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Desarrollo de un sistema de riego automático como recurso educativo para la asignatura de electrónica digital

Development of an automatic irrigation system as an educational resource for the digital electronics subject

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Abstract:

This paper deals with the development of a didactic precision agricultural irrigation control system using fundamental electronic devices that are typically presented and analysed in a digital electronics course. The project integrates the application of latches, counters and decoders focused on controlling an agricultural production system. Through the developed system, the amount of water supplied to a plant is controlled, using soil moisture as a monitoring variable for the water irrigation system. The calibration of the irrigation system allowed to identify that each of irrigation activation provides an amount of 0.25 milliliters of water, which allowed efficiently use of watering through the implementation using computational techniques and hardware devices. The system can be modified and adapted to other agricultural systems to regulate the supply of nutrient solutions or liquid fertilizers.

Keywords:

Digital electronics, microcontroller, irrigation, counter.

Resumen:

En este trabajo se presenta el desarrollo de un sistema didáctico de control de riego agrícola de presición utilizando dispositivos electrónicos fundamentales que se presentan y analizan típicamente en un curso de electrónica digital. El proyecto integra la aplicación de diversas aplicaciones de los latches, contadores y decodificadores enfocados en controlar un sistema de producción agrícola. A través del sistema desarrollado se controla la cantidad de agua que se suministra a una planta, utilizando la humedad del suelo como variable de monitoreo para el sistema de riego de agua. La calibración del sistema de riego permitió identificar que cada uno de los pulsos de riego provee una cantidad de 0.25 militros de agua, con lo que se utiliza el recurso de manera eficiente a través de la implementación utilizando técnicas computacionales y dispositivos de hardware de bajo costo. El sistema puede ser modificado y adaptado a otros procesos agrícolas para regular el sumistro de soluciones nutrivas o fertilizantes líquidos.

***Palabras Clave**:*

Electrónica digital, Microcontrolador, riego, contador

Introduction

The subject of digital electronics is part of various programs at the engineering level, such as Mechanical and Agroindustrial Engineering, Industrial, Mechatronics, and Electrical and Computer Systems, among others. Although there exist a large number of textbooks available for consultation and reference of the thematic contents, they usually do not focus on the presentation of practical industrial examples or real-life applications (Wang, 2011). In addition, a large part of synchronous and asynchronous sequential circuits is generally analysed only through simulations and laboratory practices, where practical development is limited to testing commercial circuits using certain inputs, to obtain different states and outputs without being focused on solving a particular situation. It is essential to motivate students to solve practical problems in their environment using the sequential circuits that they learn to use in the course, such as the integrated circuits of the TTL 74-series family in combination with microcontrollers to perform more elaborated tasks.

Within introductory courses on the subject of Digital Electronics, the use of simulators to predict the behaviour of the circuits is very useful, in addition to gaining an understanding of the distribution of physical pins of the

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integrated circuits to make virtual and physical connections (Itagi & Tatti, 2015; Mwikirize et al., 2010; Poole, 1994). In situations such as COVID-19 emergence, the teaching and learning processes are carried out online in individual environments (Barba-Pingarrón et al., 2022; Monroy-Varela et al., 2022), so it is important to still provide students with an application context for the theoretically analysed digital circuits; with this, students verify that the knowledge acquired is useful to solve multiple problems in their physical environment. To complement the theoretical knowledge and its representation through simulators, the use of a comprehensive physical project has shown good results among the students. This situation has allowed applying the theoretical and practical concepts of the course related to Digital Electronics by promoting the innovative ability to make adaptations and modifications based on the new knowledge acquired in the subject (Kohl, 2019; Liu, 2014).

In this way, students can develop their theoretical and practical skills with the analysis and synthesis of circuits that have a physical application, for example, a production process that is part of their environment and solves problems in their community; in the case of biological processes (Flores Mollo & Aracena Pizarro, 2018; Fu et al., 2019). Previously, satisfactory works have been developed focused on the automation of irrigation systems for plants using low-cost devices (M. R. Ruman et al., 2019; S. N. Kothawade et al., 2016). For the implementation of the systems, accessible elements were used both for the measurement system and for implementation of a final control element. On the one hand, it is common to use a hygrometer humidity sensor to monitor the water content in the soil, a solenoid valve, or a motor with a pump that allows irrigation. The value obtained from the humidity sensor is one of the parameters that enable the final control element to be activated or deactivated. When the system starts its operation, there exists a need to provide the user with some interface tools to modify the operating parameters quickly and easily during its operation. In addition, it was necessary to complement the system with a user display of pulse content to verify that the system works correctly, as well as to allow generating a record of its operation.

In this work, a didactic precision agricultural irrigation system has been developed that satisfies the needs described above. In addition, through the calibration of the water irrigation system, it has been possible to determine the amount of water that has been provided to the plant in a certain range of time. Interest in the development of low-cost applications in agriculture has recently increased (A. Sengupta et al., 2021; Brambilla et al., 2021; Duarte et al., 2021; Martínez et al., 2017; Simanjuntak et al., 2017). In this work, the automated irrigation of a crop is enabled with a certain amount of water at the right time to maintain the humidity of the soil where the growth of the crop takes place, improving the interface system so that the user of the system can select the operation of the parameter without reprogramming the device.

Materials and methods

An Arduino Nano-based board has been selected for implementing two control routines through software development. The measurement carried out with a humidity soil sensor is compared with the humidity set point and based on the result, the water injector is activated or deactivated for watering the plants. The microcontroller board uses two digital inputs D4 and D5 respectively. The first digital input was used to enable/disable the injector regardless of the selected set point. Input D5 was used to select the set point of the variable soil moisture. The maximum value that can be selected as a set point is 1023 and corresponds to the measurement when the soil is completely dry. As the measurement values decrease, higher water content is observed in the soil. An analog input A0 was used to obtain the analog humidity sensor measurement and a digital output D13 as the activation signal of a module with a Mosfet IRF520; as a solid state on / off switch.

The power stage module allowed the conduction of electrical current from a 12-volt battery to the water injector internal coil. Each time the coil is energized, the water flow is allowed to exit the electrical valve. A digital pulse train defines the time during which the injector allows flowing water inside it with a certain time frequency. The water injector was connected to a 2-liter water storage tank, forming a 0.80 meters water column. To determine the amount of water supplied to the plant each time the injector is activated, 100 irrigation pulses were counted with an injector opening and closing time of 1 second respectively, obtaining 25 milliliters at the end of the test. It is considered that each time the injector is activated to allow irrigation of the soil, 0.25 milliliters of water flow to the substrate. The connection diagram of the inputs and outputs of the microcontroller card shows the use of only 4 pins as shown in Figure 1.

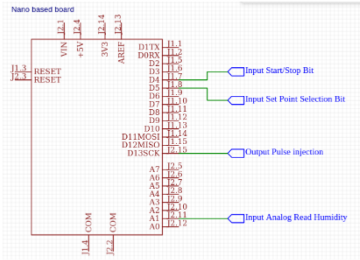

Figure 1. Inputs and outputs definition. Source: self made.

The activation and deactivation of the injector regulate the amount of water that is allowed to flow to the substrate where the plants are housed. The user can select any of the implemented control routines, this is allowed through two one-pole switches and two shots each will be used. Internally, the switches have a normally open contact and a normally closed contact, as well as a common connection terminal. According to the switch position, the operating state of the switch is manually selected, which can be interpreted as on (1) and off (0). The use of the switches is intuitive and the ergonomic design facilitates its manual use for various applications, they are frequently used to power up computers and various electronic equipment as well. On the other hand, when changes are made in the switch position, the momentary contact of the internal metals tends to generate oscillations that cause instability during the exchange of states, either during the transition from on to off or vice versa. This behaviour is considered undesirable for most electronic systems since the oscillations can be registered and promote undesired behaviour in the control systems.

To solve this situation, the application presented is part of the introductory topics in the field of Digital Electronics, such as latches and flip flops (A. N. Borodzhieva et al., 2020). An RS latch implemented with NAND gates was selected. The circuit was used to obtain clean state transitions between on and off to achieve that digital signals can be read and interpreted without oscillations through the input ports of the microcontroller. The implementation of the asynchronous sequential circuit was carried out using only an SN74LS00N integrated circuit that has four NAND gates, sufficient for the implementation of two Latch RS circuits as shown in Figure 2.

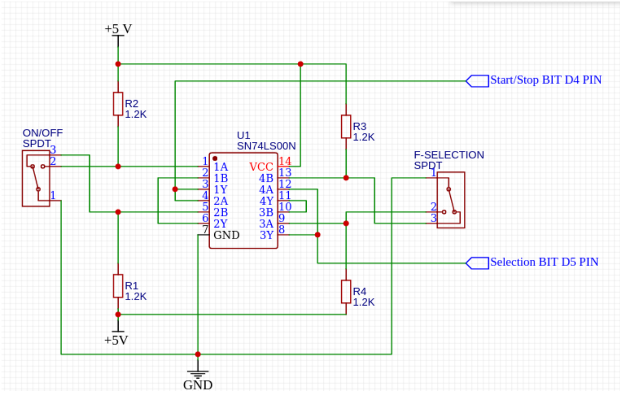

Figure 2. Implementation diagram of Latch RS circuits with integrated circuit SN74LS00N. Source: self made.

The RS latch circuit output from switch 1 was physically connected to Pin D4 of the Arduino Nano-based board. By placing switch one in position off state (0) the injector must remain inactive, regardless of the position of switch 2 that selects the two different set points for the humidity sensor reading. Placing switch one in the on position (1) enables the control system to start the irrigation injector with one of the two possible set points for the soil humidity variable. The selection switch allows using one of the two programmed set points to trigger the irrigation event towards the plants. When the selection switch is in the off position (0) the trigger value for activation is 480 and when the selection switch is in the on position (1) the trigger value for system activation for water irrigation is selected at 530. Increasing the trigger value implies reducing the humidity in the substrate and may eventually reduce water consumption during the entire growth cycle. Both injector trigger limit values can be easily modified through a programming code developed in the Arduino development environment. A flowchart for implementation is shown in Figure 3.

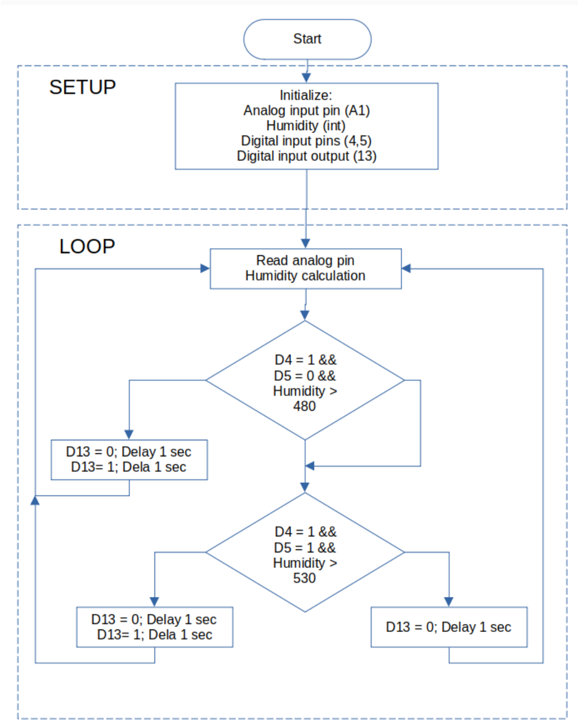

Figure 3. Flowchart used for automatic watering. Source: self made.

In parallel to the water irrigation activation system, a counting pulses system and data display from 0 to 99 was implemented, this module covers the counters and decoders found in the course. The application made it possible to have a record of the total number of water irrigation pulses since a Mentha spicata plant was acquired and the control system began with the irrigation cycle initially with a set point of 480. The counter system synthesis was made using two 74LS90 decade counters in a cascade configuration. For the power and ground connections, the 5-volt power supply provided by the Arduino Nano-based board was used. The output of each of the counters was presented in a BCD encoded way through its output pins, so it was necessary to connect a 74LS47 decoder to provide the necessary logic levels to present each number through a common anode 7 segments display. The pulse irrigation counting and display system allowed the monitoring of the control system operation and the determination of the amount of water added to the plant during each irrigation pulse. The electronic diagram of the pulse counter implementation in Figure 4 shows the electric device integration.

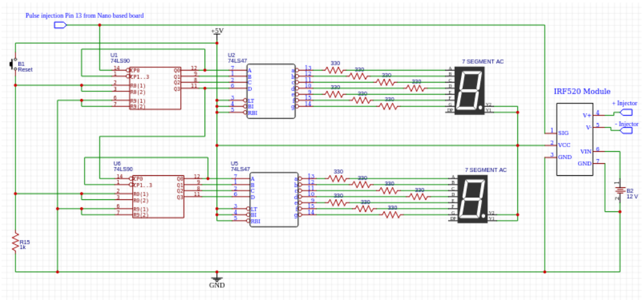

Figure 4. 0-99 circuit diagram using the 74Ls90 decade counters. Source: self made.

The couting system using 7 segment displays was easy to read for any user of the irrigation system. It allowed determining how many times the system has been activated automatically without the physical presence of the user, in addition to providing an estimate of how much water has been added to the plant since the last visit by the operator. This situation can be relevant in environments with sudden climatic changes, where factors such as a high ambient temperature promote higher soil water evaporation and higher water consumption by the plant also. The integration of the different low-cost electronic elements for the synthesis of the precision irrigation system was made using accessible devices as in Figure 5.

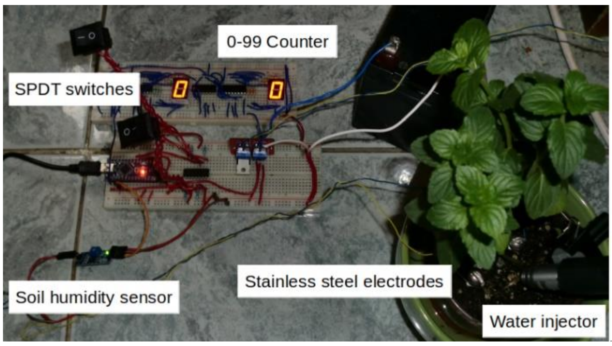

Figure 5. 0-99 circuit diagram using the 74Ls90 decade counters. Source: self made.

Results and discussion

In order to test the system, both switches were placed in the initial position of 0, in addition, the counter was initialized in 00 counts. The electrodes were introduced into the plant substrate and serial communication was enabled in the microcontroller board for registering and monitoring the soil humidity variable. The soil humidity data and time were displayed and retrieved through the serial monitor. The start of the test was at 10:40:58 hours on 07/05/2021 with an initial registered soil moisture value of 567. At that moment the control system was enabled with a set point of 480, so the water irrigation process started through the injector. The temporal evolution of the soil moisture variable was recorded for more than eight-day hours as shown in Figure 6.

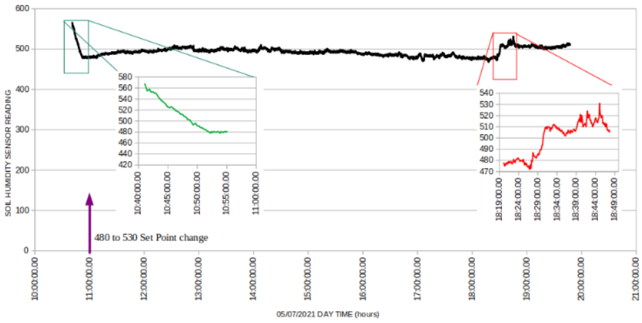

Figure 6. Soil humidity evolution selection two different set point for the soil humidity variable. Source: self made.

From the start of the test, fifty-five irrigation pulses were counted in a time of 10 minutes and 44 seconds until reaching the set point of 480. Considering that each injection pulse provides 0.25 milliliters of water, it took 13.75 milliliters of water to reach the soil moisture value reading of 480. Once the control objective was reached, the moisture variable remained stable with small oscillations around the set point. Twelve water injection pulses were necessary until the moment that the second set point was selected at 11:00:09 hours, that is, 3 milliliters of water in a time of 8 minutes. To select the second programmed set point, it was only necessary to change the position of the selection switch, which defines a set point of 530. Once the selection of the new set point was made, the humidity variable remained below I, so it was not necessary to add water, for 7 hours and 26 minutes. At 18:26:53 the beginning of an upward trend in the soil moisture variable was observed, at that time the recorded humidity was 472, which is even below the first set point. However, just 18 minutes later, the soil moisture variable increased until reaching a peak of 531 at 18:45:04, a time in which the control system correctly applied an irrigation pulse, managing to reverse the rising trend of the soil moisture variable to keep it below 530. In this way, the correct operation of the control strategies implemented in the microcontroller was verified.

The system as a whole was presented to the students of the Digital Electronics subject, highlighting the use of the application of latches, counters, and decoders integrated into the pulsed irrigation control system. The operation of the microcontroller board, the measurement system with a humidity sensor, and the power stage for activating the valve solenoid for watering plants were described. At the end of the presentation system, the student's perception of development was verbally discussed. It was found that there is a growing concern about demographic growth and growing demand for healthy foods, grown with the intelligent use of the limited resources available, such as water. In this sense, the great advantage of the system for people dedicated to agriculture was highlighted, on one side favouring a rational use of water avoiding its waste or misuse, and on the other hand reducing the most common human errors that can be committed during irrigation activity; for example, forgetting to water the plant, do it in excess or infrequently based on the climatic conditions of your environment.

Conclusions

An electronic precision agricultural irrigation electronic control system was implemented within the framework of the Digital Electronics subject. The project was part of a comprehensive application project using different electronic devices presented in the subject. Through two latches and two manual switches, an anti-bounce circuit was implemented for the microcontroller board, which regulates the irrigation of the plant. In this way, the user was allowed to activate or deactivate the irrigation system at any time, in addition to being able to select two possible set points for the soil moisture variable, 480 and 530 respectively. From the selection of the set point, the system determined to activate or deactivate the irrigation in a precise and intermittent way; the duration of the irrigation pulse activated and deactivated was 1 second respectively. Through the watering calibration test, it was determined that each of the irrigation pulses provides an amount of 0.25 milliliters of water to the soil, with which it was possible to determine the amount of water supplied to the plant in a period. Additionally, an irrigation pulse counter was developed from 0 to 99 using two-decade counters, which allowed on one side, the user can verify that the system is active and under correct operation, and on the other side, to make a record for the number of times the irrigation system has been activated in a given time interval. The registration of the number of irrigation pulses was very useful to determine the water consumption of the plant within a range of time. The integration of the different electronic elements allowed to include a project on the subject of Digital Electronics that focused on the development of an automatic control system for precision irrigation agricultural irrigation. The basic electric devices were focused on latches and counters for improving the user interface to the microcontroller. The system obtained a favourable student perception due to the advantages that its use represents; using water in a rational way and the elements that facilitate its operation for people dedicated to agriculture. The presented electronic system can be also adapted for the precisely focused supply of nutritive solutions in cultivated plants that are developed in protected environments.

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