - (\text{Analog output} * 100)$$

Equation 2: Calculating moisture percentage with the analog readings.

The sensor is connected to the Arduino using the following connections shown in Figure 14. The output pin that delivers moisture value was connected to the A0 pin of the Arduino. From the test plan results, soil moisture was found to be sufficient for recording moisture levels.

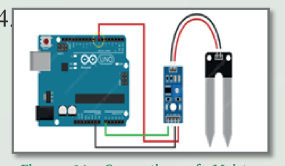


Figure 14: Connection of Moisture Sensor with the Arduino.

Measuring temperature (Thermistors)

A thermistor is an electronic component used to measure temperature in terms of its internal resistance. Relying on applications of semiconductors in DC circuits studied in (PH.2.15), the thermistor is mainly made of semiconductor material in which electrons move from the -N regions to the +P regions. When the temperature increases, electrons' speed increases and therefore, resistance decreases according to Ohm's law (R = V/I), and verse vice, as shown in figure 15. Temperature coefficient of resistance (TCR) can be estimated using the equation 3. The thermistor was connected with a 10KΩ resistance, followed by Arduino connections, as shown in Figure 16. The output pin was connected with the A1 pin of the Arduino.

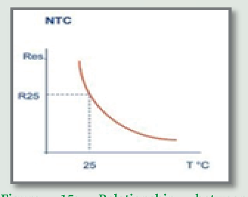


Figure 15: Relationship between temperature and resistance in thermis-

$$TCR = \frac{(R_2 - R_1)}{R_1(T_2 - T_1)} \times 10^{-6}$$

where R_2 is the value of resistance at operating temperature T_2, and R_1 is the value of resistance at temperature T_1, which is typically room temperature (25°C).

Equation 3: Calculating Temperature coefficient of resistance (TCR).

Water Pump

According to (PH.2.10) that focuses on how motors work, the structure of the water pump motor depends on the quick rotation of the impeller, which generates a high centrifugal force that pushes the water to the edges of the cavity. This reaction creates a vacuum in the middle of the impeller, which helps in sucking more water from the inlet pipe and passing it out to the outlet pipe, as shown in figure 17. DC pump is a fast solution as it can lift up to 120L/H, which meets the design requirements for generating a quick response system.

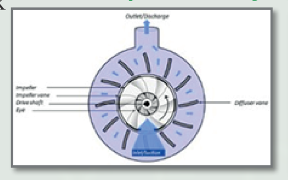


Figure 17: Internal structure of DC mini water pump.

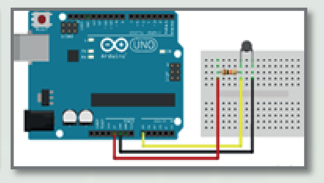


Figure 16: Thermistor connection in Arduino.

Analysis

Relay module switching circuit

The relay module's working principle is based on the idea of electromagnetic induction that was taught in (PH.2.08). It consists mainly of a coil, armature, and common channel, which represents the positive pole. When low voltage signals less than 2V is sent to the relay, the relay turns on and runs the water pump by connecting the common pole side with the NC (Normally Closed). If a higher voltage passes, it will turn off the relay by connecting the common side with the Normally opened (NO) side, as shown in Figure 18.
The water pump circuit is built by connecting the positive terminal with the common pin channel, and the positive side of the pump with the Normally Open (NO) channel. Then, the negative pole of the relay with the negative pole of the battery, as shown in figure 19. The Arduino was coded to send high signals when there is no motion of pests or safe moisture and temperature levels, and send low signals to run the pump, and vice versa.

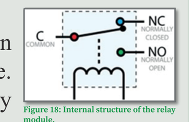


Figure 18: Internal structure of the relay module.

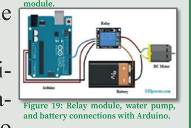


Figure 19: Relay module, water pump, and battery connections with Arduino.

Battery series connection

To get the suitable voltage supply for the pump (6V), four pieces of 1.5V AA battery are connected in series, producing one large 6V battery, which forms a cheap solution and a quick method of running the pump.

Conclusion

The main challenge was to build a modern agricultural system that focuses on detection and removal of pests and fungal activities, eliminating the use of chemical pesticides, and reducing crop losses. The solution uses a feedback system in a soilless farming medium. It uses motion, moisture, and thermistor sensors connected with Arduino that manages these inputs and respond by running the water pump. The solution successfully meets the design requirements for conserving more than 50% of water, fast detection of less than 5 seconds, neem oil efficiency of more than 80% and accurate detection of more than 80% of fungal growth conditions (moisture). The project is believed to be an efficient solution for solving pests and fungi challenges in Egypt.

Recommendations

Large Scale

For the large-scale implementation, traditional farming methods with peat moss and perlite will be used, and adjacent rows of lettuce crops will be organized with a distance of 0.3 meters between each crop in the same row and each adjacent row. The pesticide distribution system will be similar to sprinkler irrigation systems, with the source container for the system being the mixing tank for the automated neem oil preparation. Rain Bird PRS-DIAL Pressure Regulator sprinkler, shown in figure 21, will be set to cover a circular area with a radius of 1 meter, with sprinklers arranged 2 meters apart, as illustrated in figure 20. This system provides adjustable pressure settings and controls the variable flow rate. It requires 120-volt AC centrifugal pump to provide higher flow rates. Moreover, Hikvision DS-2TD2636B-15/P thermal camera sensors will be installed above each sprinkler at a height of one meter, allowing for real-time monitoring of the crops and quick detection of any issues or presence of pests within the coverage area of each sensor. The data collected from these various sensors will be transmitted to a central control system through a wireless sensor network. Pests will be detected in real-time, which will trigger neem oil sprinklers only in the affected area covered by the detected pest. The spacing between lettuce crops, as well as the arrangement of sprinklers and thermal camera sensors, has been carefully planned to optimize the efficiency of the pest detection and control system in the large-scale implementation.

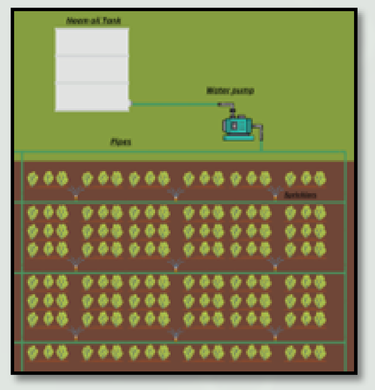


Figure 20: 2d sketch for the large scale.


Figure 21: the Rain Bird PRS-DIAL Pressure Regulator.

Automated neem oil preparation

Creating an automated system to prepare a diluted solution of neem oil of percentage 0.3% can ease removal pests. The system requires a tank, agitator, dosing pump, and process pattern for cleaning the tank. First, the large mixing tank relies on an agitator to ensure that the ingredients are well mixed. Second, the neem oil container shall be made of high-density polyethylene (HDPE). As, HDPE tanks are lightweight, durable, and resistant to corrosion and chemicals, making them cost-effective. Then, it relies on the dosing pump like Watson-Marlow 520DuN/RL peristaltic pump as shown in figure 22, which offers high accuracy and adjustable flow rate. Finally, cleaning the mixing tank is a process pattern that shall be set up in the control system. The frequency of cleaning can be set to every 2 weeks.


Figure 22: the Watson-Marlow 520DuN/RL peristaltic pump.

Hikvision DS-2TD2636B-15/P Thermal Camera sensor

The Hikvision DS-2TD2636B-15/P, as shown in figure 23, is a high-performance thermal camera sensor that offers a high temperature sensitivity of 40 mK, so it can detect small temperature differences with high accuracy. Moreover, the camera can advance their image-processing capabilities, including video analytics for advanced motion detection. Compared to the PIR sensor, the Hikvision DS-2TD2636B-15/P offers a higher ability to detect pests based on thermal signatures rather than just motion. It couldn't be implemented in the prototype due to its high cost and scarcity in Egypt. Nevertheless, for future implementations, the Hikvision DS-2TD2636B-15/P could be considered as an option for its advanced


Figure 23: Hikvision DS-2TD2636B-15/P Thermal Camera sensor

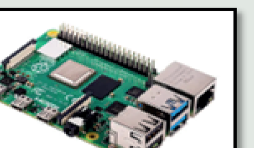


Figure 24: the Raspberry Pi 4.

The Raspberry Pi 4

Finally, The Raspberry Pi 4, shown in figure 24, is a powerful single-board computer with features such as higher processing power, larger memory capacity, built-in networking capabilities, and the ability to run a full-fledged operating system. These features make it suitable for controlling complex systems, handling multiple tasks simultaneously, storing and processing large amounts of data, and easy communication and integration with other devices in the system. However, it was not implemented in the prototype because the simple tasks could be handled by the Arduino board, which was more than enough for the scale of the project.

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