LOW-COST PHENOTYPING PLATFORM TO ASSESS WATER STRESS IN PLANTS

PLATAFORMA DE FENOTIPAGEM DE BAIXO CUSTO PARA AVALIAR ESTRESSE HÍDRICO EM PLANTAS

PLATAFORMA DE FENOTIPADO DE BAJO COSTO PARA EVALUAR EL ESTRÉS HÍDRICO EN PLANTAS

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ABSTRACT
A phenotyping platform is a set of equipment, sensors, software, and methods used to measure plant characteristics (phenotypes) in a standardized, rapid, and often automated manner. It allows the quantification of traits such as plant height, leaf area, biomass, growth over time, water use and resistance to water stress, chlorophyll and pigment content, diseases and pests, productivity, and plant architecture, among others. The phenotyping platform transforms images and sensor-derived values into measured plant data for research, plant breeding, and precision agriculture. It can be used in the field or in a greenhouse. In the case of greenhouses, there are proprietary phenotyping platforms such as Lemnatec, Phenospex, WIWAM, FluorCam / PSI (Photon Systems Instruments), Qubit Systems, and others. These platforms are not available at reasonable prices, and therefore not every research institution has access to a phenotyping platform to accelerate phenotyping-related research. This study proposes viable, low-cost alternatives for selecting more productive and water-stress-resistant plant varieties using a simplified phenotyping platform focused on water stress under greenhouse conditions.

Keywords: Greenhouse. Phenotyping Platform. Images. Sensors.

RESUMO
Uma plataforma de fenotipagem é um conjunto de equipamentos, sensores, softwares e métodos usados para medir características das plantas (fenótipos) de forma padronizada, rápida e muitas vezes automatizada. Permite quantificar características como altura da planta, área foliar, biomassa, crescimento ao longo do tempo, uso de água e resistência ao estresse hídrico, conteúdo de clorofila e pigmentos, doenças e pragas, produtividade, arquitetura da planta, etc. A plataforma de fenotipagem transforma imagens e valores obtidos por sensores em dados medidos de plantas, para pesquisa, melhoramento genético e agricultura de precisão. Pode ser usada no campo ou casa de vegetação (estufa). Para o

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caso da casa de vegetação, existem plataformas de fenotipagens proprietárias como: Lemnatec, Phenospex, WIWAM, FluorCam / PSI (Photon Systems Instruments), Qubit Systems e outras. Essas plataformas não são acessíveis a preços razoáveis e assim nem toda instituição de pesquisa tem sua plataforma de fenotipagem para acelerar as pesquisas em termos de fenotipagem. Este trabalho propõe alternativas viáveis, com baixo custo, para fazer escolha de variedades de plantas mais produtivas e resistentes a estresse hídrico usando uma plataforma simplificada de fenotipagem voltada para estresse hídrico em casa de vegetação.

Palavras-chave: Casa de Vegetação. Plataforma de Fenotipagem. Imagens. Sensores.

RESUMEN

Una plataforma de fenotipado es un conjunto de equipos, sensores, softwares y métodos utilizados para medir características de las plantas (fenotipos) de manera estandarizada, rápida y, muchas veces, automatizada. Permite cuantificar características como altura de la planta, área foliar, biomasa, crecimiento a lo largo del tiempo, uso del agua y resistencia al estrés hídrico, contenido de clorofila y pigmentos, enfermedades y plagas, productividad, arquitectura de la planta, entre otras. La plataforma de fenotipado transforma imágenes y valores obtenidos por sensores en datos medidos de las plantas, para investigación, mejoramiento genético y agricultura de precisión. Puede utilizarse en campo o en invernadero. En el caso del invernadero, existen plataformas de fenotipado propietarias como Lemnatec, Phenospex, WIWAM, FluorCam / PSI (Photon Systems Instruments), Qubit Systems, entre otras. Estas plataformas no son accesibles a precios razonables y, por lo tanto, no todas las instituciones de investigación cuentan con una plataforma de fenotipado para acelerar las investigaciones en términos de fenotipado. Este trabajo propone alternativas viables y de bajo costo para la selección de variedades de plantas más productivas y resistentes al estrés hídrico, utilizando una plataforma simplificada de fenotipado enfocada en el estrés hídrico en invernadero.

Palabras clave: Invernadero. Plataforma de Fenotipado. Imágenes. Sensores.

1 INTRODUCTION

A research institution that seeks varieties (rice, beans, soybeans, etc.) that are more productive and resistant to lack of water, pests and diseases, needs to carry out several experiments to obtain a variety that is productive in a given region, also considering climate and soil. These experiments consume various resources, such as agricultural technicians working in the field, use of agricultural machinery, inputs, etc. In order for the number of experiments in the field to be optimized, with lower cost and execution time, it is possible to carry out experiments in a greenhouse, which is easier and requires much less resources. Thus, it is possible to select the best cultivars in the greenhouse and then test and validate in the field, and in this way the number of experiments in the field will be smaller, reducing costs and time to obtain the best possible cultivar.

On the market, there are several phenotyping platforms for use in greenhouses. However, it is necessary that the greenhouse is appropriate to contain the platform. If it is not, it will have to be refurbished or build one that is suitable for some phenotyping platform. The most well-known platforms are: Lemnatec (LEMNATEX, 2025), Phenodyn (PHENODYN, 2025), Phenospex (PHENOSPEX, 2025), Psi (PSI, 2025), Qubit (QUBIT, 2025) and Wiwam (WIWAM, 2025).

This work, considering rainfed rice, proposes two actions that may help to obtain varieties that are more resistant to water stress and also more productive. It can be done by sensors and thermal images (which exist in the aforementioned platforms, but at a high cost). Although this work is for rice, it can also be used for other grasses (wheat, corn, etc.), and also beans, soybeans, etc.

The first action is to measure the efficiency of water use (USA). How much water each plant uses to produce (liters of water / kg of rice) is the question. The lower the (US) and the more productive the plant, the better. For this, a computer system was developed that can measure the (USA), and that has a low construction cost, which will be described later in this text. The amount of water that each plant receives is programmed and thus it is possible to know what volume of water each plant had at its disposal and later it is possible to know how much water evaporated or was consumed in some way through a scale.

The second action is thermal image processing. A low-cost thermal camera takes thermal images of the plant, the top or canopy of each one, to check how the leaves of the plants vary in temperature, according to the water stress that is passing and ambient temperature. With these images, whose pixels contain temperature values, it is possible to know which plant (rice variety) is more sensitive to heat and which withstands heat well (high temperatures). The more resistant the plant is to high temperatures and the more productive, the better.

In these two actions, which can be for any plant, some of the functionalities of commercial phenotyping platforms can be obtained, but at a low cost. Other actions can be made for other functionalities considering simple circuits and leaner software.

The commercial platforms are of great quality, however, given the cost of acquisition and maintenance, and the fact that it is not always necessary to have all the functionalities to obtain the variables and results of interest, it is worth building "portions" of a phenotyping platform that can generate the necessary information for the evaluation of different varieties of a crop and thus know which varieties are best available to go to the field.

In this work, the hardware and software to measure (EUA) and obtain the way the temperature varies in the canopy of each plant will be described, and this way is of interest for study/research of plants more resistant to lack of water.

2 MATERIALS AND METHODS

The low-cost platform, for studies of the behavior of rice plants (or other grains such as beans, soybeans, etc.), under water stress, was installed in a greenhouse. At Embrapa Rice and Beans there are several greenhouses and one of those that were chosen for the execution of the system is illustrated below in Figure 1.

Figure 1

Greenhouse in which the proposed platform was developed

Inside this greenhouse, the varieties that are to be evaluated for water stress are arranged in different pots. For each pot there is a hose that irrigates the plant with water, as desired, with the variation of the amount to evaluate the plant's resistance to lack of water. Figure 2 illustrates how the pots are arranged inside the greenhouse.

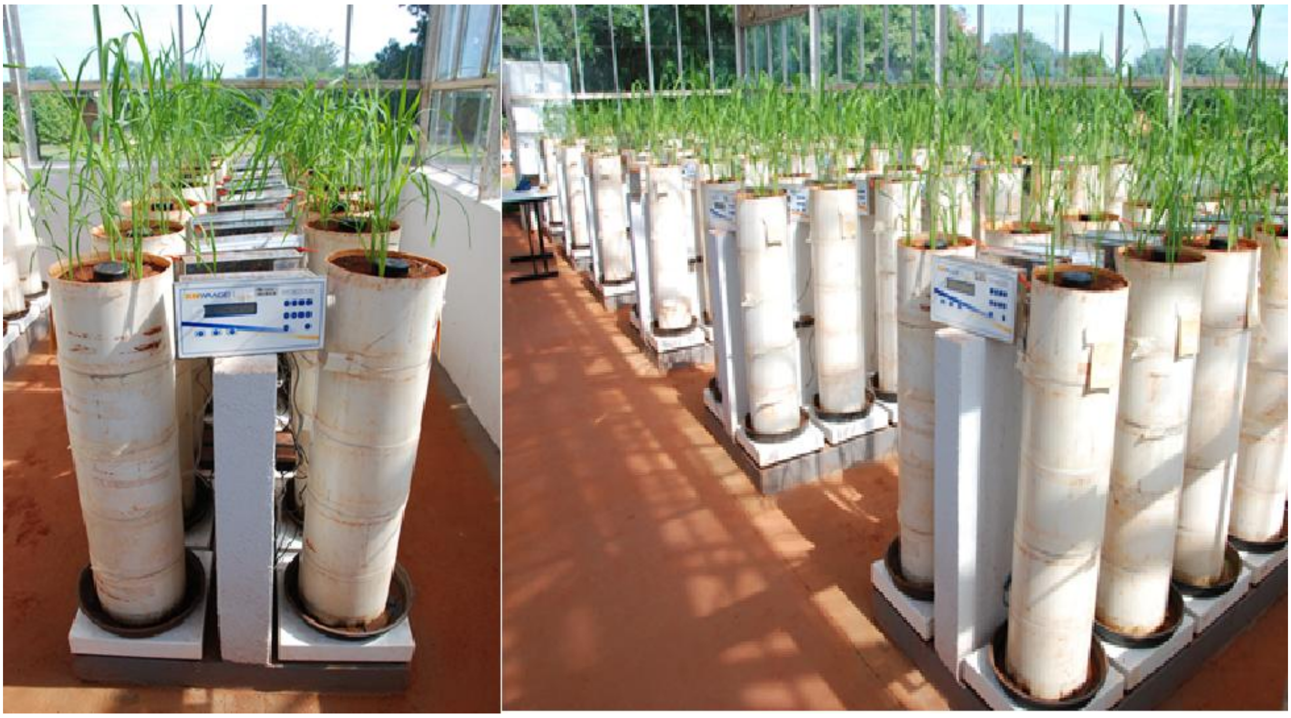
Figure 2

Pots with plants that are to be tested for the water test

Each vase is on a scale so that you know how much water evaporates and also how much water has entered the vase. In this way, you can know how much water the plant is retaining or spending. Figure 3 illustrates a series of pots, with rice plants, together with the scales, at the bottom of the pots, and the access interface with the scale, with a display of the weight values obtained and buttons for configuration. The scale has a metal box as its casing whose height is around 12 cm and the base and side have dimensions around 40 cm (40 x 40 x 12cm).

Figure 3

Pots with scales to measure water balance and results/configurations interface



Above was described the infrastructure of the greenhouse in which the phenotyping platform for experiments with water stress was developed. For the development of the proposed system, circuits and software were made for data acquisition from sensors and cameras. For the (UEA) part, the following modules or components were used:

- 1 ESP 32 Lora plate;
- 4 soil moisture sensors;
- 1 solenoid valve to control the water flow for each vessel;
- 1 x Air Humidity and Air Temperature Sensor (DHT 22)
- Electronic components for building circuits to obtain data from the scale and soil moisture sensors.

For the survey of thermal images and air temperature and humidity, the following were used:

- 1 raspberry pi 3 B+ board
- 1 low-cost thermal camera (Flir One/Lepton)
- 1 air temperature and humidity sensor (DHT 22).

The hardware and software, as well as the results, are described in the "Results" section below.

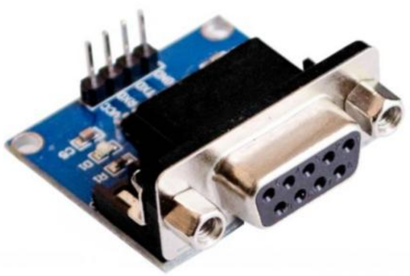
3 RESULTS

Embrapa Rice and Beans conducts various researches to improve rice and bean varieties in terms of increased productivity and tolerance to lack of water or scarcity. One of the processes for plant breeding is the evaluation of various varieties of rice and beans in a greenhouse, to select the best varieties before planting in the field for new experiments. In this way, this selection reduces the time to obtain the best varieties for each location, with their climatic and soil factors, and with high productivity and resistance to lack of water, pests and diseases. However, the selection process in the greenhouse is manual. This can be improved through an automated system, at least relying less on human intervention.

For the case of the USA, a circuit was developed that monitors the weight of the plant at all times, and thus makes it possible to know how much water arrived at each watering moment and how much water was evaporated. The scale sends data through the RS232 serial port. In order for the ESP 32 card to be readable, a DB9 RS232-TTL serial converter module, described in Figure 4, is required.

Figure 4

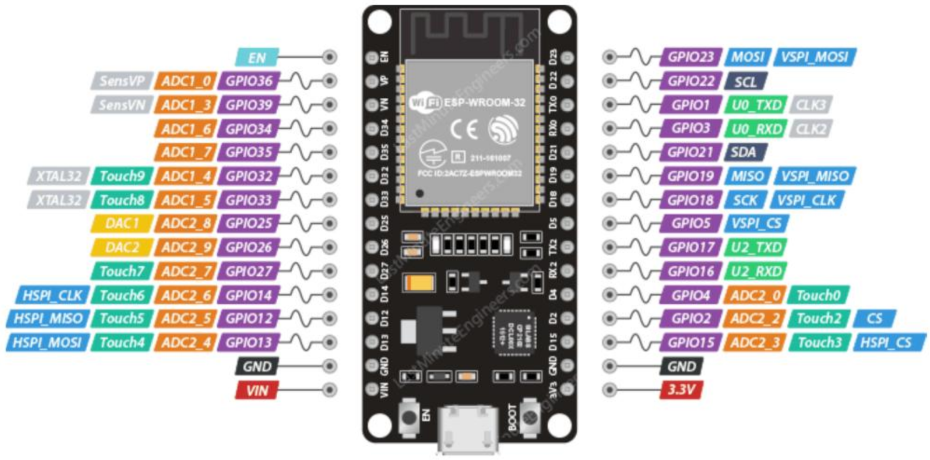
DB9 RS232-TTL serial converter module



The module, described in Figure 4, has the MAX3232 chip, which is responsible for converting the R232 signal to TTL, an acronym for Transistor-Transistor Logic, necessary for the reading to be done by the ESP32 board, illustrated in Figure 5, below.

Figure 5

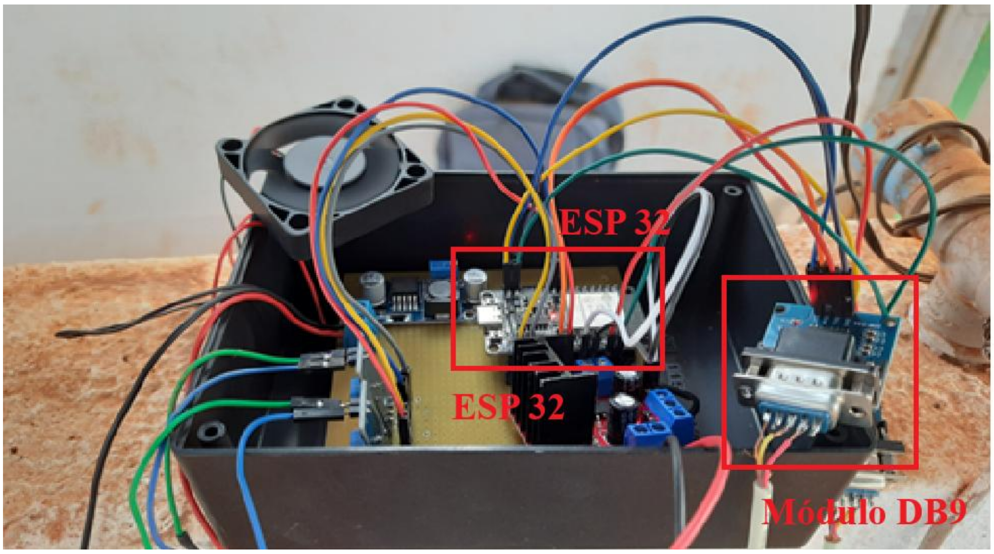
ESP 32 board with pin/port description



The DB9 RS232-TTL serial converter module is connected to the ESP 32 card as illustrated in Figure 6 below.

Figure 6

Communication between ESP 32 and the DB9 module



As illustrated in the circuit above, the embedded software, which is installed on the ESP 32, activates the scale to read the data using the DB9 module and also sends data requests and obtains data from the scale, for later storage.

Two other important components are the solenoid valve and the soil moisture sensor. The solenoid valve is used for the control of the amount of water that goes into each vessel. When it receives a signal from ESP 32, sent from its embedded software, the valve opens and the water goes to the toilet. When it receives another signal, the valve closes. This valve is not energized all the time. It opens and closes according to a signal given from the ESP 32 software. Figure 7 illustrates the latche-type solenoid valve described.

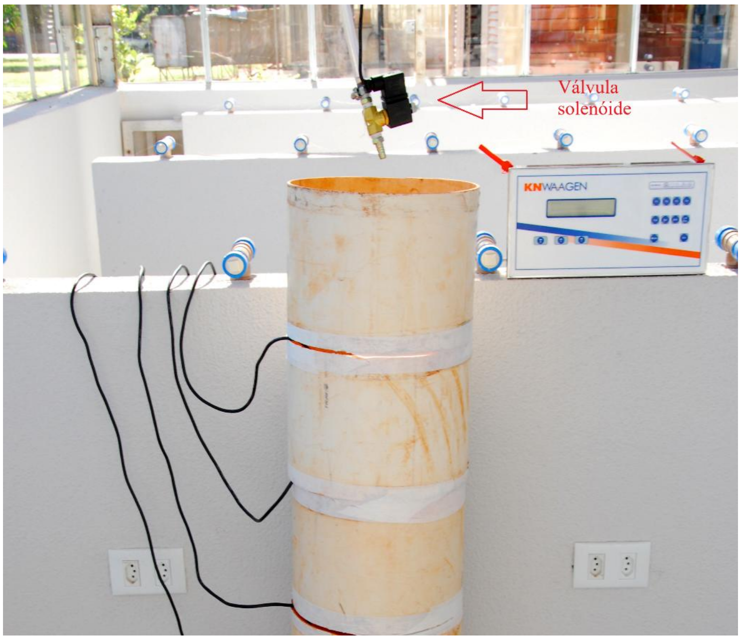
Figure 7

latch solenoid valve

Figure 8 illustrates how the valve was used to irrigate a particular vessel. In this figure, there are also some wires enter the vase. These are the soil moisture sensor cables, which will be seen later.

Figure 8

Solenoid valve and its position in the irrigation system



In the greenhouse, there are several connections for hoses in each wing or partition, as seen in Figures 2 and 3 above. Pipes are attached to these connections, like a faucet, and go to the solenoid valve of each vessel, and thus, the water can reach the plant or not, as the valve opens or closes on the command of the software that is in ESP 32.

With water flow control, it is possible to know how much water has arrived (body of water in grams) through the scale. Similarly, it can be known how much water is lost by the plant through transpiration or evaporation of water. It will be possible to know which plant retains more water to better get through the dry season.

On the other hand, the more the plant uses its roots to absorb water, the better. To be able to measure this, albeit indirectly, soil moisture sensors are used at different depths, as shown in Figure 9. Between one ring and another of the pot, a soil moisture sensor is inserted. Each ring is 20 cm high. Thus, every 20 cm the moisture of the earth is measured. This measurement will tell you how much the plant absorbs every 20 cm and with this it is possible to know which plant absorbs water at depths greater than the surface and which do not.

With the data on water consumed and also the data from the moisture sensors, it is possible to know how much water the plant uses and also its efficiency in absorbing water at greater depths of the soil. The humidity sensor used in each pot is illustrated in Figure 9.

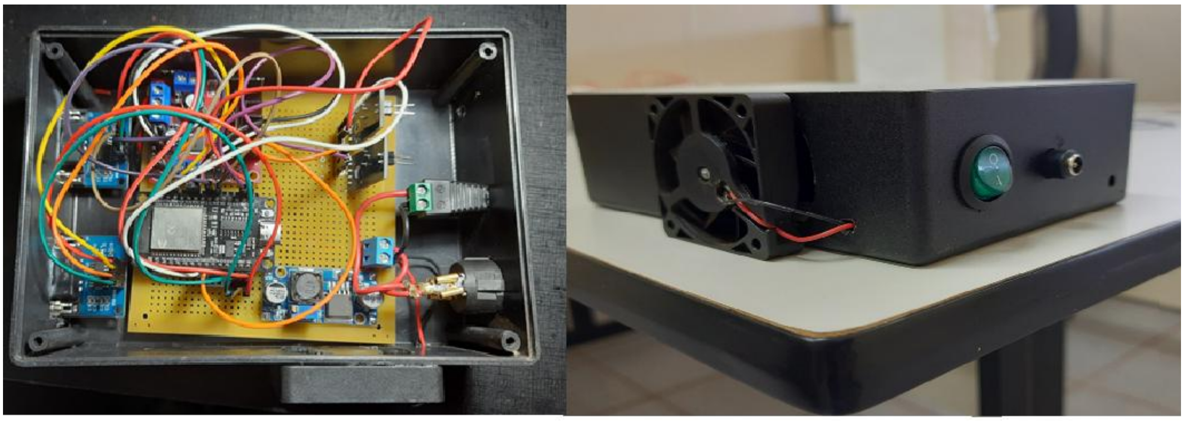
Figure 10

Soil moisture sensor used in this project

The final circuit, which controls the action of the valve and also the sensors, in addition to obtaining the data from the scale, at any time, is illustrated in Figure 10.

Figure 10

Electrical circuit that controls the valve and obtains data from the scale and soil moisture sensor



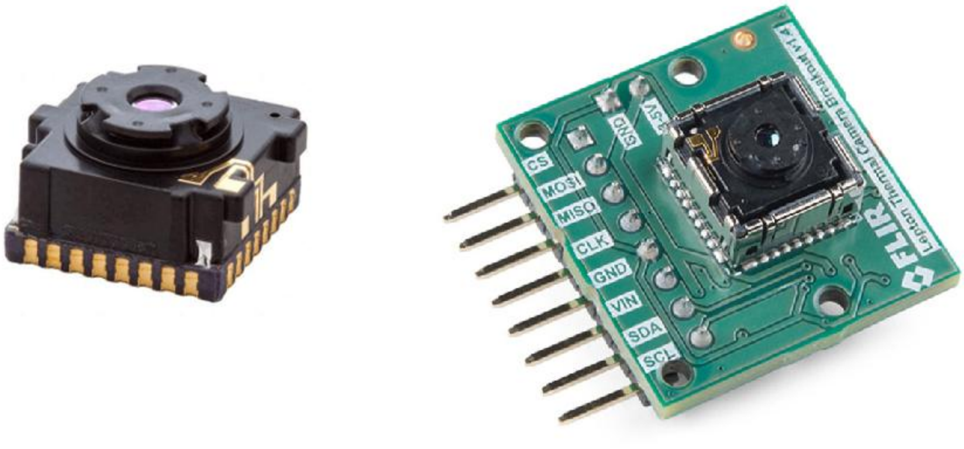
Each module, as illustrated by Figure 10, controls one vessel. For N vessels, n modules are required. The hardware equipment to control each vase costs, in 2025, approximately 100 dollars. This value is affordable for those who want to do US research for plants using many pots in a greenhouse. More information about this system can be found in (Mendes, 2023).

Another way to measure water stress is by imaging. For this, using the same greenhouse, pots, and controlled irrigation, thermal images of each plant are taken and, with these images, and temperature values in each pixel of the images, it is possible to infer about the water status of the plant. You can see how the temperature varies on each leaf of the same plant and also how it varies during the day. The advantage of using a camera instead of a sensor is that multiple temperature measurements can be taken simultaneously. With a temperature sensor, such as the MLX90614, which measures the temperature up to 4 m away, it would only be possible to measure one point of the canopy or crown of the plant, which would be too little for a more precise measurement. The camera would be at a height from the top or canopy of the plant in such a way that images of 2, 4 or 8 plants could be taken per camera. Although the camera is more expensive than a sensor, the accuracy of the measurement and also the images taken to verify how the temperature varies in a plant throughout the day are of great value for research.

The thermal camera used was a relatively inexpensive 3.5 Flir one lepton for thermal imaging. Figure 11 illustrates the camera.

Figure 11

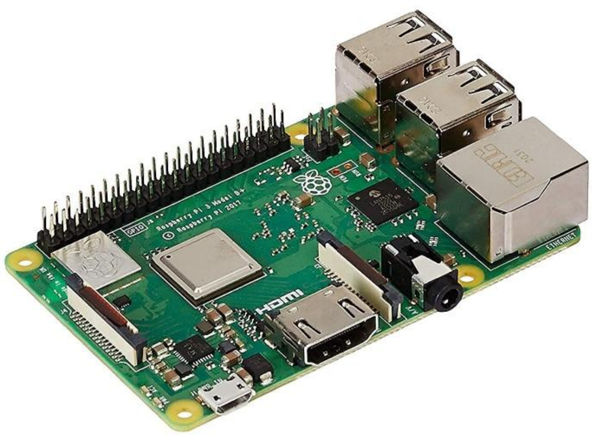
Lepton 3.5 Flir one camera and breakout for the camera



To control the camera, to obtain images and save them for further processing, to obtain from each image the temperature of various parts of the plant and to send the results of the processing to a server database, a compatible processor is required. For this, the raspberry pi 3B+ board was chosen, a raspberry pi model with the minimum processing quality necessary to obtain image data and subsequent processing, i.e. 1.4 GHz quad-core ARMv8 CPU, 1 GB of RAM. Figure 13 illustrates a raspberry pi 3 B+.

Figure 12

Rasberry pi 3 B+



The image data obtained is stored on a 128 GB SD card and later sent to a database through the wifi network available in the greenhouse. For the processing of the image, as well as capture and storage, a code in python language was used. The operating system installed on the raspberry pi was raspian, but it could be any other Linux distribution. To control the thermal camera, Pylepton packages must be used to manage communication via SPI and

I²C to capture the raw thermal frames. In addition, using the Numpy library to convert this data into arrays and allowing complex calculations and matrix manipulation for the conversion of values to temperature. Finally, you must use the OpenCV library to process the values and generate the thermal images, being able to apply color palettes, resize, detect regions of interest and create visual interfaces.

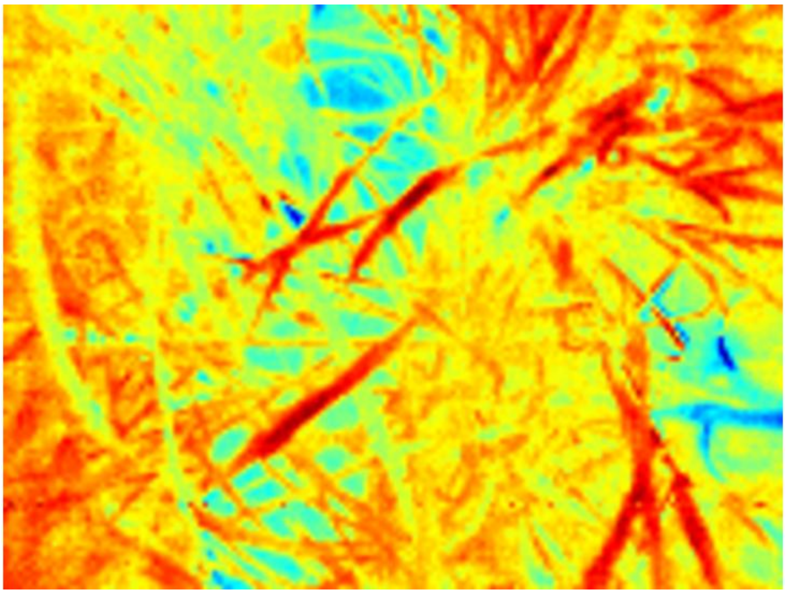
To obtain the thermal image, a capture and processing routine is used, whose steps are described below:

1. Collection of raw data: the Lepton camera sends to the Raspberry board several 14-bit data, each containing information on the intensity of radiation detected by a pixel;
2. Frame reconstruction: the collected data is organized in a 160x120 matrix;
3. Conversion to temperature: radiation intensity data is processed to obtain temperature data A raw image is generated that then undergoes post-processing;
4. Equalization: the contrast of the image is increased, highlighting subtle temperature differences;
5. Color palette application: a color map is applied to the image.

Finally, a thermal image with a color map is generated. For tests of the camera's operation, the image was captured with the unitary execution of the code. For application in the greenhouse, a constant procedure (an infinite loop) was created in which a capture is made and stored, the system goes on hold for 15 minutes and then starts a new capture. A captured image is illustrated in Figure 13.

Figure 13

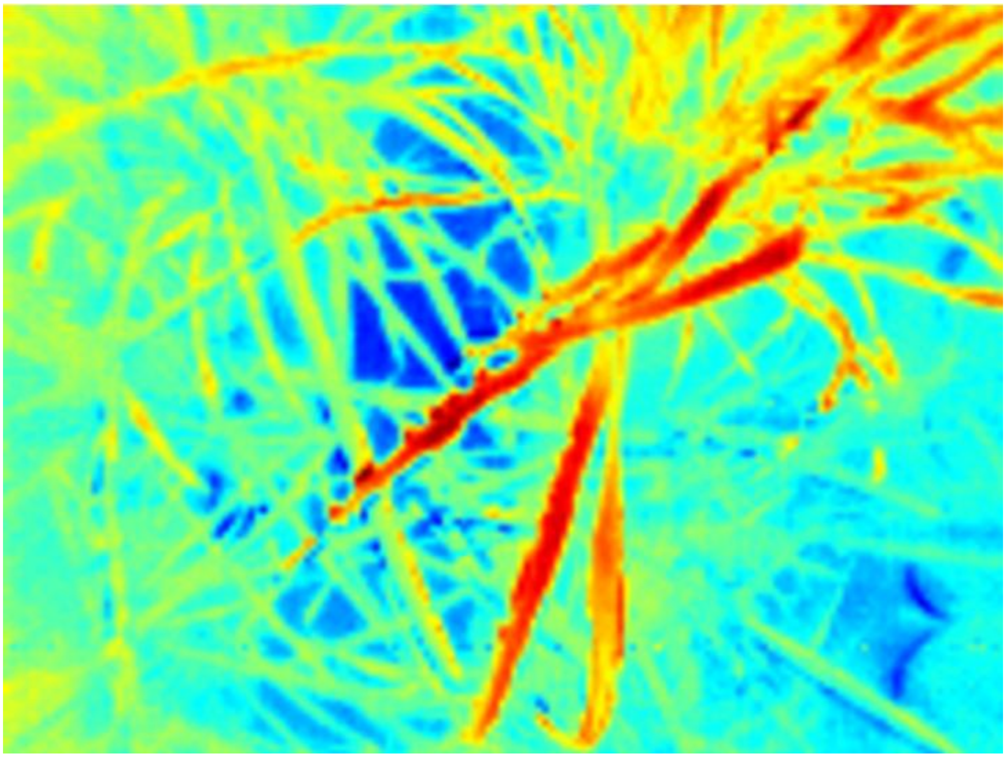
Thermal image of a plant with water stress



In the image above, you can see rice leaves. These leaves have temperature values above average or reference. The orange or red shade demonstrates this color above normal. On the other hand, it can be observed in which part of the plant the heat is greater and how it varies in the plant. Figure 14 below shows a plant with little stress.

Figure 14

Thermal image of a rice plant with little stress



Of the two thermal images shown for two rice plants, it is observed that the first is under more stress than the second. In each pixel of the image, there is the measured temperature value. In this way, it is possible to see how much the plant is stressed in relation to the previously measured reference (one or more control plants, which are properly managed so as not to have water stress).

More information about this system involving a thermal camera can be seen in Borges (2025) or in the initial works, the first version, made by Júnior and Narciso (2019).

4 CONCLUSIONS AND COMMENTS

The system to measure EUA is simple to obtain and with it you can have water loss data, how deep the plant consumes the most water, which plant has more or less stress, how the plant works under water stress, etc. The data is captured periodically during the day and thus various analyses can be obtained to choose which are the best plants to be tested in the field. This has an economic impact on research, as it simplifies work in the field and thus saves labor, time, resources, and also accelerates the advancement of research in obtaining which plants best adapt to water shortage or water scarcity.

The Lepton 3.5 camera has proven capable of providing images that reliably distinguish the leaf from the background. This performance demonstrates the potential of the low-cost thermography concept, validating that, under environmental conditions and with optimal operation, the sensor can capture useful information. This camera is radiometric and has a shutter, meaning that it has more accurate readings and internal noise reduction mechanisms, making it more suitable for the purpose of the project on paper.

A major advantage obtained by this prototype is process automation. This device takes the tedious and tedious burden out of attending the greenhouse in person, collecting images, and measuring environmental conditions several times a day. In addition, there is the transmission of images and data obtained by Wi-Fi to a database, for even more convenience and speed in the process. This work with respect to the thermal camera shows that it is possible to carry out in-depth studies on water stress.

These two prototypes show that it is possible to build hardware and software to obtain data of interest about plants, in a greenhouse, while spending fewer resources.

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