Environmental control for a Chip-scale seed culture laboratory

Project Plan

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Problem / Need Statement

Seedling growth chambers are able to house hundreds of seedlings, but are limited by the fact that each seedling is exposed to the same environmental conditions. The purpose of the chip-scale laboratory is to offer numerous individual seedling chambers that each house a single seed. The advantage is that each chamber can have a uniquely specified set of environmental conditions such as temperature, humidity and CO2 levels. In this way, optimal grown conditions can be found for multiple types of seedlings at a fraction of the time, space cost.

The purpose of our project is to help provide a solution to these costly facilities by implementing a 128 growth chambers on an area no bigger than a personal computer and costing much less than greenhouse facilities to own and operate for research purposes.

Our contribution consists of three main parts; A method for detecting temperature & humidity within individual chambers, a system that can interpret signals from the sensors to control an array of solenoids that use air pressure to direct liquid flow to a specific chamber, and a channel/chamber system that is designed to facilitate delivery of liquids.

System Block Diagram

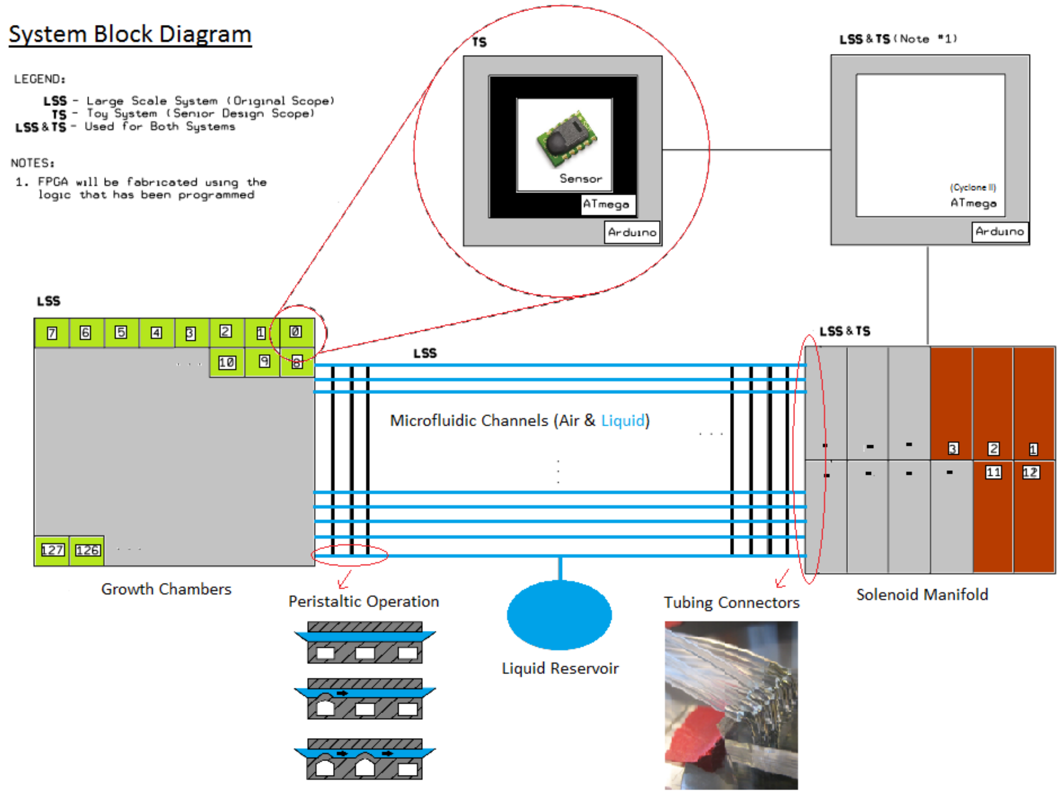


Figure 1: Block Diagram of the System

System Description

This project has an objective to enable temperature and humidity change in growth chambers easier. The outcome of the project is intended to be used in greenhouses where environmental changes are to be extremely precise, accurate and fast. The project has been divided and elaborated as three separate parts for easier understanding.

Sub-Project 1

Design the control logic of solenoid valves to control the liquid flow into the growth chambers and select a specific growth chamber out of 128 growth chambers that are fabricated on an interface. The solenoid valves are mounted on an electronic manifold and are controlled using an FPGA Microcontroller.

Sub-Project 2

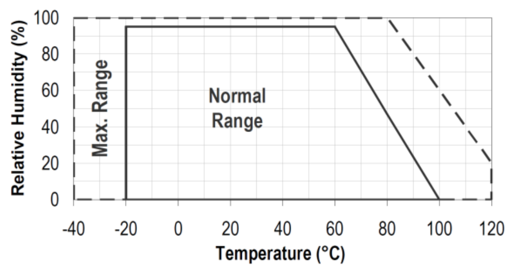
Design a channel/chamber system capable of delivering very small amounts of liquid to chambers. The process requires discovering the right amount of UV strength for the SU-8 glass fabrication and using available masks to come up with satisfying PDMS designs for the interface.

Sub-Project 3

Using a temperature and humidity sensor to measure and display the current environmental variables. The sensor is controlled by a master-slave relationship with a microcontroller.

Operating environment

This project provides maximal environmental freedom in studying phenotype environment interactions. The operating environment for this system would be a laboratory environment. Operating range for the temperature/ humidity sensor, Sensiron SHT11, shows as follows.



The temperature range requested by the vendor was 18°C to 40°C. The technical operating environment for the microprocessors used in this project is in Verilog.

Functional Requirements

1. **Sensor Array**
   a) Find a sensor with dimensions less than $100mm^2$ that is capable of measuring both temperature and humidity with a tolerance of 0.5 C^o and 0.5% RH(Relative Humidity)
   b) Design a circuit layout that is capable of receiving digital information from the sensor at the required resolutions stated above as well as the address of the individual chamber from which the data is received.
   c) Program a control element that sends data in a serial digital format to a different system designed to regulate flow of liquid to the individual seed chambers to maintain correct environmental conditions.
2. **Solenoid Control System**
   a) Design a system using Verilog or VHDL capable of receiving and decoding a serial digital signal that contains chamber addresses and sensor information.
   b) Using the address and sensor data, send control signals to a set of 7 solenoids that correspond to a 7-bit addressing scheme designed to restrict flow of liquid to one chamber at a time

c) If pumping of liquid is required, control 3 additional solenoids designed to work as a peristaltic pump until environmental conditions are corrected. If temperature correction is required, control of a heat exchanger until environmental conditions are corrected

3. **Water Flow Channels**
    a) Fabricate a flow channels capable of delivering liquid to individual chambers at volumes of 1µm^3.
    b) Fabricate 7 air flow channels designed to depress and restrict flow through liquid channels using air pressure.

Non-Functional Requirements

a) Use of FPGA and Verilog/VHDL to program the control system for solenoids.
b) Provide documentation for any circuit elements to be submitted for review before any testing occurs.

Standards

Project Management Standards

- Process Improvement:
  A clear standard for deliverables was laid out by our client/advisor. We met every week with our advisor to examine the progress of the project and to determine any needed changes to the scope of the project. The requirements changed over the project span so we as a team were to adapt to those changes to improve our project.

Software Standards

- Verilog Language: Code used to implement Solenoid Control System
  *Standardized by **IEEE 1364-2005** Verilog Hardware Description Language Standard*

- C Language: Code used to implement Sensor Array System
  *Standardized by **ISO/IEC 9899:2011** C programming language Standard*

Hardware Standards

- Micro Fabrication Standards:
  A specific standard provided by our client/advisor was used in the process of fabrication. This process included initial cleaning procedure of the materials. There were also standards that were followed for reaction temperatures as well as durations.

Market and literature survey

We can control three main parameters which are humidity, temperature and carbon dioxide that can affect seed growing. We are designing a chip that can be used for seed testing in 128 kinds of environment. Then people can find out which set parameters of air fit the seeds well.

The merit of the chip is obvious. The user can have 128 greenhouses only on one chip but not in 128 rooms; also user can test their seeds with variability parameters allowing more efficiency than regular greenhouse. Therefore all testing becomes more accurate.

Iowa is famous for agriculture, at the end of our project researchers are hoping to replace regular greenhouses by using that microchip with controllable environmental parameters.

A similar product in the market called "Microfluidic Large-Scale Integration" was developed by creating high-density microfluidic chips that contain plumbing networks with thousands of micromechanical valves and hundreds of individually addressable chambers. These fluidic devices are analogous to electronic integrated circuits fabricated using large scale integration.

According to the ***Craftsman National Building Cost Estimator program***, the pricing on a greenhouse measuring 12'x12' would be around $3587 in US (around $2834 in Iowa) , or $25 per square foot. Furthermore, researchers can only have one kind of growing condition in one greenhouse. But our product can provide 128 greenhouses and cheaper than that

Deliverables

The expected end product will consist of three systems that will work together to create a lab chip that will enable the user to simulate different environmental conditions. The overall project is to incorporate multiple chambers in the lab chip and control environmental variables in multiple chambers. Our client has only requested the testing of one chamber from our senior design group.

1) End Product

- Temperature and Humidity Sensing Unit:

We will deliver a circuit that will detect and convert raw digital data from a sensor and deliver an output to the control system of the main system.

- Solenoid Control System

We will deliver a system that will that will receive data from the sensing unit and control humidity via a peristaltic pump.

- Liquid flow channels

We will deliver a system with flow channels capable of delivering liquid to individual chambers at volumes of 1μm3. This system will also contain 7 air flow channels designed to depress and restrict flow through liquid channels using air pressure.

2) Required Design & Technical Documents

- Project Plan Document
- Project Design Document
- Project Presentation
- Project Operation Instruction

Risks

We only have risks associated with the second sub project:

The thickness between the control channels and flow channels should be about 0.6mm after our testing. The control channels are on the bottom of the flow channels. When the thickness is about 0.6mm, air in control channels can push up to flow channels so that control channels can work as pump.

The associated risk is that, if layer between two channels are too thin, liquid from the top channel may flow through to bottom channels and if the layer is too thick, air in the control channels cannot work as pump. The thickness of flow channels is flexible and can vary from 2mm to 3mm

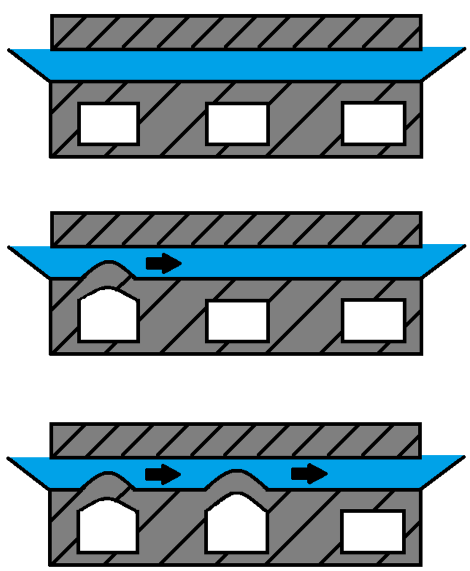
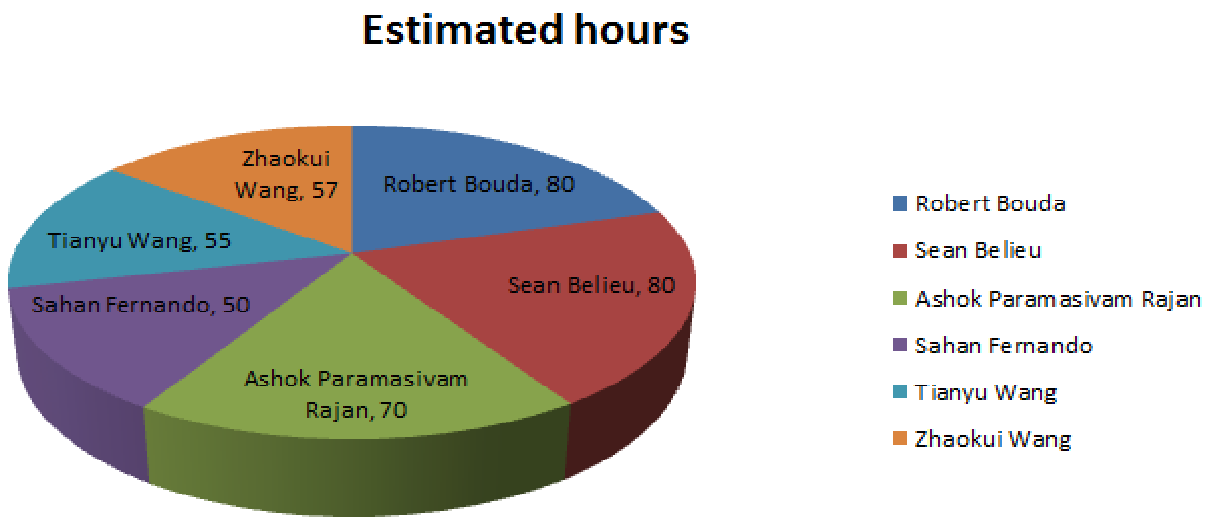


Figure 2: Peristaltic Pump

Resource requirements / Cost

Product	Quantity	Cost
SHT11X	4	$200
EMC-12-06-20 Solenoid Manivold	1	$500
MISC Tubes and Connectors	MISC	$20
Atmega Cyclone II	1	Provided
Arduino	1	Provided
IBA Fabrication Glass	-	Provided
	Total	**$720**

Labor



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