

Autonomous Smart Device for Managing Irrigation, Fertilization, Diagnosis, and Treatment of Plants in Urban Agriculture

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Abstract

In Senegal, given the limitations in terms of precision, speed, and mandatory presence requirements associated with traditional farming methods, digital technology plays a remarkable role in the rigorous execution of important tasks. This document presents the development and various tests carried out on a prototype. This device incorporates a combination of electrical, electronic, hydraulic, and computer resources. In addition, artificial intelligence (AI) based on machine learning is used to make certain tasks, such as monitoring, treatment, and, above all, plant diagnosis, more accessible, less complex, and more accurate. Here, automatic irrigation is based on soil moisture and the visual symptoms presented by the plant. Fertilization is based on the recommended periods according to the crop and the results of the diagnosis. In other words, if a nutritional deficiency is noted, intelligent and autonomous fertilization is carried out. The treatment of the plant against attacks is essentially based on the results of the diagnosis made by artificial intelligence. The model developed was obtained after training more than 14,000 tomato images (from the public data platform Kaggle, more specifically from Plantvillage) on AWS Rekognition. Our robotization solution can identify and treat various common tomato diseases, chosen as a test crop, such as tomato blight, bacterial spot, septoria leaf spot, and nutritional deficiencies. The results obtained during testing demonstrate that this intelligent platform for experimentation in teaching and research, and for use in urban market gardening, is a significant contribution of digital technology to agronomy. Indeed, with collaboration between agronomy and technology teams, this contribution is a valuable laboratory tool for applied research. Furthermore, local market gardening in urban areas, with its

ecological challenges, is in line with sustainable development.

Keywords

Digital Technology and Agriculture, Artificial Intelligence (AI), IFDT (Irrigation, Fertilization, Diagnosis and Treatment) Smart Plant Device, Urban Market Gardening

1. Introduction

According to forecasts, Africa's population is expected to grow significantly, reaching approximately 2.489 billion by 2050 [1]. In Senegal, the latest ANSD census reported that "The resident population of the country, as recorded in 2023, is 18,032,473. It stood at 13,508,715 inhabitants in 2013, representing an average annual intercensal growth rate of 2.9%, which remained constant between the two periods." The department of Thiès has become the third most populous locality in Senegal, with a total of 880,266 inhabitants [2]. This population growth will inevitably have an impact on food needs. In the coming decades, Senegal will face significant challenges in ensuring food security and improving the incomes of its rapidly expanding and urbanizing population. This will involve not only producing more despite the threat posed by climate change to yields and their regularity, but also producing better (in terms of quality and product diversity) while preserving the environment [3]. In the years to come, digital technologies will become indispensable for making agri-food systems more sustainable and inclusive, and thus for transforming societies [4]. Much research, development, and technological innovation have been carried out in recent years in this field [3]-[12].

Despite the many innovations that have emerged in agriculture around the world, most of our farmers in Senegal, for various reasons, including accessibility, remain attached to old practices that have already shown their limitations. This has the following consequences:

- Affected yields;
- Dependence on rainfall;
- Poor water management in irrigation;
- Inaccurate irrigation and fertilization;
- Young people's lack of interest in agriculture;
- The difficulty for enthusiasts to practice agriculture;
- The arduous nature of the tasks assigned to farm technicians;
- The difficulty of managing attacks of various kinds;
- Difficulty in managing prevention.

When performing their tasks of "irrigation and water management" and "crop maintenance and monitoring," vegetable growers and even agricultural technicians carry out, among other things:

- Frequent manual watering;

- Irrigation system management;
- Reasonable water management;
- Chemical or manual weeding;
- Pesticide treatments using chemical or organic products;
- Supplementary fertilization with the use, as needed, of foliar fertilizers, urea, or NPK.

These activities, which are arduous and dangerous and require human presence on site, often affect the health and safety of those working in this sector.

Locally, in the fields of teaching and experimental research in agronomy, the lack of equipment incorporating technological innovations is striking and makes laboratory research difficult.

To remedy this situation, which is detrimental to both local agricultural development and experimentation, the use of digital technology in agriculture in our country is now becoming a necessity. It is in this context that we propose this device, IFDT (Irrigation, Fertilization, Diagnosis and Treatment), which can be used for market gardening in urban areas and in applied agronomy research laboratories. This system combines mechatronics and artificial intelligence (AI). It allows for precise management of plant irrigation based on humidity and visible symptoms. Fertilization depends on the needs and results of the AI diagnosis. Automatic plant treatment is carried out after the data obtained with the AI has been acquired and analyzed.

2. Common Practices in Local Market Gardening

Agricultural practices in vegetable production have evolved considerably with the advent of new techniques. However, some of these techniques, even those that are harmful, are still used by local producers.

Different agricultural practices have repercussions on the environment and human health. For example, the intensive use of chemical fertilizers and pesticides has altered environmental conditions through various forms of pollution (water, soil, and air). These practices expose workers and even the local population to health risks, which manifest themselves in the high prevalence of waterborne, respiratory, and skin diseases [13].



Figure 1. Common practices for watering and treating against attacks.

The effective application of artificial intelligence (AI) during the pandemic has demonstrated its remarkable usefulness in various fields. In the same way as in

health and prevention [14] [15]. AI can also, with current and evolving technological advances, revolutionise agricultural practices, especially urban agriculture. **Figure 1** shows some common local market gardening practices.

3. Materials and Methods

A functional breakdown of the IFDT system reveals the essential sub-assemblies that comprise it. The computer enables the processing, analysis, and management of data from the camera and the Arduino UNO board, which acts as an acquisition card (**Figure 2**).

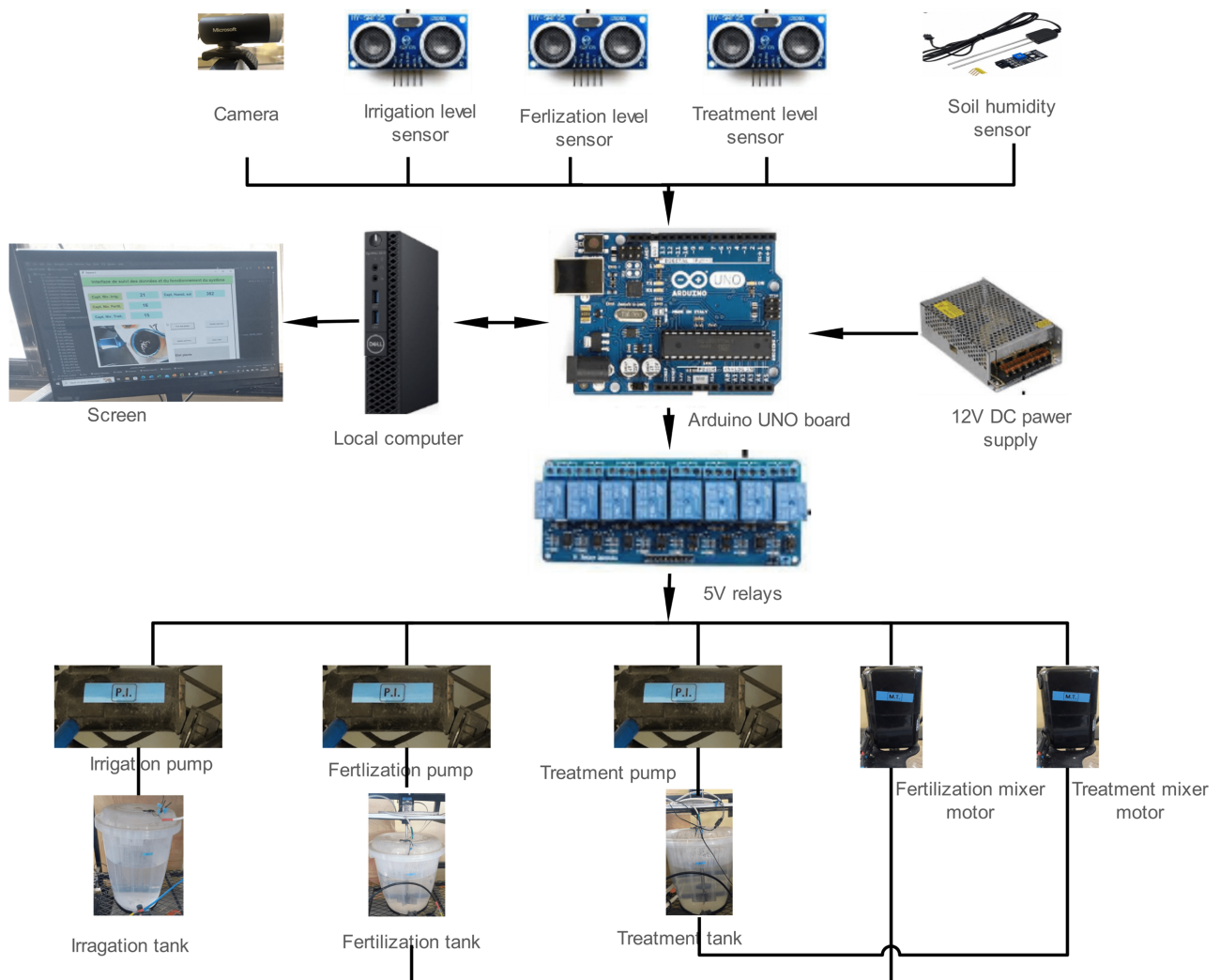


Figure 2. General structure of the IFDT system.

3.1. Computer

It represents the brain of the system, and its essential role is to interpret the information received and then give commands to the actuators so that the expected tasks are effectively carried out. These tasks are performed according to a computer program designed on the basis of an algorithm.

The computer, based on the algorithm implemented, precisely controls the operation of the various actuators. It also collects real-time data sent by the tank level sensors, humidity sensor, and camera.

With regard to the use of artificial intelligence, it is thanks to the connected computer that the data captured by the camera reaches the AWS Cloud. Prior training on Amazon Rekognition (an image and video analysis service offered by AWS, based on deep learning models, particularly convolutional neural networks (CNN)) enables effective diagnosis and provides a status report on the plant. The data is then processed and analyzed to autonomously trigger appropriate actions or to assist the user in decision-making. It also communicates with an interface that allows the operator, on-site or elsewhere, to view the information when needed.

The choice of AWS Rekognition is justified by:

- It is easy to use even for someone who is not an AI specialist;
- The free first year;
- Relatively affordable pricing;
- The speed and reliability of the results.

3.2. Arduino Uno Board

Combined with a CZH-LABS box that makes it easy to connect conductors securely, the Arduino board acts solely as a data acquisition board. This data comes mainly from the tank level sensors (irrigation, fertilization, and treatment) and the humidity sensor. It also allows the computer to control the actuators, depending on the scenario. In this project, these actuators consist of a pump for irrigation, a pump for fertilization, a pump for treatment, a motor for the fertilizer mixer, and a motor for the treatment mixer.

3.3. Screen

This human-machine interface (HMI) displays information from the camera and acquisition card. The user can therefore see the status of the system and the data generated during task execution in real time. This communication between the system and the operator, visible on the screen, is made easy and straightforward thanks to a graphical interface developed in Python with the PyCharm IDE.

3.4. Relay

As electrical pre-actuators, these components enable the power circuit of the actuators to be established or broken. It should be noted that the Arduino board only delivers a direct current (DC) voltage of up to 5 V to its outputs. The reason for using this equipment is therefore clear. In this project, the actuators consist of three (3) pumps and two (2) motors that operate at 12 V DC and 220 V AC, respectively. This difference in voltage between the board outputs and the actuator power supplies sufficiently justifies the use of these relays.

We use five (5) here:

- Three (3) on the 12 V DC circuit to power the pumps (irrigation, fertilization, and treatment);

- Two on the 220 V AC circuit to power the mixer motors (fertilization mixer and treatment mixer).

3.5. 12 V DC Power Supply

A continuous power source is required for the pumps to operate. They consume a continuous voltage of 12 V. Hence, the importance of having a DC power source. In reality, the component used is a rectifier. It converts the 220 V AC received into a continuous voltage of 12 V. This voltage is used to power the pumps. It also allows us to power the Arduino UNO board as soon as the system starts up.

3.6. AC Electric Motors/Mixers

Their main role is to drive the rotation of the mixers located in the fertilization station tank and in the plant treatment station tank. When the products in these tanks remain stationary for a relatively long period of time, settling can occur. This phenomenon, which is harmful to the pumps, can also alter the quality of the products, rendering them ineffective. This is why a mixer is provided. It consists of a motor, a shaft, and a propeller to restore a certain degree of homogeneity before each pumping.

The corrosive power of the mixtures of water and products used has influenced the choice of materials. As a result, the shafts (rods) are made of stainless steel, the propellers are made of galvanized steel, and the assembly screws are made of stainless steel. This prevents rapid corrosion of these components, which are permanently immersed in the liquid product. The characteristics of the motors used for the mixers are given in **Table 1**.

Table 1. Characteristics of mixer motors.

Type	U_N (V)	I_N (A)	P_N (W)
Ewing Machine Motor	220	0.5	100

3.7. 25-Liter Containers

One (1) 25-liter bucket is used at each station. One at the irrigation station, one at the fertilization station, and one at the treatment/protection station serve as reservoirs. They are used to receive and store water, fertilizers, and treatment products. To observe the correspondence between the quantity of water or product pumped and the level, transparent buckets graduated from 1 to 25 in increments of 2 starting at 1 liter are used. The desired lightness and aesthetics also motivated the choice of plastic as the material. They are closed by lids that also serve as supports for the level sensors. The lids of the fertilization and treatment tanks are pierced at the top to allow the mixer shafts to pass through.

3.8. Pumps

They are mounted directly on the bottom of the tanks to facilitate priming. They enable plants to be watered or fertilizers and treatment/protection products to be

dispensed in precise quantities. With remarkable efficiency, a very small footprint, guaranteed watertightness, and ease of installation, this component plays a crucial role in the overall functioning of the system. **Table 2** shows the characteristics of the type of pump used.

Table 2. Pump specifications.

Type	U_N (V)	I_N (A)
MES SWISS 6AA	12	1.8

3.9. Ultrasonic Sensors

This sensor is an HC SR04 type and has a DC supply voltage between 3.3 and 5V with an operating current of 15 mA. We use three (3) of them, placing one at each station. Mounted on the tank covers, they allow us to monitor changes in water levels for the irrigation station and product levels for the fertilization and treatment stations. They then send the information to the data acquisition card, from which communication with the main computer is established. The data is then displayed on a screen. Equipped with a 40 kHz transmitter, this ultrasonic sensor has a range of between two (2) and four hundred (400) centimeters (cm). This type of sensor is very easy to use and inexpensive (less than €4), making it accessible to those with limited means. However, experience shows that prolonged exposure to excessively humid environments shortens its lifespan. It is therefore important for maintenance reasons to take this potential failure factor into account.

3.10. Camera

The camera used is a Microsoft webcam with a power supply voltage of 1.5V DC, USB connections, 1GB RAM, and a 2.7-inch/5MP screen. It is used to take photos of the plant. The images taken are first stored on the computer and then sent to the Amazon cloud (AWS) for processing. Depending on the speculation in question, the training already carried out makes it possible to verify the conformity of the image with the following possibilities:

- Normal plant;
- Plant lacking water;
- Plant suffocating (intumescent);
- Diseased plant;
- Plants with nutritional deficiencies.

3.11. Soil Moisture Sensor

The soil moisture sensor used here is type HD-38 V2. (Capacitive, analog, and corrosion resistant). Its supply voltage is 5V DC. Connected to the Arduino board via an analog pin, this sensor allows us, when in contact with the soil, to obtain values ranging from 0 to 1023 that are inversely proportional to moisture. In other words, the higher the values obtained, the lower the moisture or the drier the environment. In this case, communication with the acquisition board also allows the

computer to analyze and interpret the data received in order to guide the next steps. Consequently, irrigation depends on the humidity set in the algorithm, as the value recorded by the sensor is immediately compared to it. The decision to start or stop the irrigation pump is then made. This type of application promotes better water management and does not require human presence during watering.

3.12. Pots

These are plastic pots with holes in the bottom, specially designed for market gardening. They are conical in shape, with a capacity of four liters (4 l), a depth of twenty centimeters (20 cm), and an internal diameter of eighteen centimeters (18 cm). Their main purpose is to hold and store the type of soil used, but they also serve as supports for irrigation, fertilization, and treatment pipes. The first pot must hold the reference plant, while the second must hold the plant being tested in the system. A filter is placed at the bottom to retain solid impurities. As a result, after the soil is saturated, the water not consumed by the plant or the soil is collected in a basin. This makes it possible, for a certain period of time, to compare the quantities poured and the quantities actually consumed.

3.13. Vases

There are two (2) of these vases, which are made of plastic. They are transparent so that you can see the amount of water or other products coming from the pots after watering or other actions. In addition to this role, they provide real support for the vegetable pots. We have made a circular opening in the lid with a diameter slightly smaller than the largest diameter of the cone formed by the pot. This ensures that the pot fits snugly and stably in the vase. Its easy opening makes it very accessible when cleaning or other tasks need to be carried out.

3.14. Check Valves and Three (3) 8 mm Diameter Pipes

The suction of the pumps under load promotes priming. This can result in liquid passing to the discharge side, creating a slight flow in the pipes. This phenomenon, which increases over time, can reach the plant and alter the accuracy of the data acquired and the normal development of the subject. This is why we have used a non-return valve (**Figure 3**) for each station. The resistance imposed by the valve prevents flow until the pump starts. At the outlet of the valves, we connected a



Figure 3. 8 mm diameter check valve.

pipe with a diameter of eight (8 mm) and a length of three meters (3 m) for each station to convey the water and other products to their destination, the plant. The choice of three (3) different pipes can be explained by a desire to separate the three substances in order to avoid any mixing. This also allows the other stations to continue operating in the event of a failure in one of the pipes or stations.

3.15. Metal Support

This is the part of the system that houses all the other components. The steel structure, in the form of a table measuring 1500 mm long, 50 mm wide, and 85 mm high (without casters), is divided into three (3) compartments:

- Irrigation station;
- Fertilization station;
- Treatment/protection station.

On the metal mesh base, a flat steel bend is made on each station to stabilize the tanks. Just above the irrigation station, we have set up a section on which electrical and electronic components are attached. Two L-shaped brackets support the pine board on which these components are attached. Above the fertilization and treatment stations, we have mounted two flat steel bars in parallel to position and hold the mixer motors in place. To ensure that these motors can be easily maintained, we have made the second bar in two (2) juxtaposed and removable pieces. This makes it easier to remove them for preventive or corrective maintenance. On the fixed bar, we have mounted a channel for the passage of certain conductors. The upper part of the table is covered by an aluminum panel. We made a groove in it to house the mini-computer mounted above. To make it easier to move, our device is mounted on four (4) casters with brakes. A cylindrical rod in the shape of a gallows with a sliding pivot connection serves as a support for the camera. **Figure 4** shows the different parts of the metal support.



Figure 4. Metal structure of the IFDT bench.

4. Results and Discussion

The system designed and built can be divided into four (4) main parts: a central computer, an electronic circuit (**Figure 5**), an electrical circuit, and a hydraulic circuit. Using a Python program, the central computer manages information from level sensors (irrigation, fertilization, treatment), the graphical interface, and the camera for artificial intelligence. It communicates with the AWS cloud following

training already carried out to provide information on the condition of the plant. It also gives the main actuators (PRI, PRF, PRT, MRF, and MRT) commands in accordance with expected operations. **Table 3** contains the addresses of the inputs and outputs used on the Arduino board.

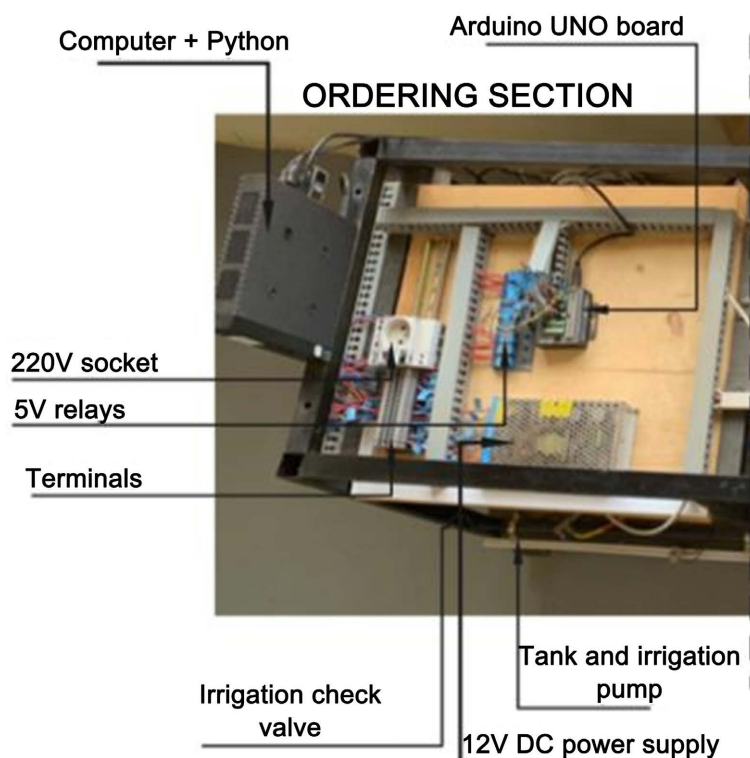


Figure 5. Control unit (electronic) of the IFDT system.

Table 3. Addressing inputs and outputs on the acquisition board (Arduino UNO).

N°	Designation	Code	Terminals	Address
1	Tank level sensor—irrigation	Trig. I	Trig.	Pin 3
		Echo. I	Echo.	Pin 4
2	Tank level sensor—fertilization	Trig. F	Trig.	Pin 7
		Echo. F	Echo.	Pin 8
3	Tank level sensor—treatment	Trig. T	Trig.	Pin 12
		Echo. T	Echo.	Pin 9
4	Moisture sensor	In_CH	In	Pin 13
		A0_CH	A0	A0
5	Treatment pump relay	R_P.T	In 1	Pin 10
6	Fertilization pump relay	R_P.F	In 2	Pin 11
7	Irrigation pump relay	R_P.I	In 3	Pin 2
8	Fertilization mixer motor	R_M.F	In 8	Pin 5
9	Mixing-processing motor	R_M.T	In 7	Pin 6

4.1. Pump Testing

▪ Influence of level on flow rate

For this experiment, three levels are considered: a low level, when the amount of liquid in the tank is equal to three liters (3 l); a medium level, when the amount of liquid in the tank is equal to thirteen liters (13 l); and a high level, when the amount of liquid is equal to twenty-three liters (23 l).

For a more accurate study, we took several values for the volumes to be filled, recorded the filling time for each quantity, and deduced the corresponding flow rates. This data was then used to plot curves for analysis. **Tables 4-6** provide information on the data obtained, considering the low level, the median, and then the high level.

Depending on the level, we obtained the following data and curves:

– At a low level (3 l)

An analysis of the following three curves (**Figures 6-8**) shows instability in the pump flow rate up to a volume of approximately 400 ml, regardless of the level. Clearly, the pump generates a stable, almost constant flow rate above 400 ml.

Table 4. Low-level quantities, time, and flow rates.

Quantity (ml)	Time (s)	Flow rate (ml/s)
100	1.19	84.034
200	2.89	69.204
300	4.85	61.856
400	6.1	65.574
500	7.61	65.703
1000	14.95	66.890

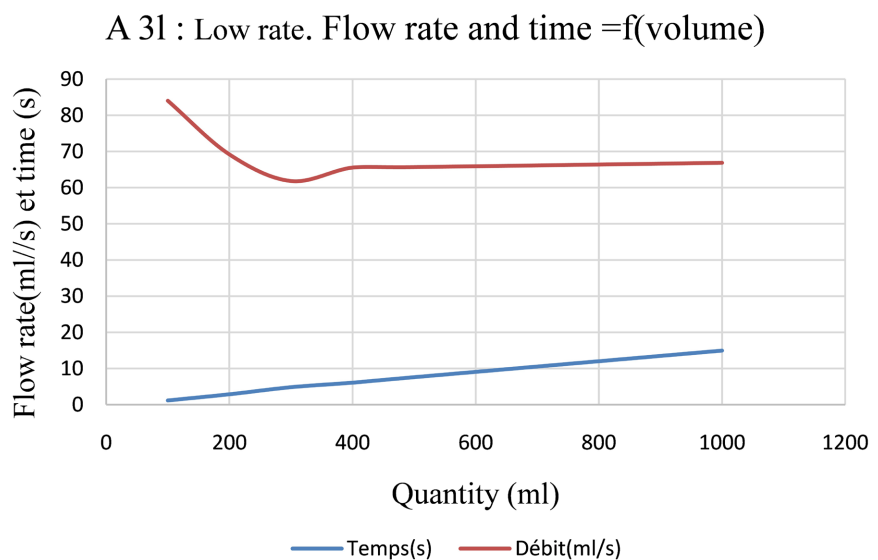


Figure 6. Flow rate and time = f (volume), at the low level.

Furthermore, we note that in addition to the instability of the flow rate for vol-

umes below 400 ml, the time corresponding to this quantity (400 ml) decreases as the level increases. We can therefore say that a drop in the liquid level has a negative effect on the flow time.

Given this, it is important to monitor the water and liquid levels in this system to avoid unwanted operation. This also influences the choice of a pot that can hold, in addition to the soil, at least 400 ml of liquid.

– **At the median level (13 l)**

Table 5. Quantities, time, and flow rates at the median level.

Quantity (ml)	Time (s)	Flow rate (ml/s)
100	1.18	84.746
200	2.88	69.444
300	4.33	69.284
400	5.91	67.682
500	7.22	69.252
1000	14.88	67.204

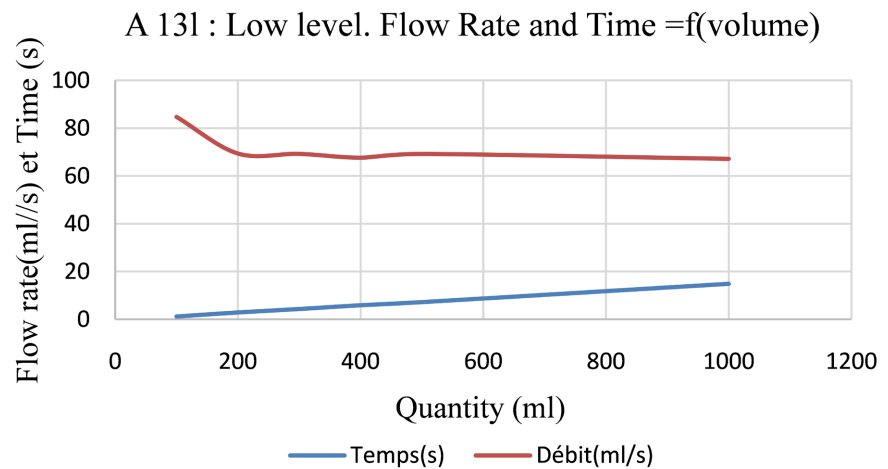


Figure 7. Flow rate and time = f (volume), at the median level.

– **At a high level (23 l)**

Table 6. High-level quantities, time, and flow rates.

Quantity (ml)	Time (s)	Flow Rate (ml/s)
100	1.6	62.5
200	2.7	74.074
300	3.8	78.947
400	5.7	70.175
500	7.26	68.871
1000	14.28	70.028

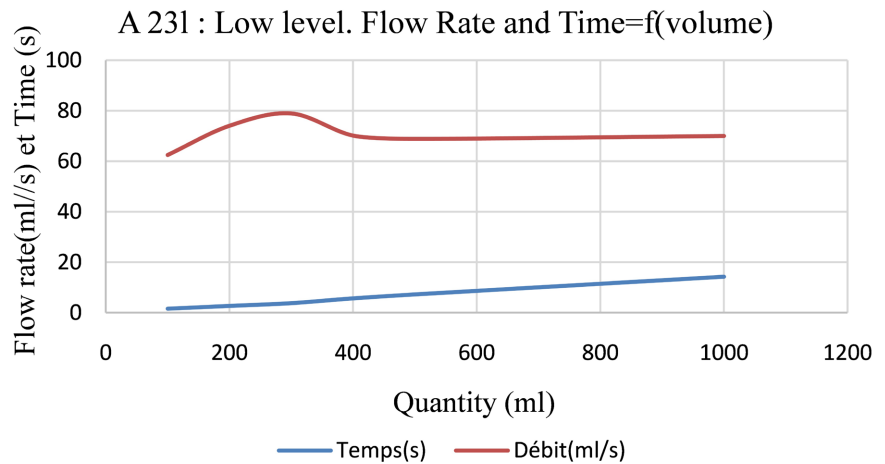


Figure 8. Flow rate and time = f (volume), at the high level.

- Influence of voltage on flow rate
- At low level (3 l) with U = 11 V and I = 1.8 A

Table 7. Quantities, time, and flow rates at the low level, at U = 11 V.

Quantity (ml)	Time (s)	Flow Rate (ml/s)
100	1.59	62.893 082
200	3.42	58.479 532
300	5.26	57.034 221
400	6.96	57.471 264
500	9.26	53.995 68
1000	17.17	58.241 118

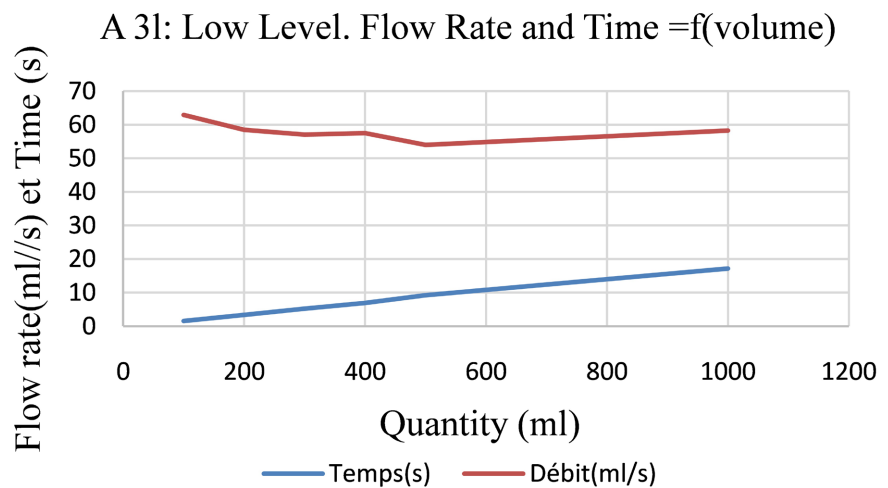


Figure 9. Flow rate and time = f (volume) at the low level, at U = 11 V.

To study the influence of voltage on pump behavior, we varied it to 11 V, 10 V, and 9 V, considering the worst-case scenario (low voltage). The data obtained are

contained in **Tables 7-9**. This allowed us to obtain the results shown in the following three (3) curves (**Figures 9-11**). Analyzing these curves, we see that the time taken to reach 400 ml increases from 6.1 seconds to 6.96 seconds for a voltage of 11 V. For voltages of 10 V and 9 V, the time taken is 7.61 seconds and 8.73 seconds, respectively. Clearly, the decrease in the pump's supply voltage results in an increase in the time taken to reach the 400 ml volume, at which point the flow rate begins to stabilize. We also note that the flow rate drops from 65.574 l/min to 45.819 l/min when the voltage drops to 9 V. We can therefore say that the flow rate is affected by the drop in voltage. It is therefore important to have a stable power supply.

– **At low level (3 l) with U = 10 V and I = 1.5 A**

Table 8. Quantities, time, and flow rates at the low level, at U = 10 V.

Quantity (ml)	Time (s)	Flow Rate (ml/s)
100	1.58	63.291 139
200	3.84	52.083 333
300	5.67	52.910 053
400	7.61	52.562 418
500	9.7	51.546 392
1000	19.82	50.454 087

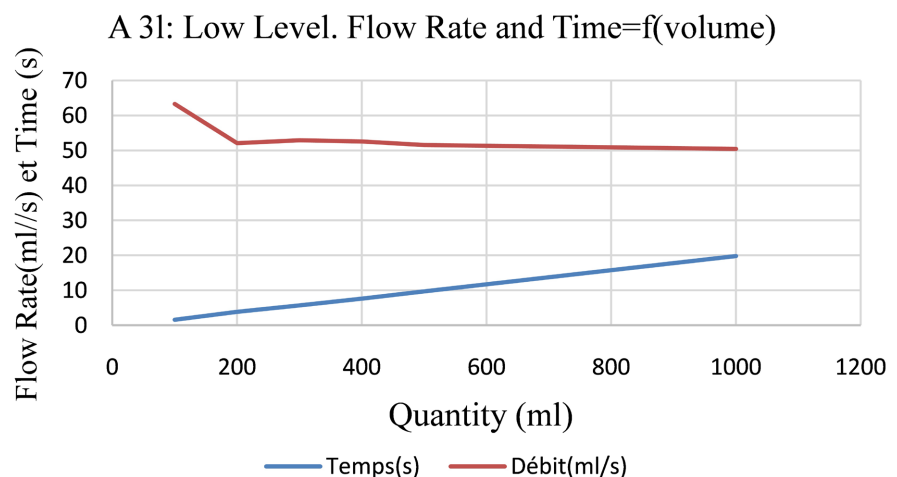


Figure 10. Flow rate and time = f (volume) at the low level, at U = 10 V.

– **At low level (3 l) with U = 9 V and I = 1.34 A**

Table 9. Low-level quantities, times, and flow rates at U = 9 V.

Quantity (ml)	Time (s)	Flow Rate (ml/s)
100	1.98	50.505 051
200	4.29	46.620 047

Continued

300	6.43	46.656 299
400	8.73	45.819 015
500	10.97	45.578 851
1000	22.29	44.863 167

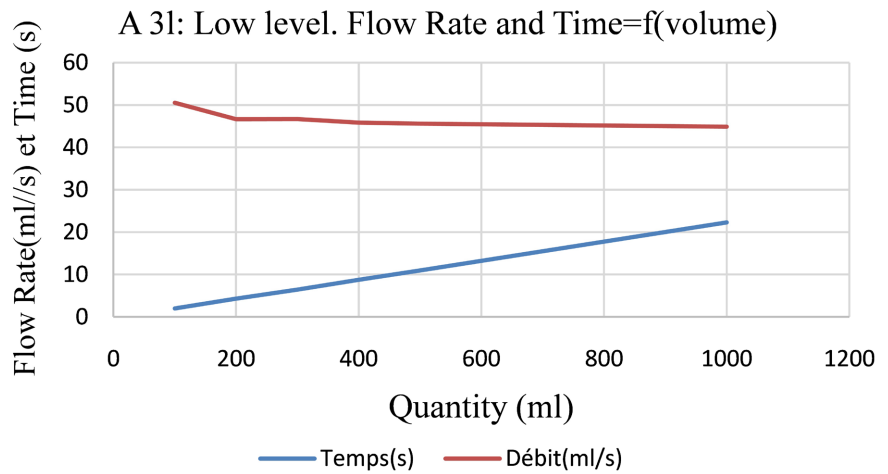


Figure 11. Flow rate and time = f (volume) at the low level, at U = 9 V.

4.2. Level Sensor Test (HC-SR04 Ultrasonic Sensor)

The analysis of the data obtained (contained in Table 10) and the corresponding curve (Figure 12) highlight the non-linearity of this function volume = f (height). We can find the explanation in the conical shape of the chosen tank. Despite this observed phenomenon, we still note that the variation in level is accurately reflected by the sensor. For comparison, we have shown the linear trend curve and the characteristic equation.

The level sensor test gave us the following results:

Table 10. Correspondence between height and reservoir level.

Height (cm)	Volume (l)
35	1
31	3
28	5
26	7
23	9
21	11
18	13
15	15
13	17
11	19

Continued

8	21
6	23
4	25

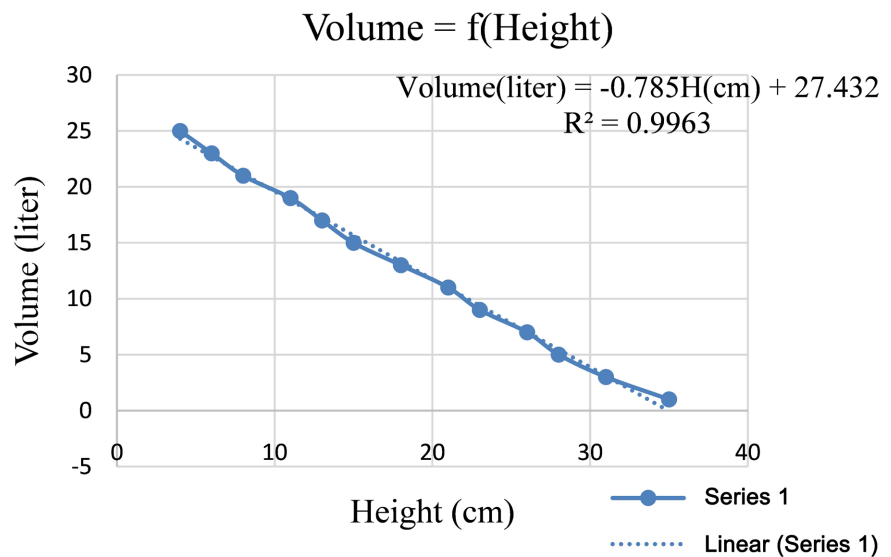


Figure 12. Volume based on measured height.

4.3. Humidity Sensor Test (HD-38 V2)

For comparison purposes, depending on the environment, tests on this sensor were carried out in the open air, in water, and in soil obtained by mixing sand and potting soil:

- Potting soil (1/3 of the mixture);
- Sand (2/3 of the mixture).

The following results were obtained from the experiment:

Maximum values obtained:

- In the open air 1023;
- In potting soil (1/3) mixed with dry sand (2/3) (not watered), 1016.

Minimum values obtained:

- In water, 529;
- In potting soil (1/3) mixed with sand (2/3), watered, 549 for a few minutes, then 547, 546, 542, 540.

Saturation value of potting soil_1: the first watering gave a saturation value of 547.

Saturation value of potting soil_2: 44 minutes after the first watering, a second watering gave a saturation value of 540.

Based on these findings, the type of soil used here in this test has a saturation value of 540 according to the sensor. This must therefore be taken into account for the overall operation of the system in order to ensure accuracy and good irrigation management.

4.4. Artificial Intelligence (AI) Testing

Figure 13 shows all the elements involved in the effective application of AI in the process of diagnosis, fertilization and treatment of plants.

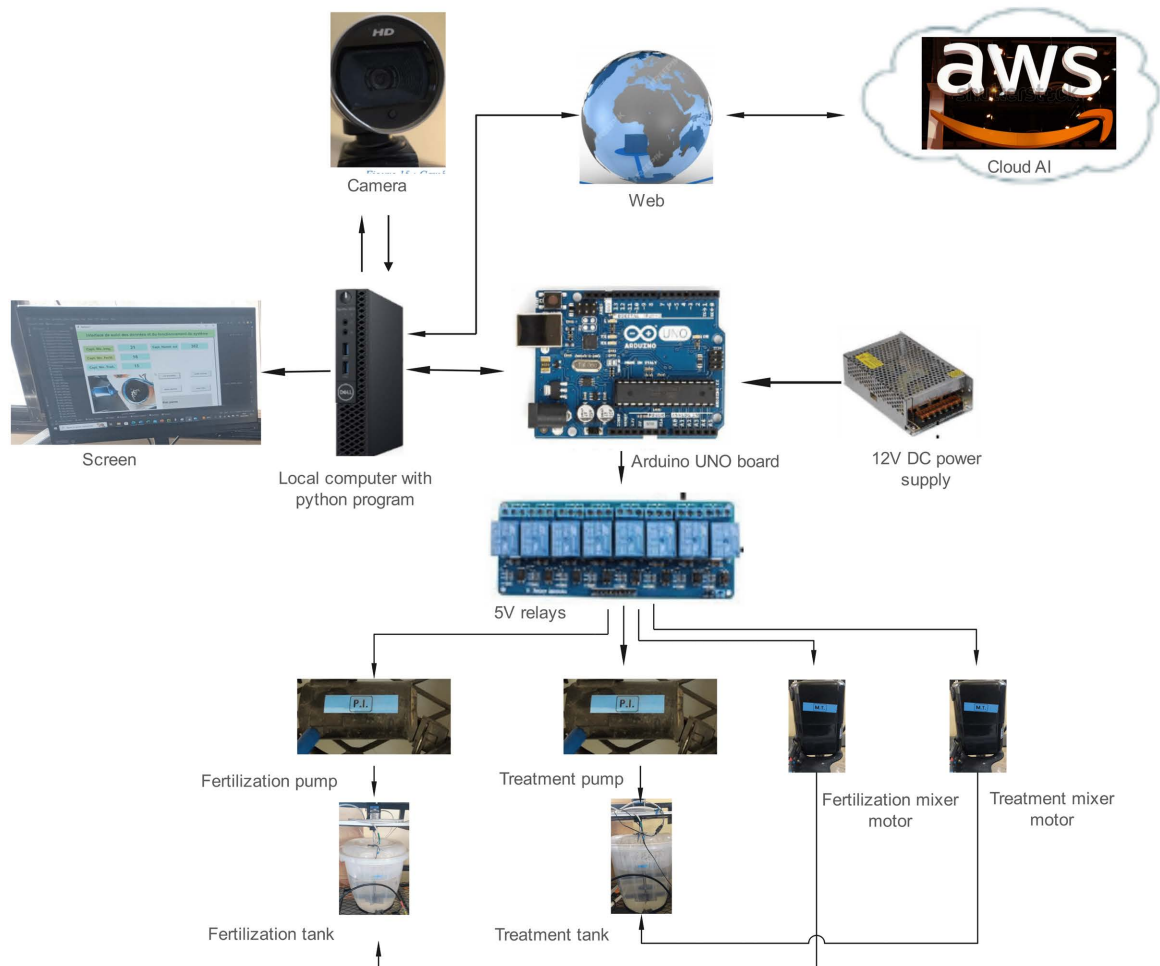


Figure 13. Using artificial intelligence (AI) for DFT.

Figure 14 and **Figure 15** show the graphical interface that displays the values recorded by the sensors measuring the levels in the irrigation, fertilization, and treatment tanks. It also displays the value read by the soil moisture sensor. It also offers the option, if desired, to view the plant in real time, to stop viewing it, or even to examine it by performing a diagnosis to determine its condition. An area called “Name” is reserved for displaying the diagnosis result.

Figures 16-18 show the results obtained following the diagnoses made during the IFDT system test. They are applied to photos taken of a tomato plant from the CGEA (Conduct and Management of an Agricultural Operation) program at the LTP/FXN technical high school in Thies. **Figure 16** clearly shows a result corresponding to a “nutritional deficiency” with 100% accuracy. **Figure 17** and **Figure 18** show results corresponding to the tomato disease known as “tomato blight” with accuracies of 97.81% and 99.86%, respectively.

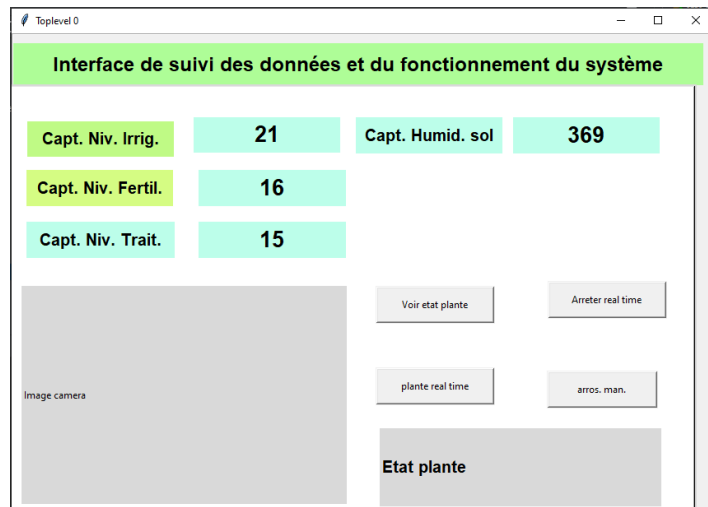


Figure 14. Graphical interface displaying tank levels and humidity in real time.

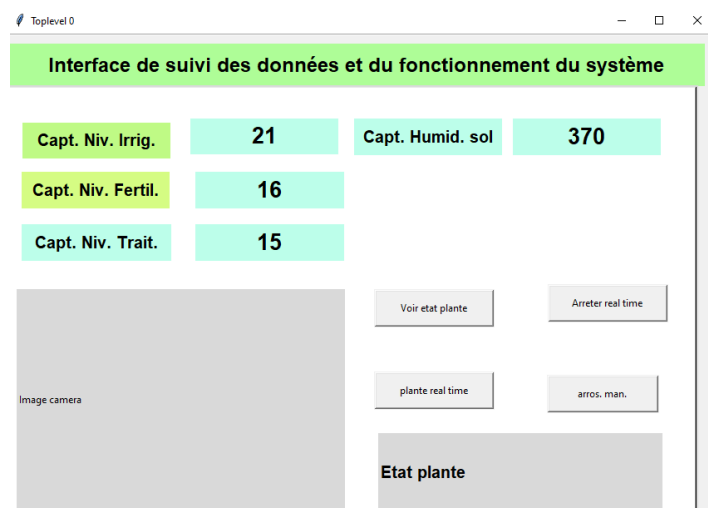


Figure 15. Graphical interface displaying tank levels and humidity variation in real time.



Figure 16. Result 1 of a diagnosis made on a photo of a tomato taken.



Figure 17. Result 2 of a diagnosis made on a photo of a tomato taken.



Figure 18. Result 3 of a diagnosis made on a photo of a tomato taken.

The result shown in Figure 19 corresponds to a “nutritional deficiency” with an accuracy of 99.80%. This analysis is applied directly to our test plant, five (5) days after transplanting.

In accordance with the expected results of this test phase, fertilization and treatment tasks were requested and effectively carried out based on the diagnostic results. In other words, according to the preparation made, when the result obtained is “nutritional deficiency,” the mixer (MF) at the fertilization station operates for a programmed time, at the end of which fertilization is carried out by fertigation using the PF pump for a specific period of time.

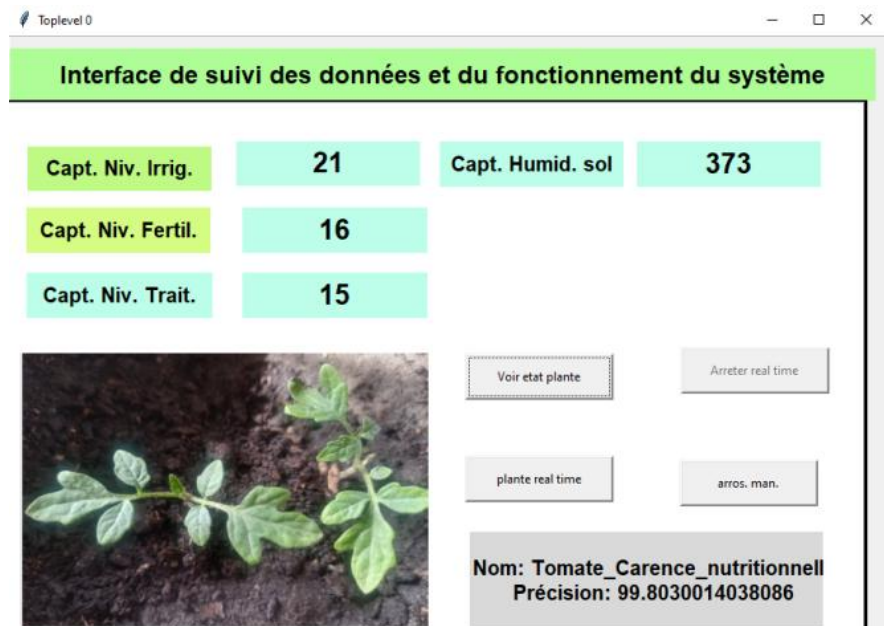


Figure 19. Result 3 of a diagnosis performed on tomato plants in real time on the IFDT bench, five (5) days after transplanting.

Furthermore, if the plant disease identified by the IFDT system's artificial intelligence is "tomato blight," the mixer (MT) at the treatment station operates for a programmed period of time, at the end of which treatment is carried out using the PT pump for a specific duration, depending on the pre-recommended quantity.

Figure 20 shows an image of the IFDT device prototype that has been built and put into an experimental setting.

Figure 21 is a top view of the prototype and shows the different parts of the system with all its components.



Figure 20. Version 1 of the IFDT system prototype.

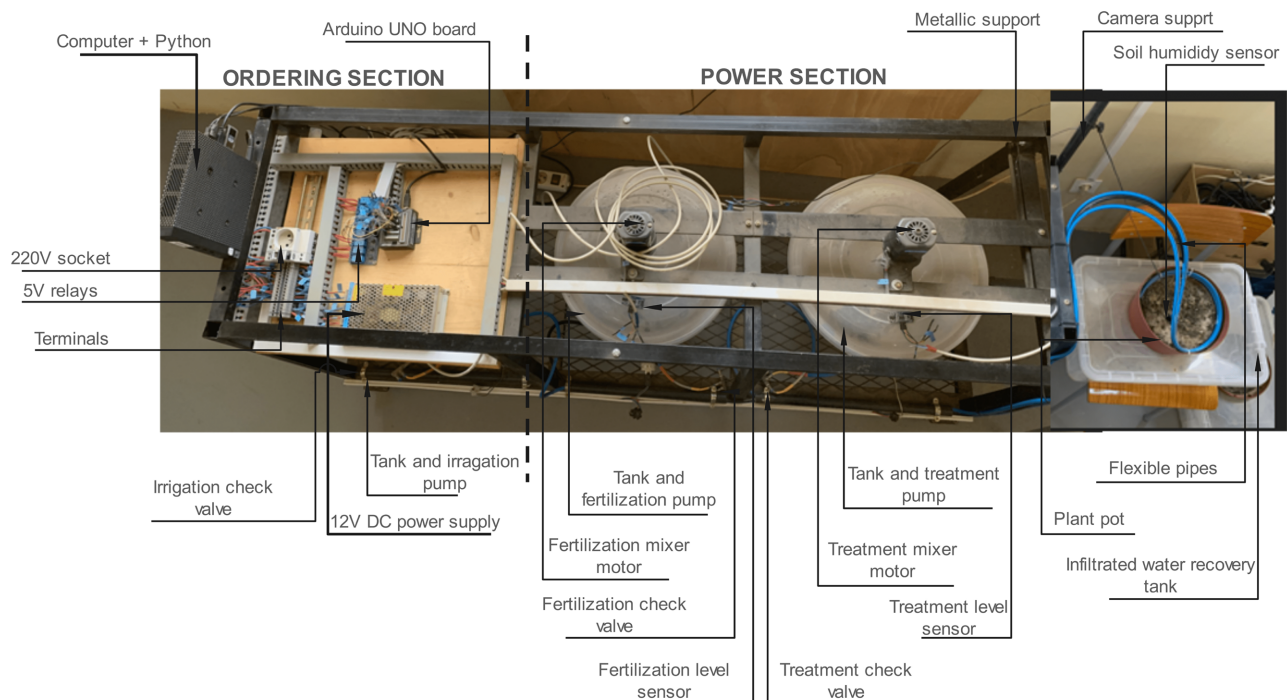


Figure 21. Top view of version 1 of the IFDT system prototype.

However, the IFDT prototype, like any work, has its limitations. It can only (at this time) be used indoors and where there is access to an electrical power source. If there is a potential need to work with a crop other than tomatoes (used here as a test crop), it is necessary to adjust the soil type and retrain to obtain a suitable AI model. The model used is not generalizable to all types of crops. Nevertheless, these limitations are still interesting because they can be exploited when the device is used as a teaching tool in experimental research.

5. Conclusions

The acquisition of reliable data, both in the field and in research laboratories, is essential for precision agriculture. Irrigation, fertilization, treatment, and even plant protection measures depend largely on the data collected and analyzed.

Our contribution is based on a solution that allows for the autonomous execution of actions related to irrigation, fertilization, diagnosis, treatment, and monitoring of the crop in question. It is also a tool for implementing technological innovations in educational practices and experimental research, particularly in agronomy.

- Furthermore, it can have a considerable positive impact on various aspects:
- The arduous nature of agricultural work;
- Public health;
- The health and safety of those involved;
- The environment;
- The economy;

- Loss of time;
- Attractiveness to young people.

In reality, it is a study and implementation of an intelligent, autonomous device for managing a plant throughout its life cycle. It is capable of diagnosing the condition of plants and taking action. In view of the results obtained by the work, this system, as a technological platform, is a major contribution to agronomy and experimental research in this field.

A combination of mechatronics and artificial intelligence has led to remarkable technological innovations that can improve the quality of our agriculture and help to bridge the technological gap observed in current agricultural practices.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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