

Automated Hydroponic Controller using System Verilog HDL

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Abstract—The boom in the human community and rapid climate changes have left scientists puzzled about finding ways to sustain the world. Supplying adequate food to an escalating population requires taking away arable lands for use from traditional agriculture. This would lead to food scarcity. Hence the agriculture sector is on the way to adopt alternate practices for better and increased crop yields. Hydroponics is one way of soilless cultivation with better yields. This paper proposes an idea of hydroponic greenhouse where parameters essential for plant growth are monitored and automatically controlled efficiently.

Index Terms— Hydroponics, parameters, sensors, nutrients, automated controller, system verilog HDL.

I. INTRODUCTION

Farming has always been reserved for rural areas as the primary occupation. With a growing population throughout the world and abrupt climatic changes comes problems in providing sufficient food and shelter to everyone [1]. Rural areas are being urbanized to provide people with shelter. This urbanization and industrialization decrease the arable land that has been a media to provide the world population with food [2]. To address the issue of food scarcity, there is a need to increase crop yields. This is difficult with the aid of traditional agriculture with limited land. Thus, alternate ways of landless farming are being explored and introduced in the agronomy sector. Transforming the growth medium is a way out for sustainable production and to conserve depleting lands. Hydroponics is one way of soilless cultivation to grow plants in water [3]. The concept has been rising in fame.

Hydroponics has proved to be a better method evolved for farming because of productive resource management and high yields. By virtue of hydro-agriculture a number of commercial and specialty crop species can be grown in less time [4]. Hydroponic systems can be taken for urban cultivation to feed people with fresh foods. A few systems are introduced in the agriculture market that are easy to maintain. Nowadays they are integrated with the Internet of Things (IoT) to remotely monitor the parameters essential for plant growth like temperature, humidity and air quality.

Most of the existing systems are based on microcontrollers like Arduino. In this paper, an automatic hydroponic controller is designed that can monitor various parameters at regular intervals and control the entire system without any human intervention. This system can further be easily implemented on an FPGA board. The intent behind designing a self-regulating controller for soilless cultivation is to increase the crop yield and introduce more nutritional hybrid crops with minimal human intervention.

II. LITERATURE REVIEW

Domingues et al. [5] developed an automated hydroponic system that can efficiently monitor and fix pH and electrical conductivity of the nutrient solution using a software ControlHidro and a webcam. It was proved to be energy-saving by growing lettuce in the developed system under greenhouse conditions and in soil, and then comparing the parameters.

Sihombing et al [6] used Arduino uno microcontroller to develop a system that can automatically control the flow of nutrients for hydroponically grown plants. The system used some sensors to measure temperature and height of growth medium, and sent this accumulated data via WiFi module to Android smartphone. The values are also displayed on LCD display.

P. M. Koge et al [7] proposed a hydroponic system that would collect and store values of some essential parameters like air temperature, root's temperature, humidity, pH and LEDs via wireless fidelity (WiFi) module. The output data is stored on the cloud. The plants grown in the proposed system were found to have higher growth rate as compared to soil-grown plants.

Gokul Anand K. R. et al [8] proposed a system that riveted on tomato cultivation. The system was implemented on an Arduino Uno microcontroller interfaced with IoT enabled sensors and a WiFi module. The system measures the growth rate with respect to the amount of nutrients supplied and automates the irrigation process. The system helped to understand the growth ambience needed for tomato plants via the ebb-flow method.

Shreya T. et al [9] proposed a system implemented on an Arduino microcontroller that uses LED grow lights. The system measures temperature, humidity, pH, EC and light level and sends this data to the cloud location. This data can be accessed and monitored remotely.

B. S. Shubhashree et al [10] built a hydroponic system based on Arduino Mega microcontroller that fetches the sensed values for air quality, pH and flow rate and compares them with the threshold values in the Blynk application. This application enables the users to set the values needed for smooth operation of the system and to monitor the system remotely.

The paper [11] concentrates on operating on a single microcontroller to grow multiple crops. The hydroponic system uses the notion of embedded systems. Water level and pH values are taken into account to control the flow of water and nutrient supplements to the plants using the proposed algorithm.

The authors in paper [12] conducted an experiment under artificial lighting to investigate the plant's responses to various nutrient flow rates. To study this effect, the authors designed four replicates of the system with four different flow rates. Parameters like temperature, humidity and air pressure were measured by employing the required sensors. After growing plants for 21 days, they were analyzed based on certain parameters. It was observed that excess flow rate resulted in lower root surface, decreased nutrient absorption and poorer growth.

The rationale of Titan Smartponics [13] was to extend the application of hydro agriculture. Once the seedling is planted inside this indoor system and all initial parameters are set, the system constrains the parameters to foster healthy plant growth. It used two Arduino microcontrollers to scrutinize and regulate the captured variables, and one Raspberry Pi module to update the data in the software Domoticz. The monitoring and controlling can also be done through a mobile app.

The methodology suggested in [14] clubs Greenhouse and Nutrition Film Technique to intensify the plant growth under controlled environment. The design is based on an Atmega microcontroller integrated with a number of sensors to quantify different parameters. The intention behind this design was to remotely monitor and control the closed ambience by means of the developed Android application.

The authors in paper [15] suggested a fuzzy logic controller for balancing the electrical conductivity (EC) and pH of the nutrient solution. Raspberry Pi module is integrated with EC and pH sensors to regulate the working time of the pumps. The values for controlled and uncontrolled plants for 19 days were set side by side to deduce that the proposed mechanism is proficient in regulating the EC and pH values.

III. METHODS

Xilinx Vivado 2018.2 tool has been used for simulating and synthesizing the design. The RTL description of the controller is written in System Verilog Hardware Description Language (SV HDL) and is verified using System Verilog testbench. The user is only required to plant a seedling and set the limits for all the variables as different crops have different variable needs. Further, the system can operate without any human intervention.

The controller measures air and water temperature, humidity, pH and Dissolved oxygen (DO) values of the growing medium employing suitable sensors. If the values measured by the sensors are outside the desired range, then it will activate corresponding actuators that provide desired amount of thrust to correct the parameters.

Temperature values control the heater and cooling fan. Exhaust fan takes care of humidity inside the system. The amount of nutrition solution in the water is controlled by pH values. Likewise measured DO controls the air pump. Figure 1 describes the flow of the designed system.

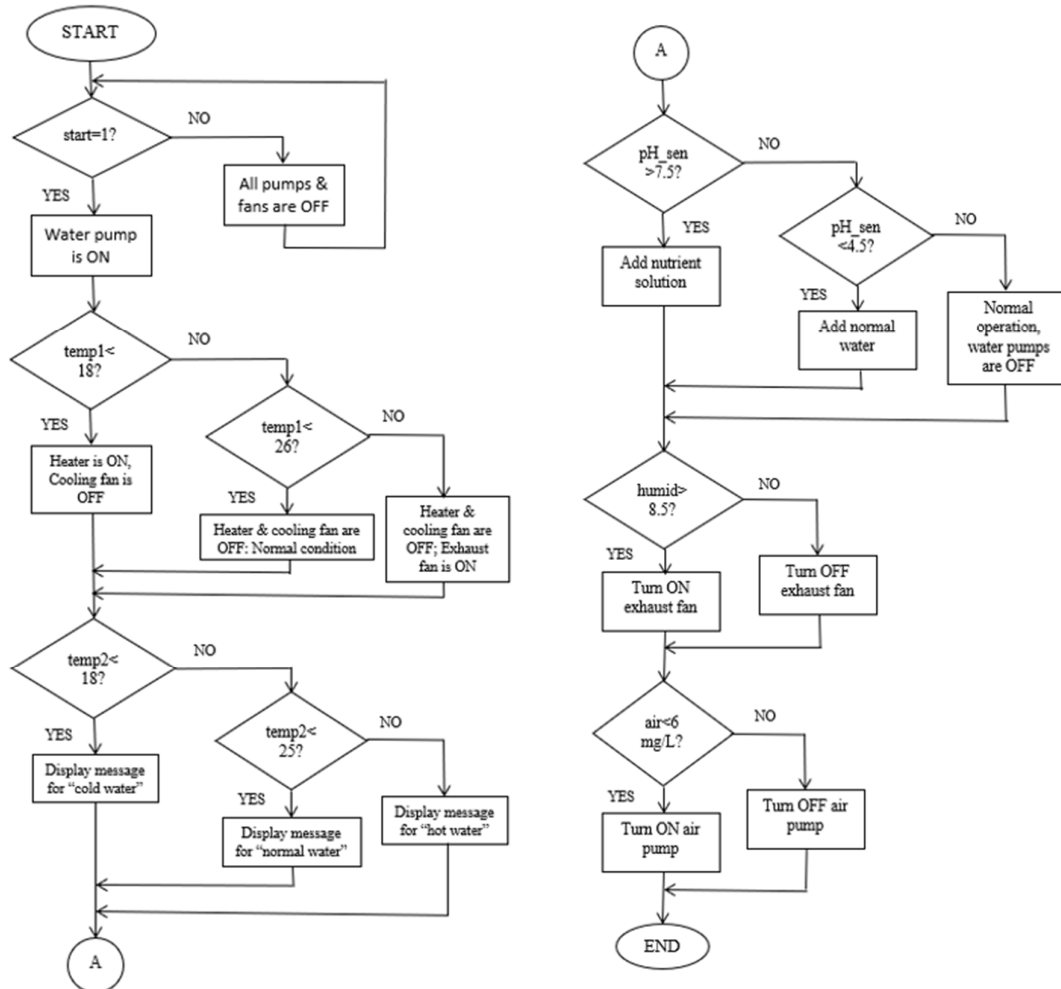


Figure 1. Flowchart

The desired range for the air temperature sensor is kept to be 18°C - 26°C. If the temperature is below 18°C, then the controller will automatically command the heater to turn on and the air conditioner will be turned off. If the temperature is more than 26°C, then the heater will be turned off and the air conditioner will start. In the similar way, the favorable water temperature range is kept to 18°C-25°C. The water temperature is monitored by the controller at regular intervals and suitable messages are displayed. For example, if the water temperature goes below 18°C, then it will display a message "Water is too cold for the plants".

Next in the flow diagram we have a pH sensor block. If its value is below 5, it signifies that the growth medium has become more acidic and needs normal water. So, the water pump gets activated. Likewise, if the value goes beyond 8, it means the nutrient solution is to be added.

There is another important parameter being monitored-humidity. The humidity sensor is measured in percentage. Here values are taken from 0 to 10, where 0 corresponds to 0% humidity and 10 corresponds to 100% humidity. Exhaust fan is activated when humidity is more than 80%, else it is deactivated for other times.

In the end, there is a block for automating the air pump as depicted by the figure 1. This block uses the DO value to activate or deactivate the air pump. Ideally, the growth medium must have a minimum of 5 mg/L of dissolved

oxygen. In the proposed system, the deciding dissolved oxygen value is taken as 6 mg/L. If the sensed value goes below 6 mg/L, then the air pump is activated, else not.

IV. RESULTS

The design has been simulated and synthesized in the Xilinx Vivado tool with the help of System Verilog testbench. The testbench is covering all possible test cases for the system to work effectively. Figures 2 and 3 show the output waveforms obtained after simulating the design. In figure 2, when the system is off, all actuators are also in sleep mode. After 10 ns, when the system is woken up, the sensors get activated and check for the parameters.

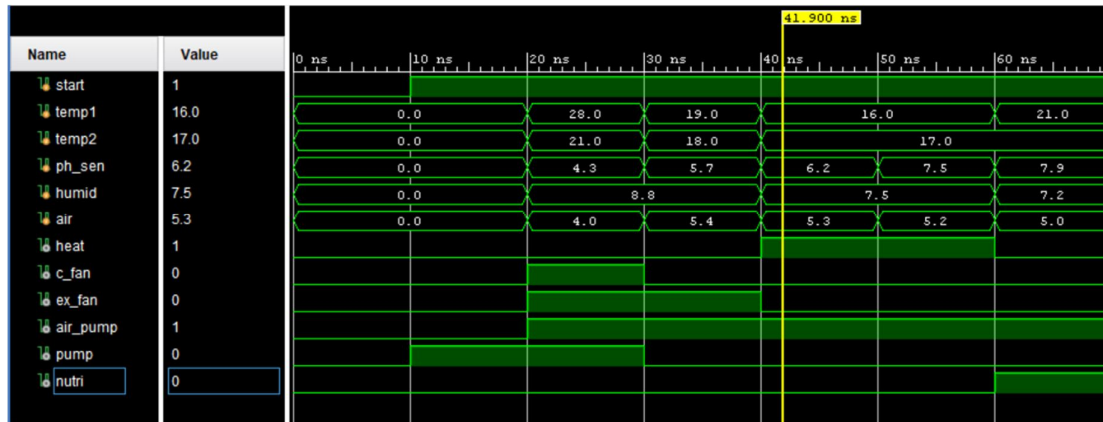


Figure 2. Output waveform when the system is just started and measures the parameters

If the sensed values are not meeting the criterion, then they are corrected by suitable actuators. The status of the actuators is also specified in the Console window. As the system is commanded to shut down by resetting the “start” flag to 0, all fans and pumps are turned off. This reset condition is visible in the last timestep of figure 3. The system has been observed to be energy-saving as according to the power report obtained after synthesis, the design consumes 79mW of power. Whether or not the measured values meet the desired conditions, the status of all the actuators along with the values get displayed in the TCL Console window as shown in figure 4.

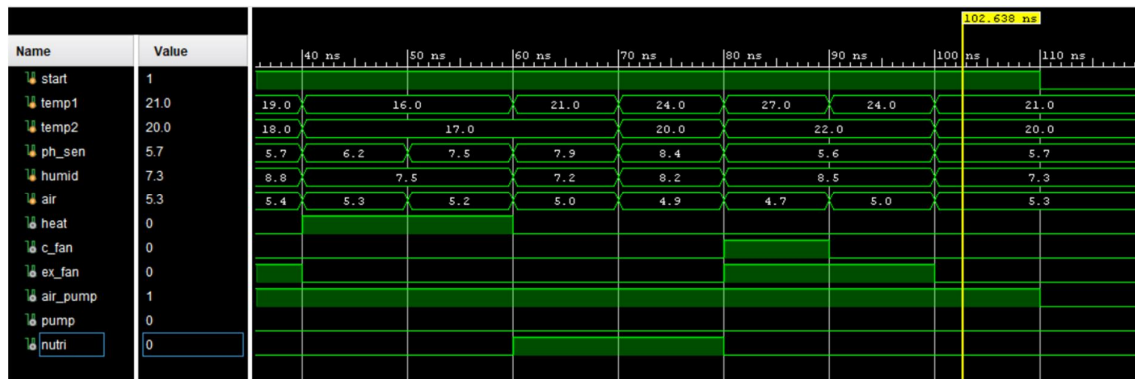


Figure 3. Output waveform when the system continues quantifying the parameters and then is turned off

V. DISCUSSION

Most of the prevailing hydroponics systems are based on microcontrollers integrated with IoT devices. Microcontrollers are power-hungry devices and cannot provide parallelism. On the contrary, the proposed controller design can be implemented on FPGAs overcoming the above stated limitations.

Plying System Verilog instead of VHDL or Verilog has been proven to be advantageous for the proposed design. Hydroponic system uses liquid nutrients which are diluted in water before supplying to the plants. These

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# run 1000ns
Temperature is 0.00: Heater turned ON
Water temp= 0.00 -- too cold for plants
System started: water pump is ON
Growth medium has pH= 4.30 -- acidic
DO is 4.00: Air pump is turned ON
Water temp=21.00 -- good for plants
Temperature is 28.00, hence greater than 26: Cooling fan is ON
Growth medium has pH= 5.70 -- within normal range
DO is 5.40: Air pump is turned ON
Water temp=18.00 -- good for plants
Temperature is 19.00, it is in nominal range
Growth medium has pH= 6.20 -- within normal range
DO is 5.30: Air pump is turned ON

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Figure 4. Console Window Snippet

nutrients need to be supplied in a very precise quantity for which usually peristaltic pumps are used. System Verilog enables the users to enter real inputs which otherwise are not possible in VHDL and Verilog HDL.

VI. CONCLUSIONS

The suggested system is observed to have an edge over existing systems in terms of power consumed. It can control the parameters in a more precise manner.

There are a number of technologies which can be added to enhance the controller. A camera can be incorporated to capture the progress of plant growth once or twice a day. More parameter blocks can be added as per the requirement to enhance the crop yield.

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REFERENCES

- [1] R. Rayhana, G. Xiao and Z. Liu, "Internet of things empowered smart greenhouse farming", IEEE Journal of Radio Frequency Identification, vol. 4, no. 3, pp. 195-211, Sept. 2020.
- [2] D. Adidrana and N. Surantha, "Hydroponic nutrient control system based on Internet of Things and K-nearest neighbors," 2019 International Conference on Computer, Control, Informatics and its Applications (IC3INA), pp. 166-171, 2019.
- [3] Madhuri Shrikant Sonawane, "Hydroponics: An upcoming and innovative way of future farming", International Archive of Applied Sciences and Technology; Vol 9, Issue 1, pp. 69-74, March 2018.
- [4] Nisha Sharma, Somen Acharya, Kaushal Kumar, Narendra Singh and O. P. Chaurasia, "Hydroponics as an advanced technique for vegetable production: An overview", Journal of Soil and Water Conservation, Volume 17, Issue 4, pp. 364-371, October-December 2018.
- [5] D. S. Domingues, H. W. Takahashi, C. A. Camara, and S. L. Nixdorf, "Automated system developed to control pH and concentration of nutrient solution evaluated in hydroponic lettuce production," Computers and electronics in agriculture, vol. 84, pp. 53-61, 2012.
- [6] P. Sihombing, N. A. Karina, J. T. Tarigan and M. I. Syarif, "Automated hydroponics nutrition plant systems using arduino uno microcontroller based on android", Journal of Physics: Conference Series 978, IOP Publishing, 2018.
- [7] P. M. Koge, N. B. Deshame, K.T. Chhatwani and P.S. Shetgar, "Developing and monitoring of hydroponics using IoT", International Journal of Recent Technology and Engineering, Volume-8, Issue-6, pp. 4876-4879, March 2020.
- [8] Gokul Anand K. R., Rajalakshmi N. R. and Karthik S., "Hydroponics a sustainable agriculture production system", International Journal of Innovative Technology and Exploring Engineering, Volume-9, Issue-6, pp. 1861-1867, April 2020.
- [9] Shreya T. Sahar Khan and Rujuta A. "IoT based automated hydroponics system ", International Journal of Scientific & Engineering Research, Volume-9, Issue-2, pp. 67-71, February 2018.
- [10] B. S. Shubhashree, Divya D., Harsha M. H., Jyothi T. U. and Yashonidhi Y., "Design of hydroponics system for remote automation", International Journal of Engineering Research & Technology, NCCDS - 2020 Conference Proceedings, Volume 8, Issue 13, 2020.

- [11] Mitali V. Shewale, Devendra S. Chaudhari, "IoT based plant monitoring system for hydroponics agriculture: A review", International Journal for Research in Applied Science & Engineering Technology (IJRASET), Volume 6, February 2018.
- [12] Bateer B., Kotaro T., Mina Y., Xinyam W., Satoshi Y., Yang S., Ping An, Sadahiro Y. and Yasuomi I., "Effect of nutrient solution flow rate on hydroponic plant growth and root morphology", Plants 2021, Volume-10, September 2021.
- [13] Vaibhav Palande, Adam Zahir and Kiran George, "Fully automated hydroponic system for indoor plant growth", Procedia Computer Science, Volume 129, pp.482-488, 2018.
- [14] Dr. Asawari D., Tarit Das, Sakshi S., Rajeshwari D. and Tejas K., "Automated hydroponics with remote monitoring and control using IoT", International Journal of Engineering Research & Technology, Volume 9, Issue 6, June 2020.
- [15] C.-H. Chen, S.-Y. Jeng and C.-J. Lin, "Fuzzy logic controller for automating electrical conductivity and pH in hydroponic cultivation", Applied Sciences, Volume 12, Issue 1, 2022.