Water Consumption Reduction: Electronically Controlled Drip Irrigation Systems

Luciano Ledesma, Jerónimo Politi Livoni

Electronics Engineering Department

Universidad Tecnológica Nacional, Facultad Regional Paraná

Abstract Starting from the global problem related to water scarcity and focusing on the technological resources related to our electronic engineering studies, we approached the investigation of a drip irrigation system with electronic control that allows managing water resources for agricultural production. After evaluating and studying the problems, analyzing the advantages and disadvantages of the system, evaluating ground sensing methods, as well as the components and sensors to be used, we proposed a system based on the Arduino open source platform. This system allows us to have a specific control of irrigation through soil sensing and controlled pumping, which allows efficient use of available water. Also, this system is capable of granting and storing data for a later analysis and improvement of production in general. We finally conclude that by using this system, the main problem of efficient water use is solved, reducing the unnecessary expense of water resources and, in turn, providing great benefits for agricultural production.

***Index Terms*—Lack of water, water crisis, conservation methods, drip irrigation, smart irrigation systems, automated agriculture, Arduino based irrigation.**

I. INTRODUCTION

IT is a well-known fact that nowadays the world is facing a big crisis related to water and its scarcity. In many areas, the water systems which are essential for sustaining life have become stressed and this situation is getting even more difficult to manage year after year due to the population growth and lack of supervision over the use of services and resources.

In the current context, technological solutions to the water problems must be a priority and must be implemented within systems that recognize and address the inequities in terms of access to clean water and sanitation, which determine what life options are possible. That is why this problem has been already discussed by the National Academy of Engineering and incorporated as one of the Grand Challenges for Engineering [1]. This initiative aims at fostering the creation of new technologies to provide water, especially in remote areas, where fresh drinking water is not available. But water unavailability also critically affects health since without this basic resource, appropriate sanitation services cannot be guaranteed. In order to find solutions in this aspect, the United Nations has set the access to clean water and sanitation as the 6th goal of the Sustainable Development Goals agenda [2].

Latin America is a region that contains large rivers and tributaries and is also one of the regions with the biggest agricultural development in the world. According to the United Nations, agriculture is responsible for about 70% of the global water consumption every year [3], and specifically in Argentina, this activity represents the main national income. In these terms, finding a solution to decrease the water consumption by incorporating more effective methods to replace the current irrigation systems being used throughout the region must be a priority and could contribute to the sustainable development in agricultural matters.

The aim of this paper is to study and present the benefits of the drip irrigation system, introducing innovating electronic control systems that can be applied to improve this

---

Luciano Ledesma is an electronic engineering student at National Technological University, Paraná, Entre Rios, Argentina (e-mail: lucianoledesma@alu.frp.utn.edu.ar).

Jerónimo Politi Livoni is an electronic engineering student at National Technological University, Paraná, Entre Ríos, Argentina (e-mail: jeronimopolitilivoni@alu.frp.utn.edu.ar).

The present manuscript is part of the research activities in the Inglés II lesson at Universidad Tecnológica Nacional, Facultad Regional Paraná. Students are asked to research into a topic so as to shed light on a topic of their interest within the National Academy of Engineering's Grand Challenges or the United Nations' Sustainable Development Goals frameworks. If sources have not been well paraphrased or credited, it might be due to students' developing intercultural communicative competence rather than a conscious intention to plagiarize a text. Should the reader have any questions regarding this work, please contact Graciela Yugdar Tófalo, Senior Lecturer, at gyugdar@frp.utn.edu.ar
.

modern irrigation alternative. Apart from helping save water, the environmental conditions readings made by sensors of the electronic system can be stored in a memory or cloud service in order to study, from this information, the growth of the crop and crop yield according to different conditions over time. This can help to improve the management of the field season after season and make the crop more effective in terms of productivity and sustainability [4].

In order to achieve this objective, the discussion begins with a description of the concept of the drip irrigation system and its advantages over traditional irrigation techniques. Then, some soil and environmental characteristics that must be measured are going to be explained. This will allow us to get enough information in order to turn this simple system into a smart one. Finally, the reader will become acquainted with one of the most used platforms that can control sensor readings to keep continuous control over the cultivated land: Arduino. These is an open source platform and with it a reliable and affordable system can be developed in the interest of saving water from irrigating just when is needed and provide the farmer with information to study the crop productivity.

II. DRIP IRRIGATION

Subsurface drip irrigation (SDI) was developed some decades ago as part of investigations about the water consumption and management in crops and agricultural processes. Due to its equal or even better efficiency over other systems, SDI became a real and convenient option for plantations of different characteristics, in terms of composition, distribution, local weather, products, among others.

Drip irrigation is based on the application of water in a slow and localized way to the plant. Basically, it consists in placing tubes in a row near the stems of the plants and the water flows through the droppers that are inserted into the tubes, drop by drop as its name suggests it, in a constant way or at a scheduled time.

Among all the advantages that this system offers, the following should be considered potential advantages when properly managed and when the site conditions and cropping systems allow the advantage to become effective. In relation to water and soil issues, there are advantages connected with more efficient water use, observing that soil evaporation, surface runoff, and deep percolation are greatly reduced or eliminated. There is also less water quality hazards confirming that runoff into streams is reduced or eliminated, and there is less nutrient and chemical leaching due to deep percolation [5].

In terms of advantages related to cropping and cultural practices, enhanced plant growth, crop yield and quality can be observed. Improved plant health with less disease and fungal pressure occurs due to drier and less humid crop canopies. An improved fertilizer, pesticide management and better weed control are also present when drip irrigation systems are used [5] – [6].

There are further advantages related to system infrastructure like automation of the irrigation plan, leaving behind processes controlled by time and incorporating environmental and soil conditions sensing. The closed-loop pressurized characteristic of the system that can reduce application variability and soil water and nutrient redistribution variability make the system ideal for automation and advanced irrigation control technologies. Decreased energy costs are a great advantage too because, when the system is automatized, the pumps, valves, filters, and other electrically managed components, are operative only when the soil moisture has reached the lower limit and the land has to be irrigated until the nominal moisture value is reached. Flexibility of design and longevity of the system are also highlighted among the infrastructure advantages.

Despite the advantages of drip irrigation, it also has some disadvantages in the same areas developed previously. Regarding water and soil issues it can be stated that the wetting pattern may be too small on coarse-textured soils, resulting in a too small crop root zone. Monitoring and evaluating irrigation events are disadvantages too because water applications may be largely unseen, and it is more difficult to evaluate system operation and application uniformity. As well as this, emitter discharge rates can exceed the ability of some soils to redistribute the water under normal redistribution processes, being a significant disadvantage.

Within the disadvantages related to cropping and cultural practices there are problems with multiple aspects. The location and positioning of the driplines is something that must be carefully considered when the system is designed and implemented, because this can reduce the tillage options if they are placed near the surface. Also, restricted plant root development is a problem as smaller crop root zones can make irrigation and fertilization more critical issues from both a timing and amount perspective.

Within the ambit of system infrastructure, it is known that costs are a very important aspect and, in this case, a low budget is a clear disadvantage due to the fact that SDI has a high initial investment cost compared to some alternative or traditional irrigation systems. Also, SDI systems typically have a shorter design life than other ones, which means the crop yield and productivity must increase to provide for system replacement. Nevertheless, it is estimated that a well-designed system can remain operative for 10-20 years. Filtration issues, operational issues, design issues and other maintenance issues are found in this type of irrigation system and they should be considered when learning more about the subject [5].

III. SOIL AND ENVIRONMENTAL PARAMETERS INVOLVED

In order to determine those parameters that should be measured to control an irrigation system, it is important to know about how the amount of water that is going to be distributed is estimated and whether the crop has an effective response to that quantity. From this information, even if it is just an estimation, it is possible to design a system which can work by keeping a continuous control over the soil moisture to determine if it needs to be irrigated or whether the amount of water applied is sufficient. A dynamic system design should allow to review and correct the parameters according to the real development of the crops.

The amount of water will depend on the crop and soil types, but there are basic aspects related to their characteristics that will help determine it. One of the most used methods to determine how much water must be applied to the crop is the water balance method, which as its name specifies, relates and balances water inputs and outputs.

The main water output is produced by a process called "evapotranspiration" (ET). The ET is the sum of two processes. The first one is called transpiration, which happens when the plants extract water from the soil by its roots and then this water escapes to the atmosphere through the leaves and stems as vapor. The second process is called evaporation, which refers to the water on the soil surface and on leaves and stems escaping to the atmosphere also as vapor.

The units used to determine the ET are usually millimeters of evaporated water per day, and then it will define the crop water requirement as the sum of its value for the complete season or crop growth period. However, the ET is affected by some conditions such as the developing state of the crop, general water management, and mainly weather and environmental conditions, more specifically, solar radiation, wind speed, altitude, air temperature and relative humidity. These are parameters that will need to be measured to keep a continuous control over the ET value and, thus, the crop water requirements [6]. With the introduction of this concept, it is possible to determine the water balance by using the following equation [4]-[7]:

$$I + R = ET_c + P + S + R_{off} + d_w \quad (1)$$

Here, I represents the amount of water applied from irrigation, R is the water input from rainfall, ET_c is the evapotranspiration for the crop under study, P is the percolation (movement of water through the pores in soil), S is seepage (subsurface flow in or out the root zone), R_{off} is surface runoff, and d_w is the change in soil water content over the time period studied. In order to simplify the final system, it is possible to consider the main parameters of the equation and those which are easier to measure: I, R and ET_c.

Previously, the ET process was described, but for the water balance equation it is necessary to estimate the ET_c value. This is possible by applying the following equation [7]:

$$ET_c = K_c \cdot ET_0 \quad (2)$$

Where, Kc is a dimensionless coefficient called crop coefficient which modifies the reference crop evapotranspiration (ET_0) to the crop where the system is going to be implemented. The ET_0 can be estimated from the weather conditions on daily steps or longer periods, as stated by the modified Penman–Monteith equation [7]-[8]. The value to K_c can be taken from charts according to the crop type or can also be calculated.

In terms of the complexity of the system that the user or client will prefer to implement, it is possible to add more parameters to the equations (1) and (2), in order to accurately calculate the crop's water needs. In this case, after the simplifications made in the water-balance equation (1), the water needs are going to be determined as follows:

$$I = ET_c - R \quad (3)$$

From this information it is easy to see that the main parameters that must be measured in order to develop the automation of the system are the soil moisture, relative humidity, ambient temperature, altitude, water flow rate and volume and rainfall quantity. Most of them will be useful to estimate the ET_0. Also, it is possible to add other parameters such as wind speed and sun radiation, which could help to obtain a more accurate system by monitoring almost every environmental variable. However, this would increase the cost of the final product and in most cases measuring the first five parameters is enough to small or medium scale crops. Nevertheless, missing parameters can be estimated from those that were included [7].

IV. SYSTEM ARCHITECTURE

As it was described, one of the advantages of the SDI system is its capacity to be automated. Moreover, most of the installed SDI systems are controlled manually or by time-based setups, which open and close valves and turn pumps on or off according to a programmed schedule. This technique does not make a rational use of water because, according to what was previously described in relation to the weather and soil conditions, the moisture of the irrigated land could be still between nominal values for the crop when a new irrigation cycle is started. The aim of this section is to introduce the basic aspects of a sensor-based system, capable of determining when it is necessary to perform and irrigation cycle according to soil conditions.

Due to the growth of the market related to open source embedded systems, nowadays it is possible to find a lot of inexpensive sensors and transducers which can be easily implemented within those systems to sense different parameters. For the purposes of this work, some of those that could integrate the irrigation system are going to be described. As this system is going to be developed using Arduino as the main platform, the sensors listed below have Arduino libraries specifically designed to control them or it is easy to carry out their connection and start-up. There are many versions for the Arduino board, including UNO, MEGA, NANO, LEONARDO, among others. The choice of one or the other will depend on the amount of inputs and outputs to be used, so it is at the discretion of the designer or end user.

As soil moisture sensors, the following are recommended: SparkFun Soil Moisture Sensor (with Screw Terminals), which acts as a variable resistor using its two large exposed pads [9]; FC-28 soil moisture sensor, a resistive-based sensor which provides both digital and analog output [10]; Grove - Capacitive Soil Moisture Sensor, which is a corrosion resistance sensor since there are no metal pads in direct contact with the soil [11].

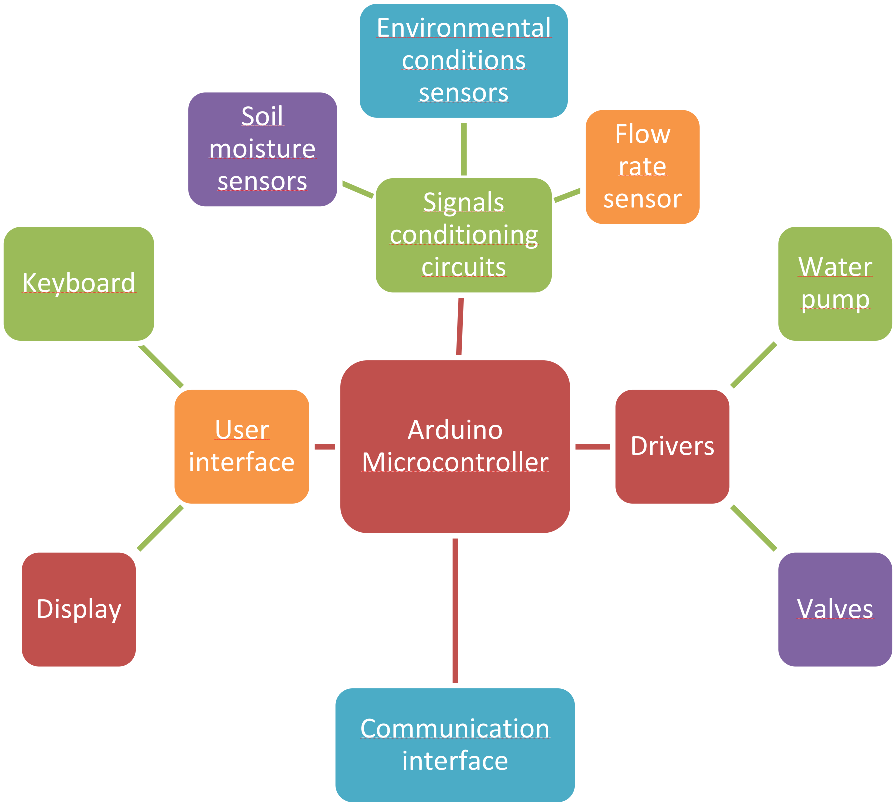

Fig. 1. Arduino based electronic unit architecture.

There are a lot of sensors to measure temperature and relative humidity, but the Adafruit BME280 sensor [12] is a useful one, because it provides temperature, relative humidity and barometric pressure in a 0.7 inches square board. From this information it is also possible to calculate the altitude. Two cheaper options are the DHT11 and DHT22 sensors, which can only measure temperature and humidity [13].

In order to measure the water flow, there are sensors such as the YF-S201 sensor, which sits in line with the water line and contains a pinwheel sensor to measure how much liquid has moved through it. Inside, it has an integrated magnetic Hall effect sensor that outputs an electrical pulse with every revolution. The pulse signal is a simple square wave. Therefore, it is possible to convert the readings into liters per minute using the following formula [14]:

$$\frac{Pulse\ frequency\ [Hz]}{7.5} = flow\ rate\ \left[\frac{L}{min}\right] \quad (4)$$

The rainfall is the most difficult parameter to keep track of. Instead of using a specific sensor to achieve this, it is necessary to develop a rainfall gauge or use parameters provided by a weather station or weather service.

As indicated by [4]-[15], it is possible to show both the system electronic unit [Fig. 1] and general architecture [Fig. 2] schemes. Water pump, water filter, chemical injection, valves, power supply, and complementary hardware and devices will be added as part of the system.

The electronic unit [Fig. 1] operates with an Arduino microcontroller as its core. As such, it will the responsible of controlling the peripheral devices, activating or deactivating them, and determine when it is necessary to irrigate the soil according to the information obtained from the sensors. In order to achieve this, the water pump and valves have to be activated.

The communication interface stage can be based on a wired or wireless system which will allow the Arduino to send data that can be stored for statistics analysis. Also, it is possible to develop a web or mobile phone interface that could control the system via Wi-Fi, Bluetooth, GSM, or all together.

The user interface is formed by a display and a keyboard. Through them, the user will have the option of setting parameters such as soil moisture threshold, water consumption threshold, scheduling, among others. Also, the sensor reading, current status and parameters can be continuously displayed on the screen for user-monitoring of the system’s performance. This will allow the user to improve the performance of the system after the field test periods.

The driver unit and signal conditioning unit are complementary circuits specifically designed to allow the Arduino to send or receive reliable information. Some of these circuits are already included in the sensors themselves, but some others must be implemented separately.

All the sensors are exposed to climate and soil conditions, which could mean a premature corrosion or malfunction. In order to solve this, it is possible to add a Real Time Clock (RTC), to control a schedule-based irrigation program in case of sensors failure.

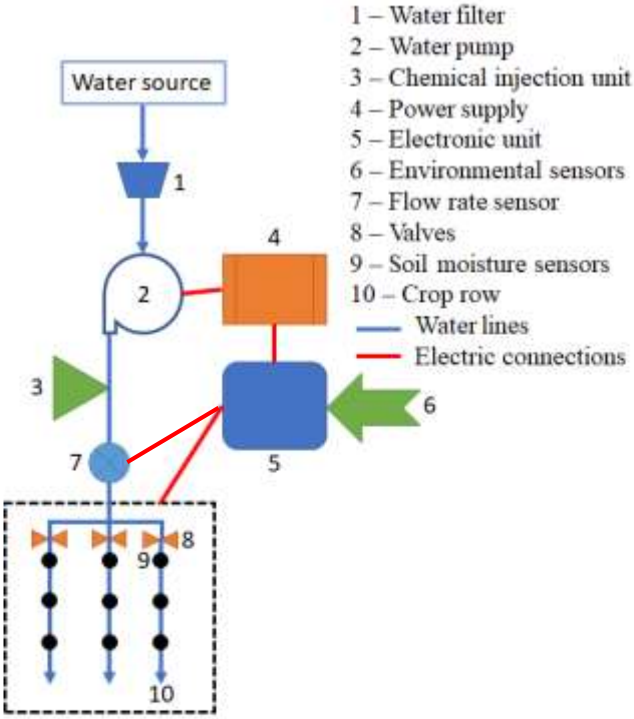

Fig 2. System architecture includes the water management devices and previously describe electronic unit.

As mentioned, the entire system [Fig. 2] must be implemented with its respective water management devices, adding the electronic unit described above. The soil moisture sensors must be buried at a specific depth and spacing on every crop row. The system can then make an average estimation of the general crop soil moisture or even take the average of every row in order to individually determine which must be irrigated according to the moisture threshold, since there is a valve before every row's dripline. The filters are needed to make a proper treatment of the water before it reaches the crop. The chemical injection unit is necessary to apply fertilizers and pesticides mixed with the water when they are needed. After this unit, the flow rate sensor is placed and connected to the electronic unit. It will allow the system to control the amount of water applied to the crop. This information will help the user to know how much water was saved compared to the consumption before the implementation of the automated SDI.

Finally, the power supply will provide the energy to the system. It can be implemented from standard circuits which take the energy from the grid. Also, it is possible to combine this circuit with a solar panel unit to power the system during daytime or night by using batteries and adaptation circuits, saving electrical power.

V. CONCLUSION

An Arduino-based system proves to be a real time feedback control system which monitors and controls many of the activities and parameters included in a drip irrigation system, making it more efficient. It is an effectively model to modernize the agriculture industries at any scale with optimum expenditure, but it can be specifically applied on small and medium scale crops, where budget can be a problem especially in developing countries. This system can provide irrigation to larger areas of plants with less water consumption and lower pressure, since it is continuously monitoring soil and environmental conditions and it starts irrigation cycles only when it is needed.

Systems like this are beginning to be used throughout Argentina and the region, demonstrating their efficiency and productivity. Using this system, it can be assured that electricity and water can be saved without affecting production and, ultimately, obtaining more profits.

REFERENCES

[1] National Academy of Engineering: "Grand Challenges for Engineering," Diamax, 2012. [Online] Available: www.engineeringchallenges.org [Accessed: Aug. 15, 2020].

[2] United Nations: "Sustainable Development Goals". [Online] Available: https://www.un.org/sustainabledevelopment/sustainable-development-goals/ [Accessed: Aug. 15, 2020].

[3] United Nations: Water. [Online] Available: https://www.un.org/en/sections/issues-depth/water/ [Accessed: Aug. 15, 2020]

[4] U. Zafar, M. Arshad, M. Cheema and R. Ahmad, "Sensor based drip irrigation to enhance crop yield and water productivity in semi-arid climatic region of pakistan", Pakistan Journal of Agricultural Sciences, vol. 57, no. 5, pp. 1293-1301, 2020. Available: http://www.pakjas.com.pk. [Accessed 20 September 2020].

[5] F. R. Lamm, "Advantages and disadvantages of subsurface drip irrigation", Puerto de La Cruz, Tenerife, Canary Islands, 2002.

[6] M. Abou Seeda, "Evaluation and Optimization of Subsurface Irrigation (SDI) System: A review", Middle East Journal of Applied Sciences, no. 10, pp. 508-534, 2020.

[7] R. Allen, L. Pereira, D. Raes and M. Smith, Crop Evapotranspiration-Guidelines for computing crop water requirements- FAO Irrigation and drainage paper 56. 1998.

[8] S. Millán, J. Casadesús, C. Campillo, M. Moñino and M. Henar Prieto, "Using Soil Moisture Sensors for Automated Irrigation Scheduling in a Plum Crop", Water, vol. 11, no. 10, p. 2061, 2019. Available: 10.3390/w11102061 [Accessed 11 October 2020].

[9] SparkFun Electronics, "SparkFun Soil Moisture Sensor (with Screw Terminals) - SEN-13637 - SparkFun Electronics", Sparkfun.com, 2020. [Online]. Available: https://www.sparkfun.com/products/13637. [Accessed: 11- Oct-2020].

[10] Aqibdutt, "How to Test Soil With Arduino and an FC-28 Moisture Sensor | Arduino", Maker Pro, 2017. [Online]. Available: https://maker.pro/arduino/projects/arduino-soil-moisture-sensor. [Accessed: 11- Oct- 2020].

[11] "Soil Moisture Sensor - How to choose and use with Arduino - Latest open tech from seeed studio", Latest open tech from seeed studio, 2020. [Online]. Available: https://www.seeedstudio.com/blog/2020/01/10/what-is-soil-moisture-sensor-and-simple-arduino-tutorial-to-get-started/. [Accessed: 11- Oct- 2020].

[12] Adafruit Industries, "Adafruit BME280 I2C or SPI Temperature Humidity Pressure Sensor", Adafruit.com, 2020. [Online]. Available: https://www.adafruit.com/product/2652. [Accessed: 11- Oct- 2020].

[13] "Arduino - Temperature Humidity Sensor | Arduino Tutorial", Arduino Getting Started, 2020. [Online]. Available: https://arduinogetstarted.com/tutorials/arduino-temperature-humidity-sensor. [Accessed: 11- Oct- 2020].

[14] Sun Robotics, "Water Flow Meter Sensor YF-S201 1/2 Inch", SUN ROBOTICS, 2020. [Online]. Available: https://sunrobotics.odoo.com/shop/product/6174-water-flow-meter-sensor-yf-s201-1-2-inch-4466. [Accessed: 11- Nov- 2020].

[15] K. Prathyusha and M. Chaitanya Suman, "Design of embedded systems for the automation of drip irrigation", International Journal of Application or Innovation in Engineering & Management (IJAIEM), vol. 1, no. 2, pp. 254-258, 2012. Available: 10.13140/RG.2.2.18561.15207 [Accessed 10 October 2020].