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STAND-ALONE IRRIGATION SYSTEM BASED ON SOIL MOISTURE[*]

ABSTRACT

Irregular rainfall is a problem that plagues vegetable producers. One of the ways to overcome such adversity is the use of an irrigation system. When done properly it is highly beneficial since it manages water use and reduces the costs of water and labor consumed by irrigation and productivity. We developed an autonomous irrigation system for vegetable crops to improve water resources' efficiency. An Arduino Development Kit was used with a processing center, solenoid valve for flow control, unit, temperature, and luminosity (LDR) sensors for system instrumentation. In addition, two water meters and a volumetric water measurement instrument were installed in the irrigation line of the garden for a more accurate evaluation of the experiment. The prototype developed was tested at Sítio Bela Vista, in the municipality of Nova Canaã Paulista. Analyzed data were collected at the end of the vegetable production cycle, totaling 35 production days. The results show that growers can, aided by our automated irrigation equipment, maintain soil moisture at adequate levels, ensuring better production quality.

Keywords: Irrigation. C/C++ Programming Language. Arduino. Sensors.

SISTEMA AUTÔNOMO DE IRRIGAÇÃO BASEADO NA UMIDADE DO SOLO

RESUMO

A irregularidade das chuvas é um problema que assola os produtores de hortaliças. Uma das formas de contornar tal adversidade é a utilização de sistema de irrigação. A irrigação feita de forma adequada faz o gerenciamento do uso da água e traz inúmeros benefícios, como, redução dos gastos hídricos, gastos com mão de obra empenhada na irrigação e produtividade. Assim, propõe um sistema autônomo de irrigação para a cultura de hortaliças para melhorar a eficiência dos recursos hídricos. Para o desenvolvimento do sistema autônomo de irrigação, foi utilizado o Kit de desenvolvimento Arduino com central de processamento, válvula solenoide para controle de vazão, sensores de unidade, temperatura e luminosidade (LDR) para instrumentação do sistema. Adicionalmente, foram utilizados dois hidrômetros, instrumento de medição volumétrica de água, instalados na linha de irrigação da horta para uma avaliação mais precisa do experimento. O protótipo desenvolvido foi testado no Sítio Bela Vista no município de Nova Canaã Paulista. Os dados avaliados foram coletados ao fim do ciclo de produção da produção de hortaliças, totalizando 35 dias para a produção. Os resultados mostram que, com a ajuda do equipamento automatizado de irrigação. os produtores podem manter a umidade do solo em níveis adequados, garantindo uma produção de melhor qualidade.

Palavras-chave: Irrigação. Linguagem Programação C/C++. Arduino. Sensores.

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1 INTRODUCTION

This work is relevant within the current Brazilian context due to the lack of rainfall or unexpected torrential rain, which routinely cause small producers numerous losses.

In recent years, the state of São Paulo has experienced the worst droughts and the northwest of São Paulo-the project's focus region- was classified as an area of exceptional drought, the most severe degree, as shown in the National Water Agency survey (ANA, 2022).

One of the ways to overcome such adversity is the use of an irrigation system. Such systems have proven to be of great support and value to Brazilian rural producers, in the most varied cultures.

Producers interested in implementing an irrigation system must first evaluate the best solution, considering that there are systems that do not control the water content in the soil, as noted by Batista (2012) and Reis et al. (2015, p. 1).

The benefits of adopting an autonomous irrigation system are numerous. Increased production, reduced labor, water, fertilizer are amongst them. Gornat e Silva (1990) and Jesus et al. (2021, p. 7) mention a wide range of benefits that automated irrigation systems provide to producers, such as better property management, higher productivity at a lower cost given its labor, energy, and fertilizer savings.

In view of the above, the project aims to develop an autonomous irrigation system prototype, reducing water costs as well as the workforce engaged in irrigation, which, in this case, is tasked with manually switching the irrigation system on and off.

On top of others, the issue of manually switching and controlling crops run on a manual irrigation system, is solved by the adoption of an automated irrigation system which frees producers to use their time more intelligently in other functions.

We used an Arduino Development Kit for the development of an autonomous irrigation system. An Arduino should be understood as *"[...] An open-source electronic prototyping board. The project, which emerged in the city of Ivrea, Italy, in 2005, includes free hardware and software and aims to offer adaptable and low-cost tools for the creation of interactive projects of various kinds"* (CANALTECH, 2015).

The development and implementation of such a prototype is very promising, feasible and urgent in a region such as the interior of São Paulo. Generally, the development and production of vegetables are greatly affected by climate conditions and soil moisture. Lack of

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soil moisture is usually a limiting factor in obtaining high yields whereas high humidity can also be harmful, as it favors the development of diseases.

In our state, rainfall occurs irregularly. Often, there is either a shortage or excess of water in the short term, which seriously affects the productivity and quality of vegetables. This damage is almost always irreversible, since most produce has a short cycle and is very sensitive to moisture imbalances (ABCSEM, 2022).

In addition to the above, human error also contributes to crop diseases caused by excess water or other inadequate cultural treatments. The latter occur when individuals damage the crop by unnecessarily watering soil of unknown moisture levels (ABCSEM, 2022).

2 METHODOLOGY

The equipment’s construction factored several aspects- preponderantly its weather-protected impermeable structure which grantees the integrity of the system and its electrical parts inside.

To configure all irrigation parameters, holes and openings were made in the plastic structure so that all the Buttons and Encoder were on the outside of the equipment but still weather protected (Figure 1).

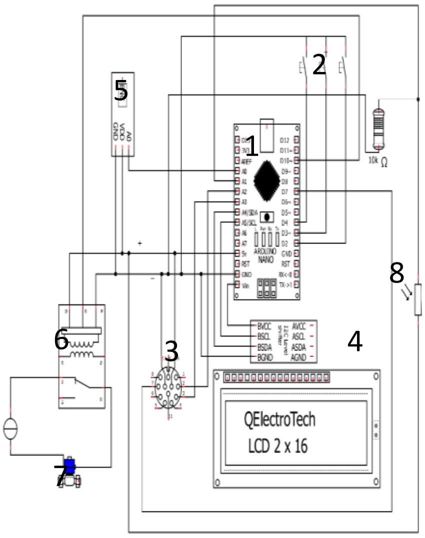
Figure 1 - Buttons, Encoder and LCD Display

Source: From the authors themselves.

To avoid the electrical parts of the Buttons and the Encoder coming into contact with water, waterproof threads models were purchased to prevent liquid penetration. To waterproof the entire equipment, the LCD Display was installed through an opening made in the front part. To this end, an acrylic sheet was added, superglued and another layer was added to the hot glue edge (all to ensure maximum sealing of all the internal components mentioned) so that all the information displayed by the LCD inside the equipment was still visible (Figure 1).

An LDR (Light Dependent Resistor) sensor was added to allow the equipment to identify the external ambient light at a given moment (Figures 2 and 3), thus deciding whether to irrigate or not. As described by the author Torezani (2020), the water consumption of plants is linked to their photosynthesis process which only happens in daylight. It's thus fair to say that plants consume more water during the day.

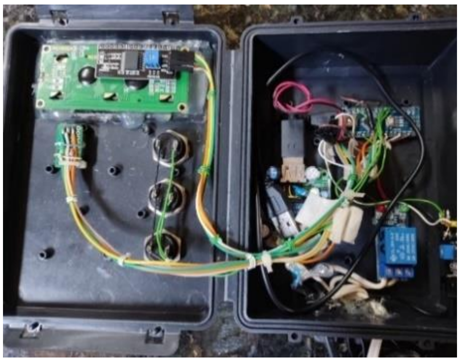
Figure 2 - Wiring diagram.



1: Arduino
2: Buttons
3: *Encoder*
4: LCD i2c
5: Soil moisture sensor
6: Relay
7: Solenoid valve
8: LDR

Source: By the authors.

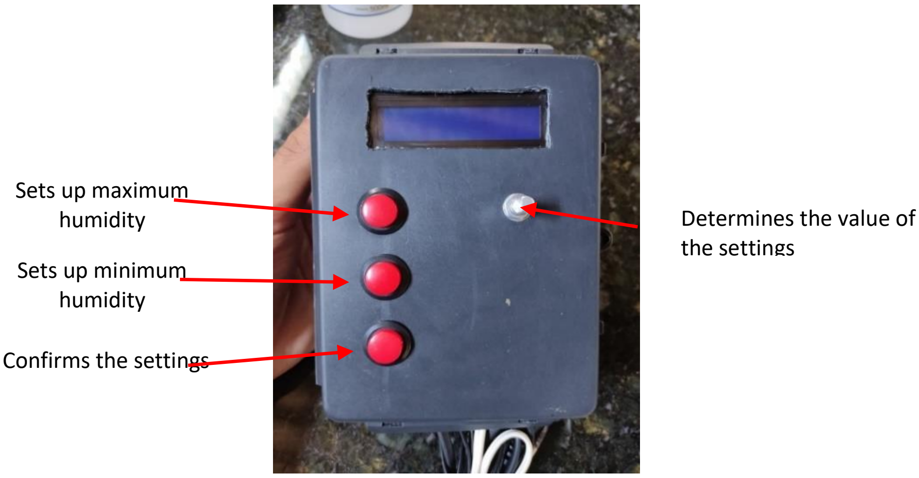
Figure 3 - Electrical part.



Source: By the authors.

As for the operation of the equipment created, it is configured in a simple way and the texts displayed on the screen help operational control and activation. Figures 4 to 10 demonstrate the operation.

Figure 4 – Buttons' functions.



Source: By the authors.

Figure 5 - Equipment Home Screen

```
IRRIGACAO
Umidade: 20 %
```

Source: By the authors.

Figure 6 - Setting Maximum Humidity.

```
IRRIGACAO
MAX:        84
```

Source: By the authors.

Figure 7 - Setting Minimum Humidity.

```
IRRIGACAO
MIN:       50
```

Source: By the authors.

Figure 8 - Confirming Settings

```
IRRIGACAO
SETANDO...
```

Source: By the authors.

Figure 9 - Irrigation paused overnight

```
IRRIGACAO
NOITE
```

Source: By the authors.

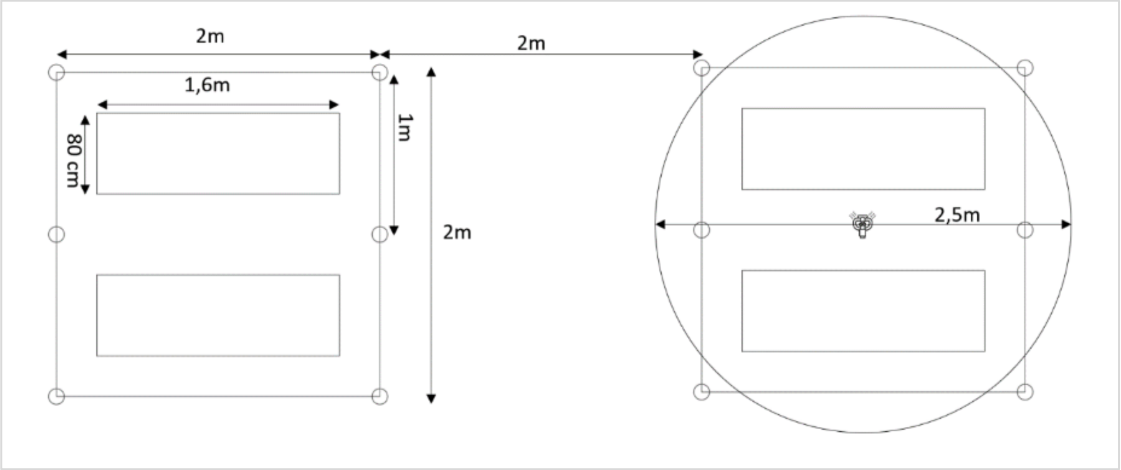
Figure 10 - Connected irrigation.

```
IRRIGACAO
** IRRIGANDO **
```

Source: By the authors.

Two greenhouses of similar proportions were created to test the prototype. Figure 11 illustrates the 6 wooden platforms, wire and 50% shading screen used in their construction.

Figure 11 – Sketch of the vegetable gardens.



Source: By the authors.

Platforms placement: 1m deep holes were dug the platforms feet, then filled with soil and subsequently compacted; the 1m-high upper part of the platforms is set throughout the vegetable garden, to ensure the shading screen protects the entire beds from solarization. The middle stands were left at 1.2 m to avoid interference with the sprinklers irrigating the two beds (sprinkler area: Radius of 2.5m).

To fix the protective screen in the vegetable chapel model, holes were drilled at the top the platforms to run a screen-holding wire. This was done in the adjacent vegetable garden, 2m away. For crop maintenance purposes, the protective screen was mounted like a curtain (Figures 12 and 13) to facilitate the entry and access to the beds.

Figure 12 - Ready-made vegetable gardens

Source: By the authors.

Figure 13 - Shading Screen Indentation.

Source: By the authors.

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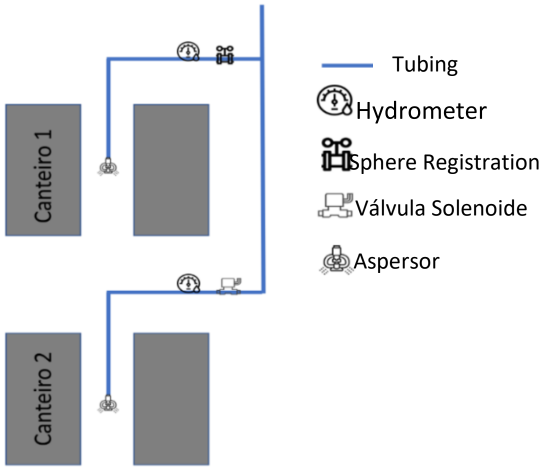
Figure 14 shows the two water meters added to the secondary irrigation lines, used for data collection. These measure the amount of water consumed by the entire irrigation process-during the full crop cycle (planting to harvest).

Figure 14 - Hydraulic Schematic



Source: By the authors.

Figure 15 - Water Meter and Solenoid Valve Installed

Source: By the authors.

The implementation of the pilot equipment took place at Sítio Bela Vista, in the municipality of Nova Canaã Paulista, GPS coordinates: 20º 22'29.11" S and 50º56'50.23" W.

Data was collected by two water meters (Figures 15) installed in the irrigation line of the garden and 2 different scenarios were evaluated: autonomous irrigation system and manual irrigation system. The efficiency evaluations of both the operator and the equipment took place at the end of the hardwood production cycle- from the seedlings transplant on August 26 (Figures 16 and 17), to harvest day September 30 (Figures 18 and 19). The criterion for harvesting was based on the experience of the operator, thus completing its 35-days cycle.

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Figure 16 – Lettuce seedlings.

Source: By the authors.

Figure 17 - Transplanting of lettuce seedlings

Source: By the authors.

Figure 18 – Lettuces ready to be picked.

Source: By the authors.

Figure 19 – Equipment in operation.

Source: By the authors.

Figure 20 – Equipment in operation.

Source: By the authors.

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3 RESULTS

The data collected by the water meters are described below in Figures 20 to 23.

Figure 21 – Water meter at the beginning of autonomous irrigation (260 liters).

Source: By the authors.

Figure 22 – Water meter at the end of autonomous irrigation (5180 liters).

Source: By the authors.

The autonomous irrigation water consumption totaled 4,920 liters, between August 26 and September 30.

Figure 23 – Hydrometer at the beginning of manual irrigation (1120 liters).

Source: By the authors.

Figure 24 – Hydrometer at the end of manual irrigation (6230 liters).

Source: By the authors.

The manual irrigation water consumption totaled 5,110 liters between August 26 and September 30.

Table 1 quantifies the wet and dry weight of leaves.

Table 1 – Average results

Autonomous System			**Manual System**		
Number of leaves	Green Matter	Dry matter	Number of leaves	Green Matter	Dry matter
24	336g	11g	19	266g	8.2g
18	252g	8.3g	18	252g	7.7g
19	266g	8.7g	21	294g	9g
21	294g	9.7g	17	238g	7.3g
32	448g	14.7g	23	322g	9.9g
19	266g	8.7g	20	280g	8.6g
22	308g	10.1g	18	252g	7.7g
20	280g	9.2g	19	266g	8.2g
21	294g	9.7g	22	308g	9.5g
18	252g	8.3g	19	266g	8.2g
19,6	274.4g	9,016g	17,7	247.8g	7,611g
Average					

Source: By the authors.

4 DISCUSSION

The equipment demonstrates great operational stability and efficiency, as shown by the similar amounts of water consumed by the two irrigation models (a delta of only 190 liters or 3.6% in relation to the autonomous system). This also indicates that the manual operator's programming of the autonomous system was very precise since it matched the manual operator's estimation of the water amount consumed by the vegetables. While in autonomous irrigation, soil moisture remained constant throughout the foliosa growth (which bettered the vegetable crops development), the foliosa's lower development in manual irrigation leads us to believe that a uniform watering was one of the factors at play.

Although the difference was minimal for manual operators with more than 5 years of experience, quantitative analyses of weight, quantities of leaves and quality of lettuce plants were made with the following results:

- **Number of leaves:** Stand-alone system had an average advantage of 1.9 sheets per foot
- **Weight of green matter:** Autonomous system had an average advantage of 26.6 grams per foot.
- **Dry Matter Weight:** Self-contained system had an average advantage of 1.4 grams per foot.

According to Barros et al. (2016) the average amount of water used by the crop cycle is 10.87 liters per single lettuce. The amount of water used in the autonomous and manual system was approximately 86 liters per plant- a much higher amount than that indicated by the author. However, this value was affected by several factors (total irrigation area, its soil, plant spacing and climatic conditions) leading us to believe this value can be reduced by 60% with some greenhouse modifications including a configuration for lower maximum humidity which saves greater water amounts.

The ease of programming of automated irrigation equipment should be factored in. Unlike other projects, such as Nunes, Pereira, and Lopes (2019), which require the source code to be changed on a computer before being transferred to the board, this equipment can be programmed directly on its dashboard. By eliminating the need for travel, this makes equipment programming process simpler, more agile and convenient. This feature makes automated irrigation equipment more accessible to growers, thereby increasing this technology’s implementation in the countryside.

With the low-cost automation system, it was possible to maintain soil moisture adequate to the programmed parameters, avoiding any water deficits or excesses for the studied crop (GIOMO, 2019).

In the work carried out by Marques Filho (2017), the environmental control system for protected cultivation showed satisfactory functioning in the activation of the actuators according to the schedule implemented for the lettuce crop. The ventilation, misting and shading actuators must be better dimensioned so that interference occurs in the internal environment of the greenhouse. Seeing as Marques Filho's (2017) research primary aim was to analyze the functioning of the electronic control and data acquisition system, and not the efficiency of the actuators, our goal was therefore successfully achieved.

5 CONCLUSION

The use of automated irrigation equipment with the Arduino kit through microcontrollers is a practical and efficient solution for water management in agricultural production. Automation technologies allow producers to spend their time in other activities whilst ensuring the correct water distribution to plants, avoiding waste and ensuring the healthy development of crops.

The implementation (development) of this equipment is particularly important for crops that are sensitive to excess water, such as vegetable crops. Excessive water use can lead to deterioration, harming not only productivity but also products' quality. With the help of automated irrigation equipment, which has been implemented and tested in-situ, growers can maintain soil moisture at appropriate levels, ensuring high-quality production. Moreover, automation environmental benefits, as proper water management contributes to the conservation of water resources. With the use of automated irrigation equipment, it is possible to reduce excessive water consumption and avoid waste, contributing to the sustainability of agricultural production.

Soil moisture is critical for plant growth and development. While these crops require adequate levels of moisture, overwatering can lead to problems such as root rot, disease proliferation, and decreased yields. Therefore, it is important that the soil moisture level is carefully monitored and that irrigation is carried out accurately and accordingly. Soil moisture sensors (such as the tensiometer) give growers accurate soil moisture measurements in real time. This allows irrigation to be adjusted to actual plants needs and prevent overwatering.

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