ECE 445

SENIOR DESIGN LABORATORY

PROPOSAL

Scrubbing CO2 Operational Prototype

Team #32

SEUNGHWAN HONG
(sh34@illinois.edu)
ALAN CARDIEL
(acard6@illinois.edu)
KINJAL DEY
(kinjald2@illinois.edu)

Prof: Arne Fliflet
TA: David Null

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1 Introduction

1.1 Problem Overview

The Sahara desert is the only region in the world where water insecurity amongst the local communities is steadily increasing. This region houses 15 of the world's 20 most water insecure countries. In addition, the Sahara desert has grown 10% in size since the 1920s, and continues to grow at an unprecedented rate due to global warming [1]. Access to clean drinking water is a basic human right, and this is a problem that must address as soon as possible.

Professor Jont Allen, of the ECE department at UIUC, has proposed a system to harness the power of the sun to desalinate saltwater and turn it into clean, drinking water. The system Professor Allen proposes involves pumping saltwater from the ocean into a tank in the desert, where the heat from the sun evaporates water, separating the salt. Then the resulting water vapor is lead to a colder tank, where it condenses and the resulting clean water is collected [2]. Currently Professor Allen's system is just a prototype that's still in the works. The issue is that Allen has a variety of ideas for modifications be made since his significant breakthrough of over 50% yield from salt water. However, since this is a prototype components are all separate and if further modifications were made without a more user friendly approach to run, his entire project could suffer from inefficiency.

Amongst the current list of issues that professor Allen is plagued by in his current prototype is that all of the components in the system are separated which can cause problems when setting up experiments by forgetting about components. Secondly there are some components that have to be set manually either by turning them on or by setting a value to them, this can also cause issues when trying to do experiments. Additionally there isn't an easy method for streamlining the data collected from experiments and storing it properly. Lastly is the efficiency of the system can be improved upon, but the lack of easy variable control limits this factor to be more difficult than it currently is.

1.2 Solution

By helping Professor Jont Allen in this research and development we will be able to solve issues that he may encounter in improving his current prototype. We will work along side professor Allen in improve upon his current model to further drive his research. We will create a control system to be able to improve the usability of the prototype. Along with that we will also need to measure input variables and predict what control variables need to be changed (direction and/or magnitude).

For each of the aforementioned solutions we plan to connect all electrical components to our board to have a centralized control with proper safety redundancies for different types of possible issues that we may run into. Set up an easy control switch so that when running an experiment a user can run the system at the simple press of a button with an input on duration of experiment. Lastly we will process and collect the data on a UI to be able to make the data readable, presentable, and usable for analysis in post testing.

1.3 Visual Aid

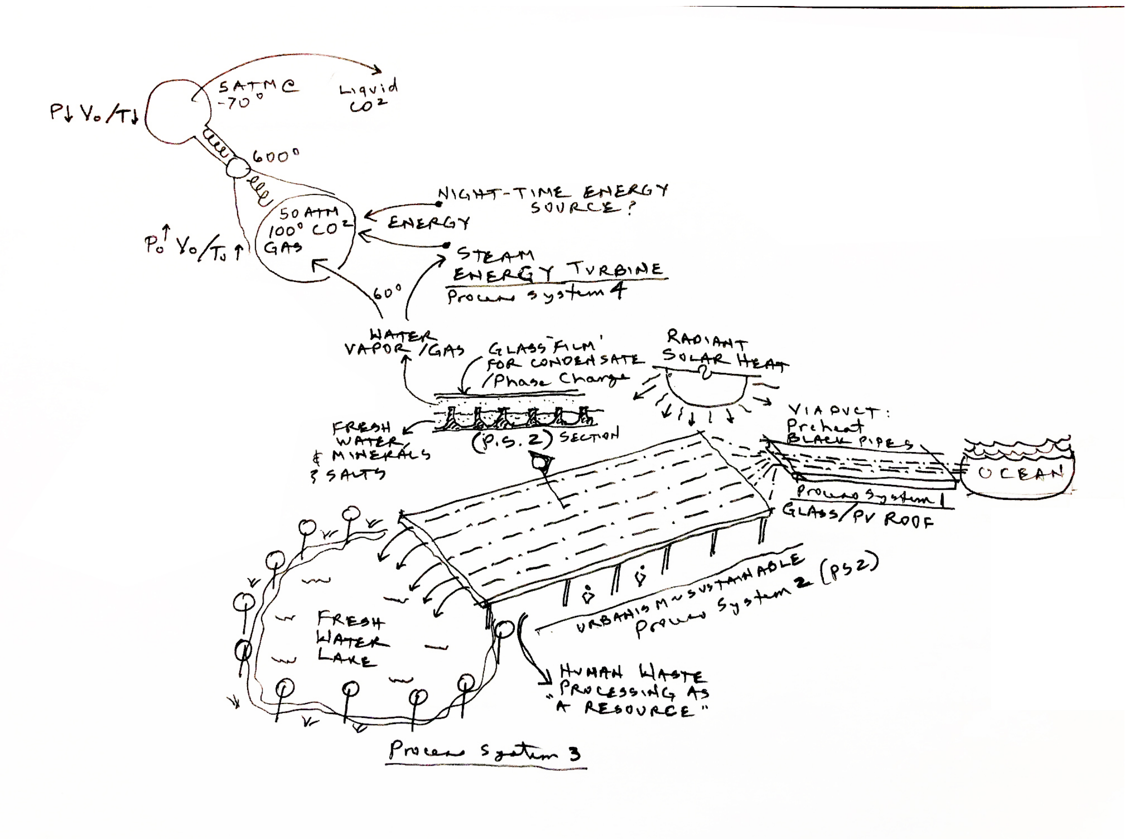
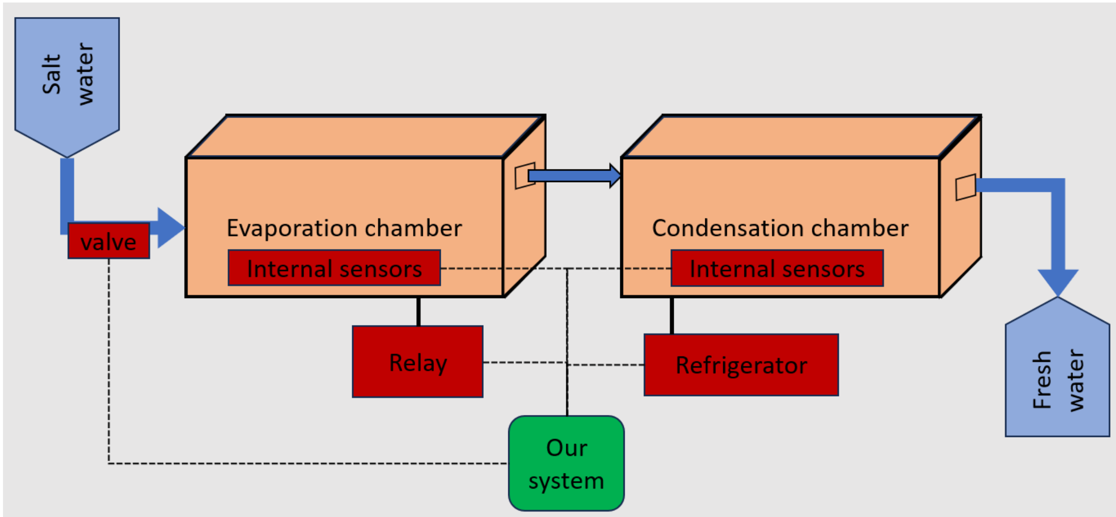


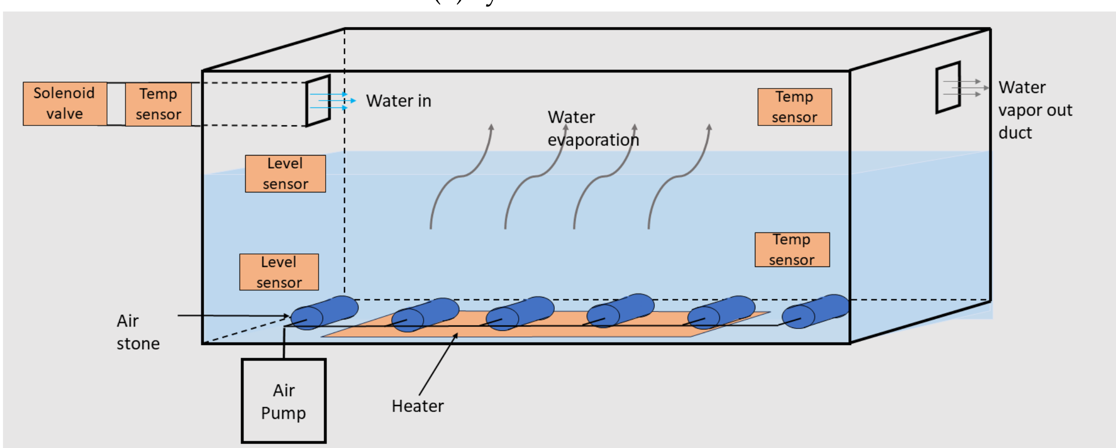
Figure 1: Desalination System: Large-scale[2]

The current prototype works by first manually powering on all sensors, valve, radiators, air pump, heater, and refrigerator. After powering on the flow rate is manually set by a flow meter. The process for conversion is the salt water intake flows into the evaporation chamber, as seen in figure 2b, where the water is evaporated by a heater to around 80°C (the air stones in the tank help to expedite the evaporation). Then vapor flows into the condensation chamber, figure 2c, through a duct between the two tanks to cool down the water vapor that is now desalinated. This happens by having a two radiators for proper cooling. The first radiator bring down the vapor from around 60°C down to about 40°C, and the second radiator with the help of a refrigerator cools the vapor down to sub 40°C where it begins to rain. The newly desalinated water is then collected in another tank for storage.

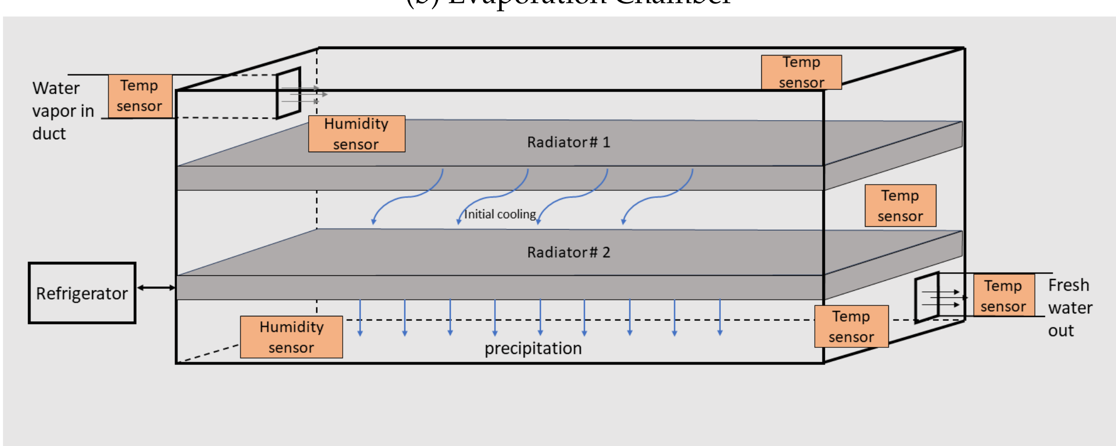
For our project we plan to take all the sensors (labeled in orange boxes) along with all external equipment to have a more user friendly and effective way to run experiments. This will allow for better efficiency of the system by determining yield percentage and better control of the various variables.



(a) system overview



(b) Evaporation Chamber



(c) condensation chamber

Figure 2: Prototype set up

1.4 High-level requirements list

The goals of our project which will determine if we are successful are as follow:

- Our system be able to take all the components 8 temperature sensors, 2 binary level sensors, 2 humidity sensors, 1 solenoid valve, relay for the heater, 110v air pump, 2 radiators and have it be controlled when powering up our PCB. This will allow us to turn on the system by the push of a button.
- With everything in one place, we will run our algorithm to power and start the system components of the 2 radiators, heater, air pump, and solenoid valve. Our algorithm will update the system every 4 minutes as it gathers new data from the 8 temperature sensors, 2 binary level sensors, and 2 humidity sensors.
- The system will collect data every 4 minutes from the sensors in CSV file format which we will present plot the data to showcase the system status. The graph will be displayed after running the experiment to show the progress.
- If time allotted then we plan to run experiments and configure the systems setting to increase the efficiency yield of the system.

2 Design

2.1 Block Diagram

Our desalination system comprises three main subsystems. Firstly, there is a power system that can provide electrical power to both AC and DC sources through converter and regulator. Secondly, a sensing subsystem is in place to gauge system control variables like temperature, humidity, and fluid levels. Lastly, there is an automated control system that manages the entire process by regulating the on/off switches of heater/radiators and a water valve responsible for introducing freshwater into our system.

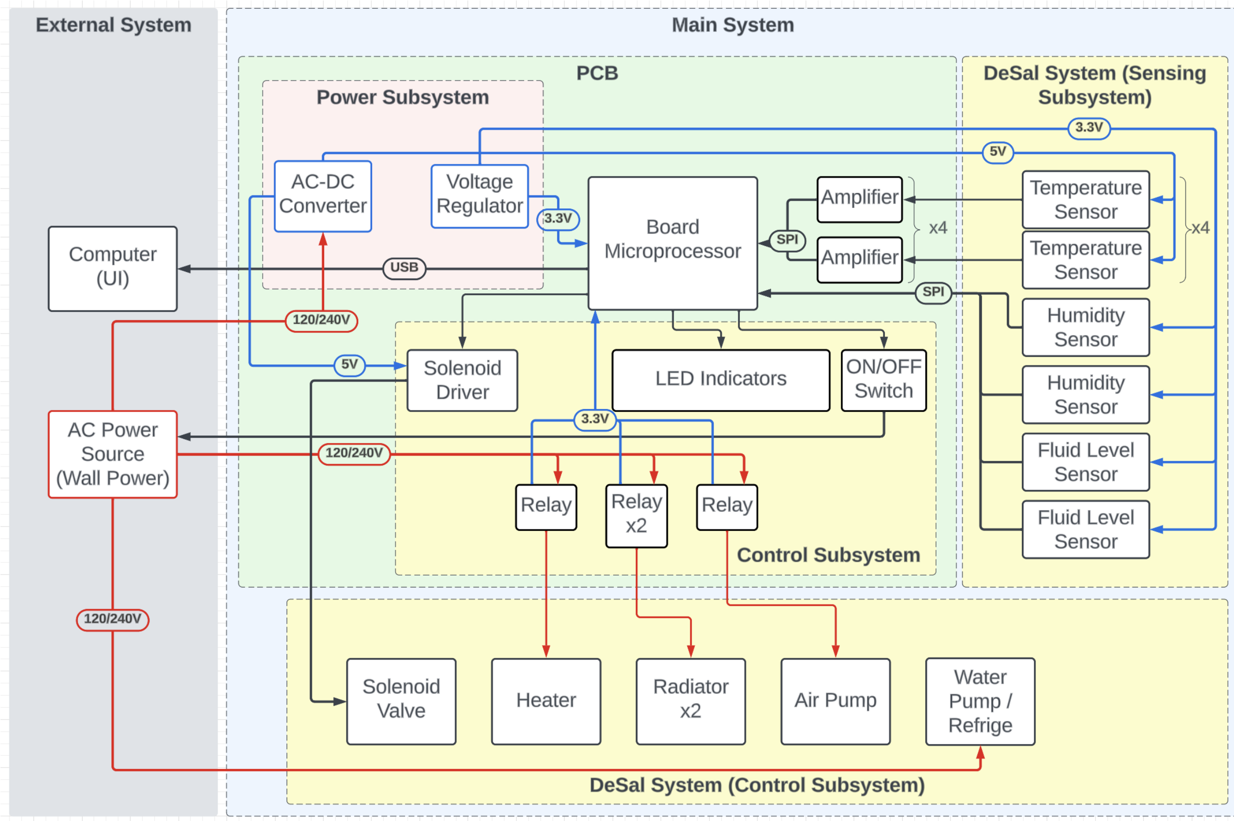


Figure 3: Block Diagram of DeSal system

2.2 Subsystem Overview

2.2.1 [Subsystem: Power]

The Power Subsystem is responsible for supplying power to all electronic components on the board, and provide the means to control the relays for the components that draw power from AC directly. AC-DC converter is responsible for converting the the power from the AC outlet into the 5V DC for 8 temperature sensors and solenoid driver. Voltage regulator is used to convert 5V DC into 3.3V DC for 2 humidity sensors and 2 fluid level sensors.

2.2.2 [Subsystem: Sensing]

The sensing subsystem has already been built by Professor Jont Allen, and we will be using it to collect raw data to manipulate in the Data Subsystem.

This subsystem consists of 8 temperature sensors, 2 fluid level sensors, and 2 humidity sensors. There are also 8 thermocouple amplifiers in the PCB which amplifies the low voltage signal generated by the temperature sensors to a high voltage that can be decoded by the microprocessor. Each sensor transmits data in SPI format to the microprocessor, allowing the microprocessor to both log and display the gathered data. The level sensors are binary level sensors each is position such that we know if water is above or below certain points in the tank.

Our microprocessor will read these sensors to know the state of the system and control the power on components in the control subsystem. This is so that the system maintains a steady state to ensure that experiments can run safely on their preventing any accident.

2.2.3 [Subsystem: Control]

The Control Subsystem is responsible for taking data from the sensing subsystem and commanding the valve and relays for the more power heavy components of the setup at the push of a button. With these given inputs, the control subsystem will have control over the relays and control variables of the setup. The Control Subsystem determines whether the setup will have power to run the experiment from the data it has gathered from the sensors with the implementation of our experiment running algorithm. Our Control Subsystem is made up of an ESP32microprocessor that interfaces with the sensors and amplifiers via SPI. These modules will be driven by the Power Subsystem via 3.3 volt outputs from the voltage regulator. To ensure that the Control Subsystem is fulfilling its responsibilities for receiving transmissions from the remote, taking data from the sensing subsystem, and commanding the relays, a requirements & verification table can be found below.

2.3 Subsystem Requirements

2.3.1 [Subsystem: Power]

AC-DC Converter: Must be able to lower the high voltage output from an outlet that can be used to safely power up components with lower voltage intake each at different voltages.

Voltage Regulator: Must be able to use the converted voltage output and set it to a constant level to be utilized by the different components in the sensing subsystem and microprocessor.

2.3.2 [Subsystem: Sensing]

Professor Allen will supply all the sensors, and our responsibility is to ensure that our microprocessor can effectively interpret the sensor output signals in SPI format.

2.3.3 [Subsystem: Control]

Solenoid Driver: Must operate with a minimum voltage of 4.5VDC.

LED Indicators: Require a total of 5 LEDs, one for each of the following components: a Solenoid Driver, a Heater, two Radiators, and an Air pump. These LEDs should turn ON when their respective components are activated (or open in the case of the Solenoid Driver) and run at 3 to 5VDC.

ON-OFF Switch: A single ON/OFF switch is needed to activate all system components (a Heater, two Radiators, and an Air pump) and enable its operation.

Relays: Relays should isolate the components to protect other subsystems in the system from the high voltage or currents that they carry.

Microprocessor: Must be able to decode data from the sensors to use in its calculations of our algorithm for self running experiments. Also, it should utilize our software and algorithm using the data it receives from the sensors and computer to be able to run experiments autonomously by powering relays. Lastly, it should process and send data it gathers about the sensors to the computer to be used for visualization for user interface.

Software: The software should gather data from the sensors via a microprocessor and display the variables on a single graph, allowing for the visualization of changes in control variables: temperature, humidity, and water level. Each variable should be distinctly labeled with different colors to enable the visualization of sensor at different times.

2.4 Tolerance Analysis

The most critical part of our project is to use the data we collect to give accurate predictions. To ensure that the system performs optimally, the water level must be kept to a certain level. In order to achieve this, we must predict the evaporation rate. The temperature inside the evaporation chamber is going to be held to 40°C as it is meant to imitate hot desert days. However the accuracy of the predictions will be limited by sensors' capabilities. The thermocouple amplifiers (Adafruit MAX31856) used to read the temperatures up to 1800°C with an accuracy of ± 0.1°C.

Evaporation rates can be modeled by the following equation:

$$E_0 = \frac{700T_m/(100 - A) + 15(T - T_d)}{80 - T}$$

where:

E_0 = Evaporation rate (mm day^{-1})

T = Temperature (°C)

T_m = $T + 0.006h$ where h in the elevation in meters

A = Latitude (°)

T_d = Mean dew-point (°C)

This equation is a simplified version of the Penman equation for modeling evaporation.

For our purposes variable T will be set to 39.9°C and 40.1°C as that is the range of accuracy for the thermocouple amplifiers if we set it to 40°C. Variable A will be set to 40.12°, T_m will be kept as $T + 0.006(233)$ with the value of T changing with respect to the calculation and h being set to 233m as that is the elevation of Champaign IL, and T_d will be calculated using the following formula:

$$T_d = T - \frac{100 - RH}{5}$$

where:

RH = Relative Humidity (%)

The relative humidity in the evaporation chamber will be provided by the humidity sensor inside.

From the above information, we can bound the evaporation with the following equation:

$$\frac{700(T + 0.006(233))/(100 - 40.12) + 15(39.9 - \frac{100-RH}{5})}{80 - 39.9} \leq$$

$$\frac{700(T + 0.006(233))/(100 - 40.12) + 15(40.1 - \frac{100 - RH}{5})}{80 - 40.1}$$

This can be simplified to:

$$0.074813RH + 19.483181 \leq 0.075188RH + 19.714626$$

The above equation models the range of the of the actual evaporation in terms of the mm day^{-1}. The RH variable will be the average humidity that is measured throughout the day.

Once a relative humidity level is decided, we will be able to predict when water the water is getting too low, or too high. This will allow the system to keep running optimally, and reduce the need for manual adjustment to make the experiments easier to run.

3 Ethics and Safety

The small scale version of our solution has minimal, possibly no, ethical and safety issues besides a small shock from the power source we plan to use and the potential fire safety concern associated with the heater. The heater used to raise the temperature of incoming water to 40 °C within the evaporation chamber has the potential to result in system damage through overheating if not properly controlled. To address this concern, we are implementing relays to ensure the prevention of overheating or burning incidents.

On the other hand, the full scale solution can potentially have a few ethics and safety issues. One such potential issue would be siphoning too much salt water from one specific place, thus disrupting the environmental balance of that ecosystem. This would be in direct violation of ACM 1.2 [3]. Any real-life instance of this project must consider rotating between multiple sources and saltwater ecosystems in order to keep disruption as minimal as possible. Another potential concern could be securing the perimeter of the aquifer and all other water deposits to minimize injury to any on-site engineers and any others.

References

[1] R. A. Dargham. “Water doesn’t come from a tap.” (), [Online]. Available: https://unicef.org/mena/water-doesnt-come-tap#:~:text=The%20Middle%20East%20and%20North%20Africa%20is%20the%20world's%20most,world's%20most%20water-scarce%20countries..

[2] J. Allen. “Scrubbing co2.” (), [Online]. Available: http://auditorymodels.org/index.php?n=Site.IROSE (visited on 08/22/2022).

[3] IEEE. “”IEEE Code of Ethics”.” (2016), [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html (visited on 02/08/2020).