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Automation of Hydroponics System using Open-source Hardware and Software with Remote Monitoring and Control

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ABSTRACT

This study aimed to develop and install an open-source hardware and application software for the automation of different actuators and sensors in the hydroponics system established at ARDC-Wengkhar. A prototype automation system was developed using Raspberry Pi 3 installed with open-source hydroponics application software called Mycodo which acted as a main computing hub for the automation. The automation features included the schedule or timer-based switching of different pumps, conditional switching of the ventilation fans based on temperature/humidity, alarm and notifications via email when certain parameters exceed the normal value, data logging and remote access to the system. The prototype was installed in the existing hydroponics structures containing nutrient film technique, deep water culture and vertical tower. The prototype was found efficient, reliable, useful, affordable and expandable as it offers more flexibility and advanced features for any automated hydroponics system.

Keywords: *Automation; Hydroponics; Mycodo; Open-Source; Raspberry Pi*

1. Introduction

Hydroponics is the process of growing plants in the absence of soil with the help of added nutrient solutions (El-Kazzaz & El-Kazzaz, 2017). Hydroponics has become popular especially in urban areas to grow plants without soil and several studies have shown that plants grown with hydroponics are of high quality and consume fewer resources than traditional growing methods (Kularbphettong, Ampant, & Kongrodj, 2019). In Bhutan, the concept of hydroponics farming was recently introduced by the Department of Agriculture first being established at the Agriculture Research and Development Centre (ARDC) Wengkhar in 2019 and later, different models of hydroponics systems were developed in other research centres (DoA, 2021).

In the hydroponics system, there are several parameters such as air temperature and humidity, lights, water temperature, nutrient EC and pH which are difficult to be controlled or maintained

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precisely by human intervention. These parameters are important for healthy and faster plant growth (DoA, 2021). Therefore, automation is necessary to maintain these parameters within the optimum level to provide ambient conditions for plant growth (Dudwadkar, Das, Suryawanshi, Dolas et al., 2020). Also, it is reported that labour cost is one of the biggest recurring costs for any hydroponics system (DoA, 2021). Automation of hydroponics systems can reduce the labour required for crop production and reduce labour costs. Besides reducing labour costs, automation can also improve the efficient use of inputs such as plant nutrients, water and electricity which further reduces the overhead cost for the operation of the hydroponics system (Sharma, Acharya, Kumar, Singh et al., 2018). Although various types of automation devices for hydroponics systems are available in the market many are expensive, lack local technical expertise for installation, usage and maintenance under Bhutanese conditions. Therefore, a locally designed automation for hydroponics system was developed with the following objectives:

- Develop a prototype of an internet of things (IoT) based automated hydroponics system using open-source resources (hardware and software)
- Deploy and test the prototype for automation of existing hydroponics at the research centre

The basic architecture of the prototype is given in Figure 1. The primary functions of the prototype are to monitor the different parameters of plant growth which is done by different sensors and to control the parameters within the optimum level with the help of actuators present in the system. The secondary functions of the prototype are for remote monitoring, control and data acquisition. All these operations and controls were carried out by Raspberry Pi installed with open-source automation software called Mycodo.

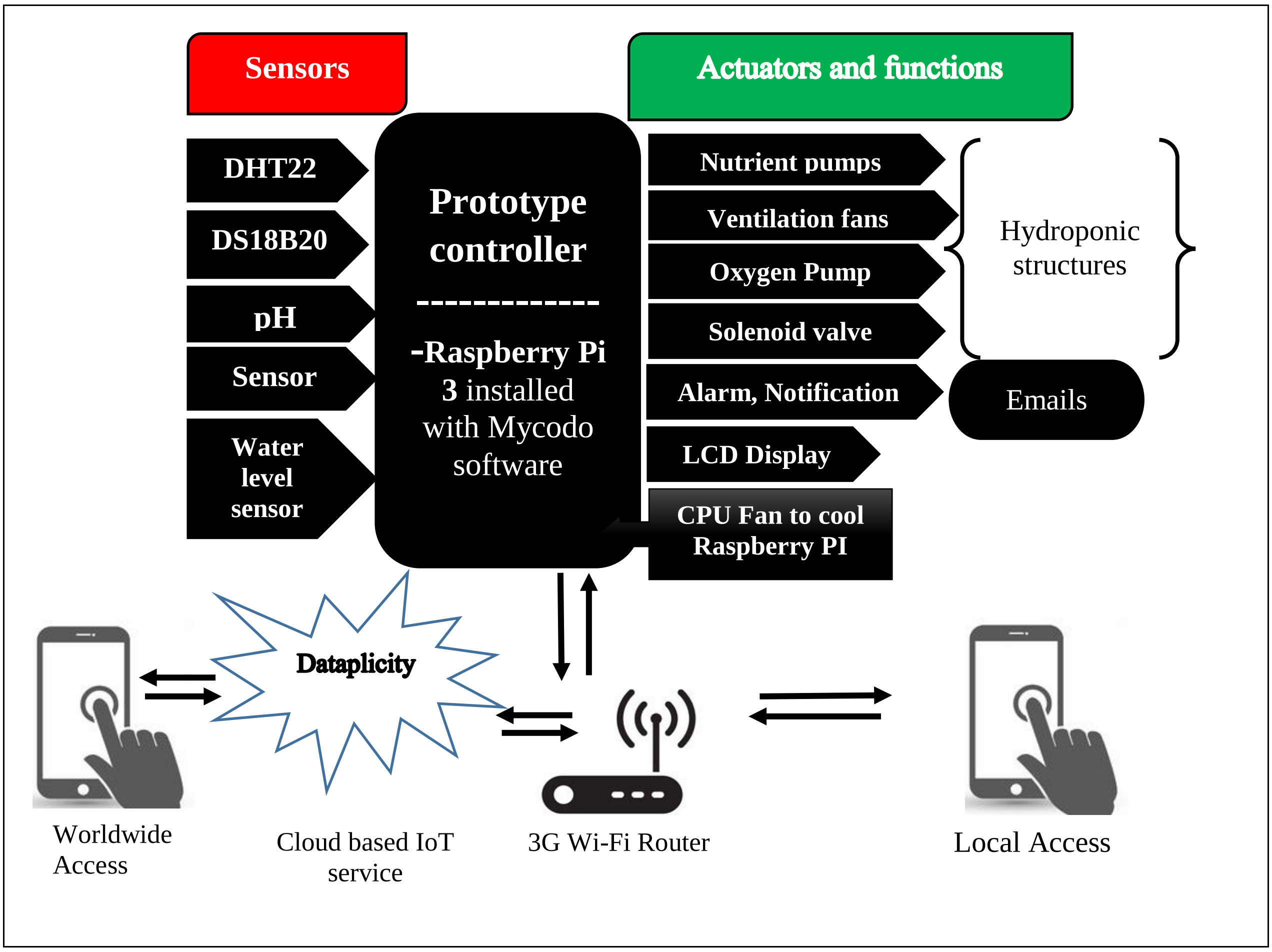

Figure 1. Basic architecture of the prototype automation of the hydroponics system

2. Materials and Method

2.1 Hardware:

2.1.1 Raspberry Pi

In this study, we used Raspberry Pi 3 model B+ (Figure 2) installed with the latest Rasbian OS Lite version downloaded from the Raspberry Pi Foundation website on 32GB micro-SD card. Raspberry Pi is a credit-card size single-board computers (SBCs) developed in the UK by the Raspberry Pi Foundation in association with Broadcom (Jolles, 2021). It is widely used in many areas as they are low cost with an open design that provides a set of general-purpose

Figure 2. Raspberry Pi 3 Model B+

input/output (GPIO) pins that allow to control electronic components for physical computing and explore the IoT.

2.1.2 DHT22 Environment Sensor

The DHT22 (Figure 3) is a low-cost digital temperature and relative humidity sensor with a single wire digital interface. It uses a capacitive humidity sensor and a thermistor to measure the surrounding air and spits out a digital signal on the data pin (Mihai, 2016). The sensor is factory pre-calibrated and does not require extra components to measure humidity and temperature. The temperature measuring range is from -40 to +125 degrees Celsius with ±0.5 degrees accuracy and humidity measuring range from 0 to 100% with 2-5% accuracy. The sensor is connected to GPIO-24 of the Raspberry Pi and is used for monitoring the temperature and humidity inside the hydroponics structure.

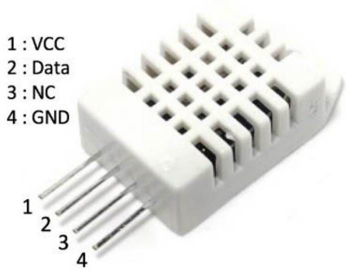

Figure 3. DHT22 Humidity and temperature sensor

2.1.3 DS18B20 Digital Temperature Sensor

DS18B20 is a 1-wire interface temperature sensor manufactured by Dallas Semiconductor Corp (Figure 4). The 1-wire interface requires only one digital pin for two-way communication with a microcontroller (Papoutsidakis, Chatzopoulos, & Piromalis, 2019). The sensor is quite accurate and does not require any external components to operate. It can measure temperatures from -55 ° C to +125 ° C with an accuracy of ± 0.5 ° C. This sensor is connected to the GPIO-15 of Raspberry Pi and used for monitoring the temperature of hydroponics nutrient solutions or water temperature.

Figure 4. DS18B20 digital Temperature Sensor

2.1.4 LCD Display

We used LCD1602 which can display 2 rows with 16 column characters with an integrated serial I^2C interface and green backlight (Boloor, 2015). The display is connected to the Raspberry Pi through I^2C interface GPIO pins and powered by a 5V power supply (Figure 5). It was used mainly for displaying critical data such as the temperature, humidity and IP address of the Raspberry Pi. It is necessary to know the IP address of the Raspberry Pi to access the system when connected to the local area network. In most home wifi routers, it is configured as Dynamic *Host Configuration Protocol* (*DHCP*) protocol which assigns IP addresses automatically and keeps changing daily.

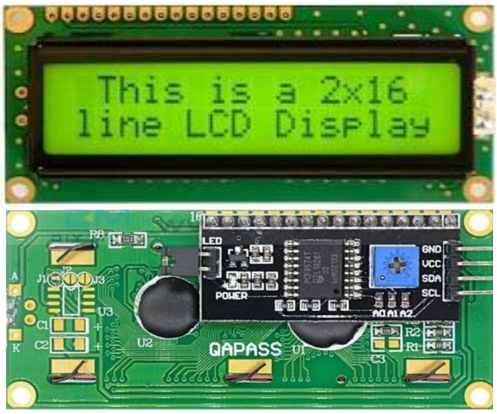

Figure 5. LCD1602 display integrated with I^2C serial interface

2.1.5 Actuators

An actuator is a device that is operated or activated based on the sensor values that are pre-set in the Mycodo software. The following actuators were used in the hydroponics structure at ARDC-Wengkhar.

- Nutrient circulation pump: Two centrifugal pumps (1HP and 0.5HP) for circulation of nutrient solutions in nutrient film technique and vertical tower
- Exhaust and ceiling fan: Two exhaust fans and three ceiling fans were installed for cooling and ventilation of the hydroponic systems
- Oxygen pump: Three oxygen pumps were installed in the DWC system for providing oxygen in the nutrient solution

2.1.6 Electronic components

Several other electronic components such as transistors, diode, resistors and relay modules were used for prototyping printed circuit board (PCB) for interfacing Raspberry Pi with sensors, actuators, and power supply (Table 1).

Table 1. Electronic components used in the study

Items		Specifications/module
1.	Relay module	10Amp, 12V relay
2.	Transistor	NPN, BC547
3.	Resistors	1 K Ohm resistor
4.	Screw Terminals	2 way, 3.5 mm pitch
5.	Male Pin header	20 pin, 2.54 pitch
6.	Female pin header	20 pin, 2.54 pitch
7.	PCB board	12X16 mm, double-sided
8.	Water pump	240V AC, 1 HP centrifugal pump
9.	Exhaust fan	240V AC, 70 watts
10.	Ceiling fan	240V AC, 80 watts
11.	Oxygen pump	240V AC, 18 watts
12.	Water filter	100 micron, flow rate 12m^3/hr
13.	Wifi router	3G or 4G wifi router
14.	SIM card	Tashi cell SIM with data package
15.	Enclosure box	30X45 mm plastic or steel box

2.2 Software

2.2.1 Automation software- Mycodo

The automation software installed on Raspberry Pi 3 is called Mycodo, which is open-source software for environmental monitoring and regulation system**s** developed and maintained by Gabriel (2021). The software was installed on the Raspberry Pi 3 by following instructions provided by Gabriel (2021).

2.2.2 Application software- Electronic Design Automation (EDA) software- KiCad

For drawing the electronic schematics and developing them into PCB, KiCad software was used, which is also free and open-source software for EDA which facilitates the design of schematics for electronic circuits and their conversion to PCB designs (Hill, 2010). KiCad version 5.1.5 was downloaded and installed on the Microsoft Windows 10 PC.

3. Results and Discussion

3.1 Schematic and prototype PCB development

The detailed circuit schematic and PCB were developed in collaboration with a local IT firm on KiCad software. Based on the circuit schematic, two prototype PCB boards were developed

(Figures 6 & 7) and printed on a 12 X 16 mm double-sided copper PCB board using HP laser printer. The printed PCB board was then itched with Ferric Chloride solution and all electronic components were soldered on the PCB board. These tasks were carried out in the local IT firm's fabrication workshop. The final prototype PCB board contained the following peripheral connectors:

- Raspberry Pi 3 or Raspberry Zero W model
- Sensor connectors for pH sensor, EC sensor, temperature and humidity sensor (DHT22 and DS18B20).
- Display connector pins for LCD 16X2 and 16X4 display through I2C bus. The other sensors and actuators which support the I2C protocol can be connected to the same connector
- Eight output connectors for actuators through relays boards
- One USB webcam connection through Raspberry Pi USB port
- Two input power supply connectors 12V and 5V DC
- One 12V DC output power supply

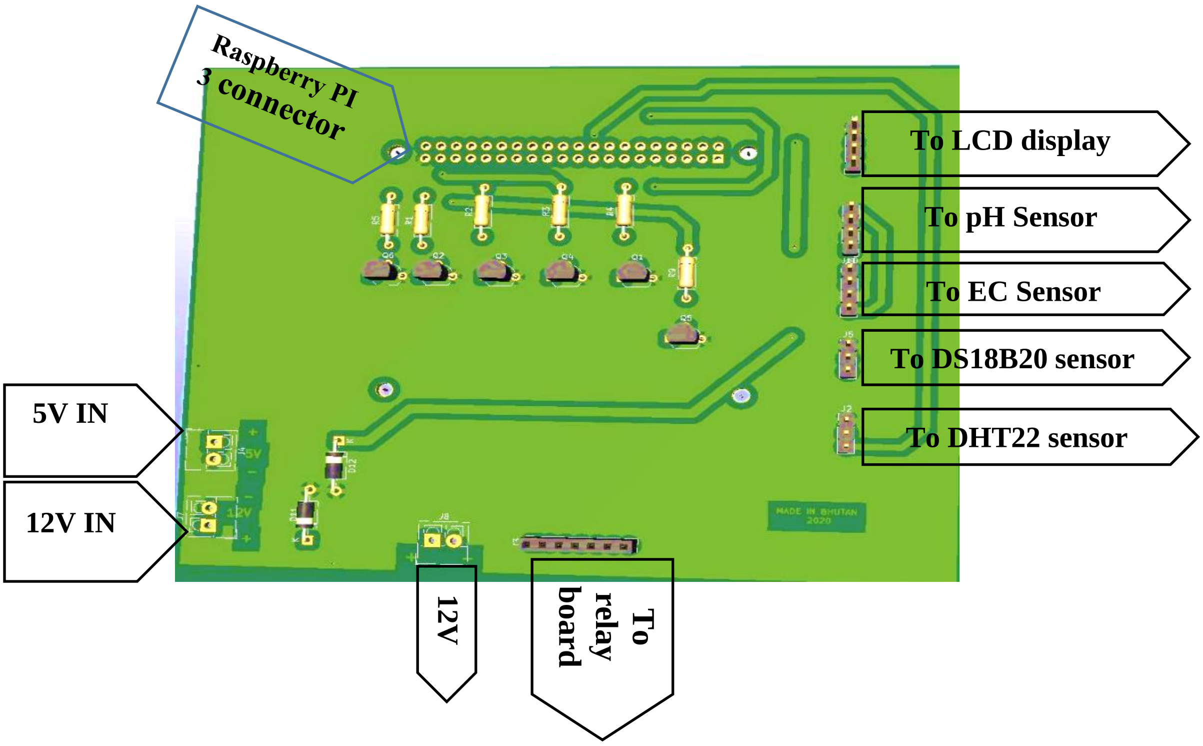

Figure 6. Front view of the double-sided PCB board for interfacing with Raspberry Pi 3, sensors, actuator and power supply

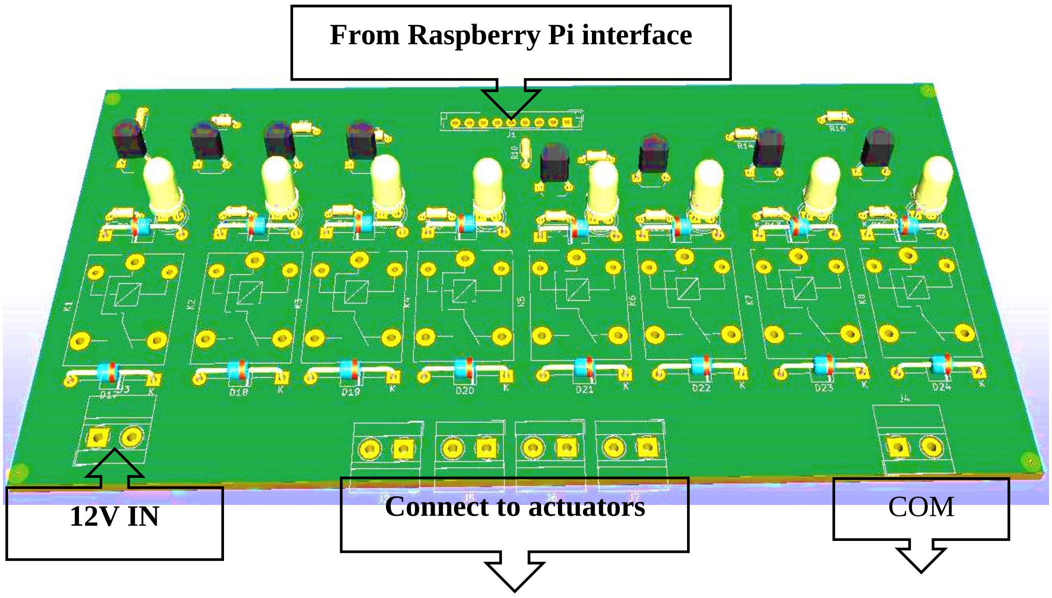

Figure 7. PCB board for relay module

3.2 Test results on the hardware configuration

The prototype PCBs were connected with sensors and actuators as shown in Figures 7 and 8 connector pins layout. Only two temperature and humidity sensors (DHT22 and DS18B20) were installed in the system. Other sensors such as pH and EC were not tested as they are not readily available for online purchase but connectors were made available on the PCB for future usage. The actuators included two numbers of AC pumps that circulated nutrient solutions in the NFT and vertical tower. For cooling and ventilation, two exhaust and ceiling fans were installed in the hydroponics structure and six numbers of oxygen pumps for providing oxygen in DWC.

Figure 8. Prototype automation box- inside view (*left*) & outside view (*Right*)

The system was also supported with a USB webcam for taking time-lapse photography and remote real-time monitoring of the hydroponics operation. The PCB boards and power supply modules were fitted into the weather-proof 35X48 mm size steel box (Figure. 8) and installed in the hydroponics structure containing NFT, DWC and the vertical tower that were already growing crops like lettuce, strawberry and medicinal herbs.

3.3 Test results on software configuration

Mycodo software installed on a Raspberry Pi acted as the main computing hub of the automation. The system consisted of two parts: a backend (daemon) and a frontend (web server). The backend performed tasks such as acquiring measurements from sensors and devices and coordinated a diverse set of responses to those measurements, including the ability to modulate outputs switch, relays, generate PWM signals, operate pumps, switch wireless outlets, publish/subscribe to MQTT, regulate environmental conditions with PID control, schedule timers, capture photos and stream video, and triggered actions when measurements meet certain conditions. The frontend of Mycodo hosted a web interface that enabled viewing and configuration of the system from any browsers using device IP address. The web interface supported an authentication system with user/password credentials, user roles that grant/deny access to parts of the system, and SSL for encrypted browsing (Gabriel, 2021). After logging into Mycodo system, the INPUT and OUTPUT features of the system were configured as follows:

3.3.1 Input device

Three inputs device were selected and activated in the system (Figure 9)

- DHT22 temperature and humidity sensor for measuring and monitoring the temperature/humidity inside the hydroponic structures
- DS18B20 temperature sensor for periodic measurement of the water temperature in the tank
- CPU temperature for monitoring the Raspberry Pi internal CPU temperature

3.3.2 Output device

Five GPIO pins of the Raspberry Pi were configured as outputs which were connected to the relay module (Figure 9). The relay module is connected to the following actuators:

- 12V CPU fan for cooling the Raspberry Pi
- Four numbers of exhaust and ceiling fans with parallel connections from one relay
- Two numbers of oxygen pump parallel connection from one relay
- One nutrient Pump (1HP) that circulates nutrient solutions in NFT

- 0.5 HP nutrient Pump which circulates nutrient solutions in the vertical tower

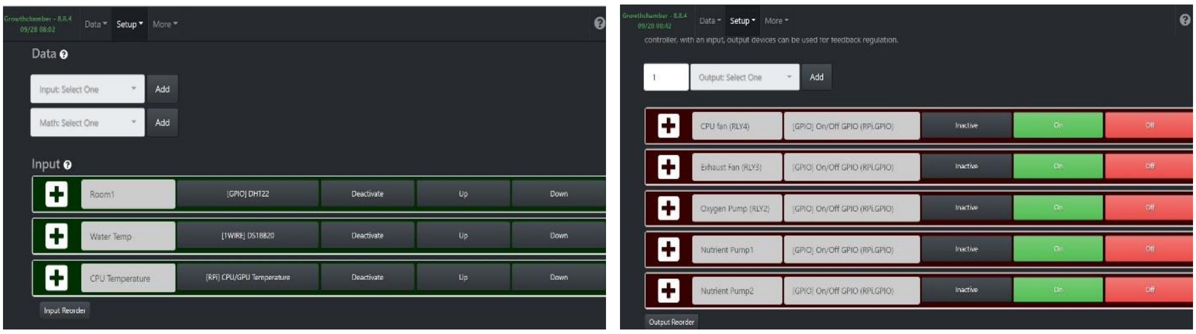

Figure 9. Configuration of INPUT (*Left*) and OUTPUT (*Right*) on Mycodo system

3.3.3 Configuring Functions

In the Mycodo software, the automation was mainly achieved by the interaction of various sensors and actuators located under the FUNCTION setting. The following functions were tested for automation of the system.

- Nutrient Pumps: The two nutrient pumps which circulate nutrient solution were configured to run for two minutes every 10 minutes interval on a timer-based module under the FUNCTION setting.
- Oxygen Pumps: Also, timer-based which runs for five minutes at every 30 minutes interval.
- Exhaust and CPU fans: Exhaust and CPU fans were configured as conditional functions which operate when certain conditions such as high and low set-point temperature of the greenhouse were met. These conditions were fed to the system in a few lines of python script under Function settings.

3.3.4 Configuring the LCD

On the Setup -> LCD page, 16×2 LCD" was set up to display the temperature, humidity and IP address of the device. 16×2 LCD has 16 Columns and 2 Rows and displays 32 characters on the screen.

3.3.5 Dashboard

Dashboard is an information management tool used to track, analyze, and display key performance indicators, metrics, and data points to monitor the overall health of the automation system. Dashboards in Mycodo are user-friendly and easy to set up.

On the Data -> Dashboard page, a custom dashboard was created as shown in Figure 10. The dashboard provided real-time detailed information on all sensors data and the status of various actuators present in the system. Based on this information, decisions were made on whether or not to turn on the air pump, water pump and lamp remotely according to the acquired information.

Figure 10. Dashboard for real-time monitoring of sensor data and the status of the actuators

3.3.6 Remote access

The remote access to the Mycodo system was done by installing a small piece of software called *dataplicity* on the Raspberry Pi that allowed to access Mycodo system which is behind firewalls and NAT (Bepery, Baral, Khashkel, & Hossain, 2019). Dataplicity's main function is similar to the port forwarding method for remote access, but it is easier, efficient and more secure than the port forwarding method. After installation, the Mycodo automation system was made accessible worldwide and can be accessed by any device (laptop, desktop, smartphone) connected to different internet networks like mobile data, broadband and lease line internet services.

3.3.7 Temperature and humidity test data

The Mycodo application showed that it received the data from sensors timely and made proper control of the actuators. It provided detailed information on temperature, relative humidity and dewpoint inside the hydroponics. Each log was updated constantly and showed the progression of temperature and humidity from day to night (Figure 11). The other sensors and actuators data (data not shown) such as water temperature, the temperature of CPU, the amount of time and duration of the different actuators (like pumps, lights, fans) ON-OFF state were also recorded and automatically logged into the system.

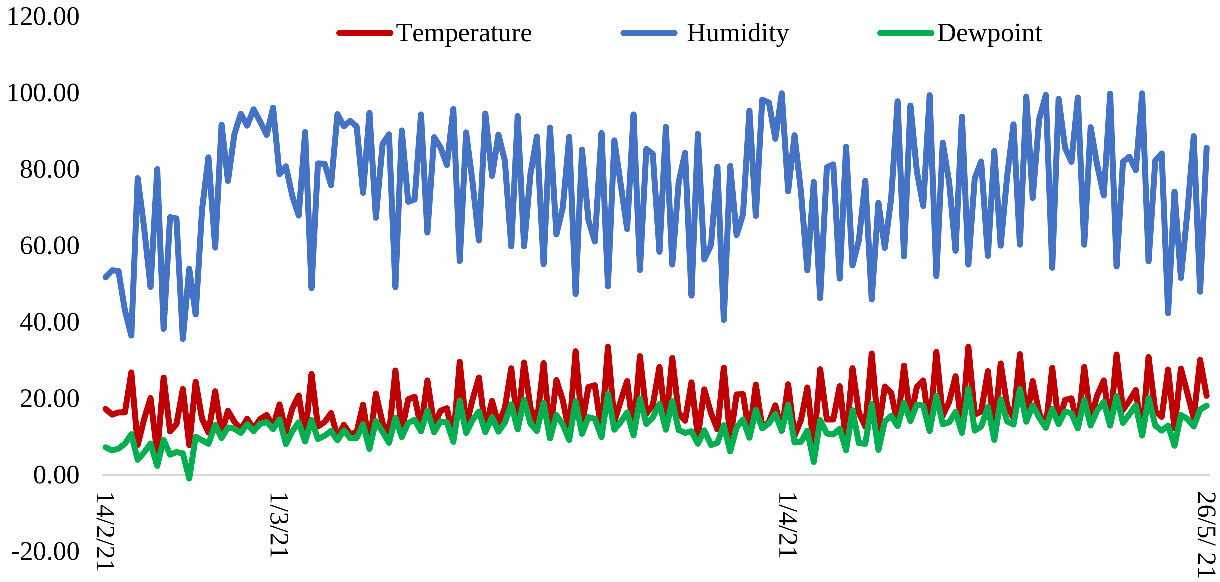

Figure 11. Log data on air temperature and humidity in the automated hydroponics system

3.3.8 Comparison of run time and energy consumption of different devices

The automation system was continuously tested for 70 days in the hydroponics structures that had been planted with different vegetable crops. The runtime and energy consumption of different devices in the automated and non-automated hydroponics system were compared using the logged data set in the prototype automation device. Figure 12 shows that the run time (hours) and energy consumption (kWatt) of the devices in the non-automated systems (manual operation) were more than 50% higher than in the automated hydroponics system.

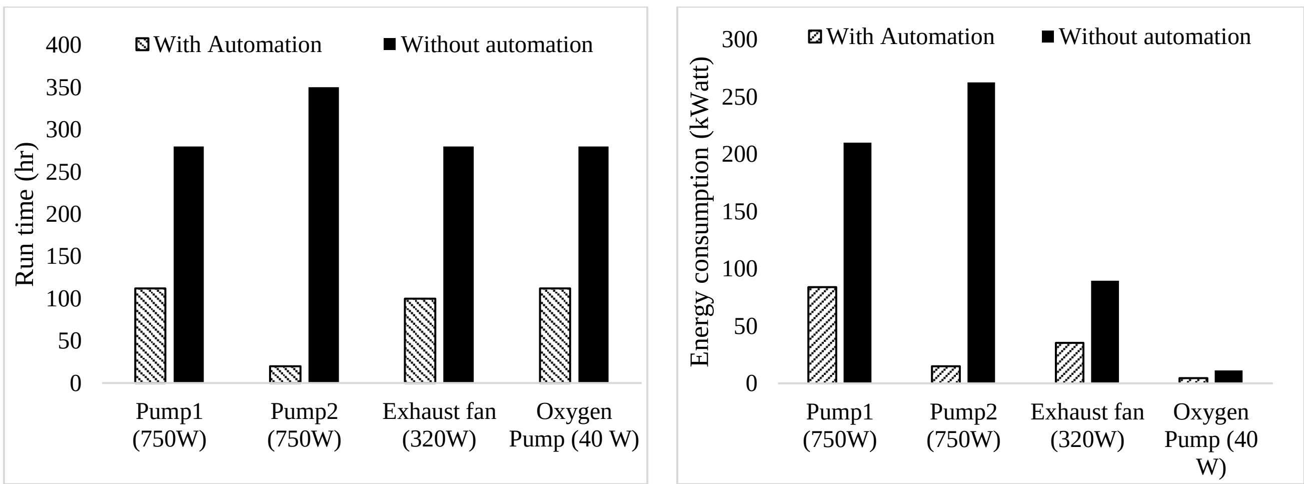

Figure 12. Comparison of runtime and energy consumption of different actuators during the testing period

4. Conclusion

Recently, hydroponics is seen as a promising technology for growing different crops as it is possible to grow short duration crops like vegetables around the year in a limited space and with limited water as it has water-saving efficiency of 70-90% compared to soil farming (Sharma et al., 2018). In Bhutan, hydroponics technology is expected to develop and be promoted as one of the means to attract youths into agriculture farming. Therefore, it is important to develop a suitable hydroponics automation system that reduces dependence on human labour and lower overall operational costs. The hydroponics automation prototype that we developed at ARDC-Wengkhar was deployed in real-field conditions for more than eight months and is tested to be efficient, reliable and useful. The prototype automation system is found to be expandable as it offers more flexibility and advanced features for any automated hydroponic systems for future upgrades and upscaling.

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