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EE445L - Lab 11 Report
TA: Andrew Lynch
12/08/2017

1 Requirements Document

1. Overview

1.1. Objectives

The objective of this project is to design, build, and test an environmental control system (*ECS*) that controls the breathability of air in a closed system. The ECS will regulate the percent CO_2 in the environment by producing O_2 and venting excess pressure and CO_2.

1.2. Roles and Responsibilities

EE445L students are the engineers and the TA is the client.

1.3. Interactions with Existing Systems

The system will use the TM4C123 microchip, an ST7735 color LCD, an 8 ohm speaker, and be powered using batteries.

1.4 Terminology

- *Environment Subsystem:* Closed system where air quality will be controlled to maintain breathability. Contains sensor measuring CO_2 in air.
- *Electrolysis Subsystem:* Actuator producing O_2 through electrolysis of H_20.
- *Controller:* Monitors input from sensor and provides output to actuator based on environment requirements. Includes an LCD and switches as input UI to manage desired environment. Includes a speaker and LEDs as output UI.

2. Function Description

2.1. Functionality

The *Controller* monitors CO_2 levels in the environment and provides a UI for the user to control the soft and hard limits of CO_2 in the environment. The soft limit will trigger the Electrolysis Subsystem to begin the production of O_2. The hard limit will continue the production of O_2, set off a loud audio alarm, and flash a red LED. To simplify the ECS, maintaining O_2 levels below a specific threshold to reduce fire hazard in the environment is not a requirement.

The *Electrolysis Subsystem* produces O_2 and safely vents H_2 (byproduct) through some form of containment (e.g. into a sealable container). The O_2 is transported to the Environment.

The *Environment Subsystem* can be modified by 2 mechanical inputs: the O_2 from the Electrolysis Subsystem and a separate input for CO_2 (via exhaling). The Environment will also have 1 output to vent excess pressure and CO_2. These inputs and outputs must not allow backflow of air.

2.2. Performance

UI must be easy to use. CO_2 measurement accuracy must be within 1% of actual. H_2 production must remain below 500mL / 5 minutes to allow for safe and manageable venting. Current usage of electrolysis must remain below 6.26A.

2.3 Usability

The *ECS* will provide an LCD interface to read current CO_2 measurement, soft limit, and hard limit. There will be 3 switches to modify the soft and hard limits. A speaker will provide a loud warning sound if the hard limit is passed. An LED will provide a flashing red warning signal if the hard limit is passed.

2.4 Safety

The top priority for the *ECS* is safe operation. H_2 is a highly flammable gas and a byproduct of the electrolysis of water. Two things will be done to ensure safe operations: First, all H_2 produced will be captured and released outdoors. Second, the production of H_2 will be limited to a maximum rate of 500mL / 5 minutes so the byproduct can be easily managed and vented. This will be achieved by limiting the current used for the electrolysis reaction to 10A, which is controlled through the applied voltage level and conductivity of the solution.

3. Deliverables

3.1. Reports

There will be written reports for Lab 7 (PCB preparation) and Lab 11 (final project).

3.2. Outcomes:

Lab 7 Report:

A) Objectives: 1-page requirements document
B) Hardware Design: Regular circuit diagram (SCH file), PCB layout and three printouts (top, bottom and combined)
C) Software Design
D) Measurement Data: Give the estimated current (Procedure d), Give the estimated cost (Procedure e)
E) Analysis and Discussion
Include a copy of the reviewed SCH/PCB and signed by your professor

Lab 11 Report (this report):

A) Objectives: 2-page requirements document
B) Hardware Design: Detailed circuit diagram of the system (from Lab 7)
C) Software Design (no software printout in the report): Briefly explain how your software works (1/2 page maximum)
D) Measurement Data: Include data as appropriate for your system. Explain how the data was collected.
E) Analysis and Discussion: YouTube video

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2 Hardware Design

Controller Circuit

Schematic and PCB files uploaded separately.

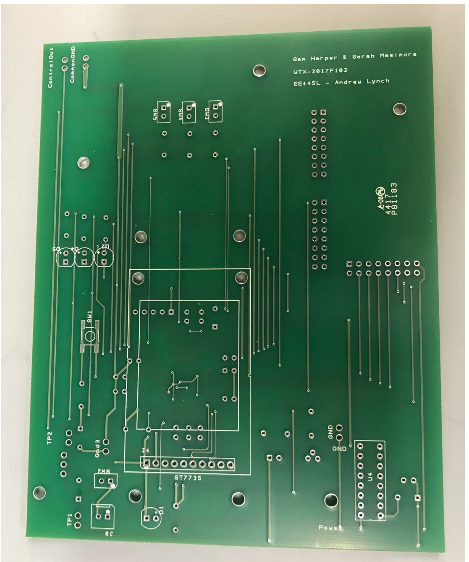

Figure 1. PCB front.

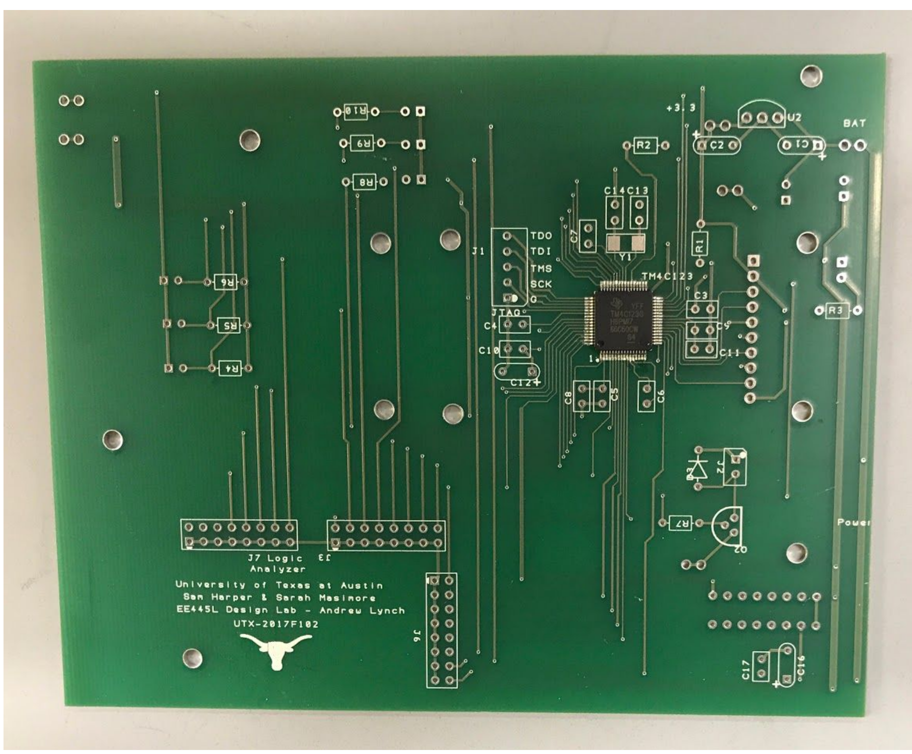

Figure 2. PCB back.

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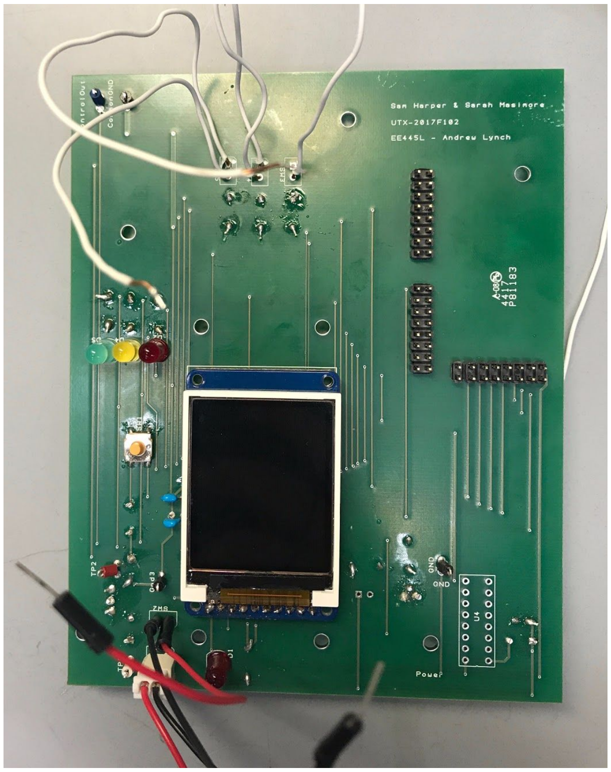

Figure 3. PCB with parts soldered.

Electrolysis Power Circuit

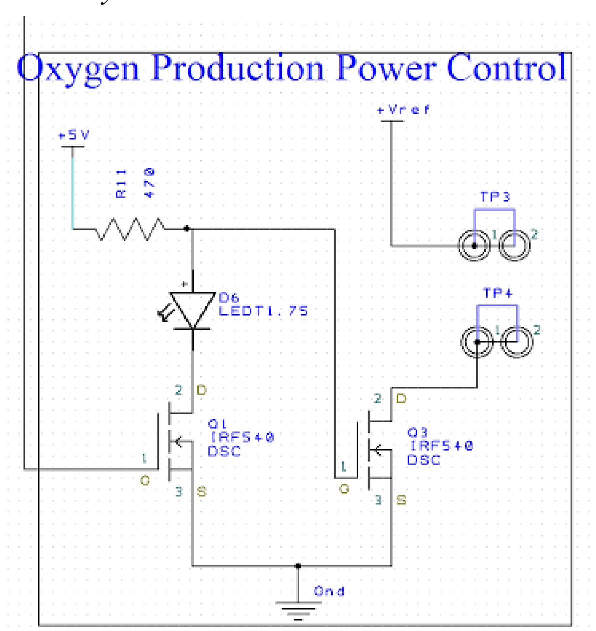

Figure 4. Electrolysis power control circuit.

The Electrolysis Power Circuit was two IRF540 MOSFETs connected such that the load of the first FET was the gate of the second FET. We did this as the 3.3V out from the controller was not sufficient to allow the current needed to pass through the IRF540. By adding the first FET we could still use the 3.3V as control but power the actual high voltage switching FET with a higher gate voltage allowing the needed current to pass unimpeded.

Electrolysis Mechanical Design

The electrolysis subsystem consisted of:

- 1 plastic container to house reaction.
- Two graphite electrodes drilled into container from below (so that gas can be captured from top). Graphite is the ideal electrode type because it has no risk of toxic byproducts (as opposed to stainless steel) and does not oxidize in the water (as opposed to copper).
- Hydrogen capture tube (left side of Figure 5) to vent hydrogen.
- Oxygen capture tube (right side of Figure 5) to send oxygen to environment.

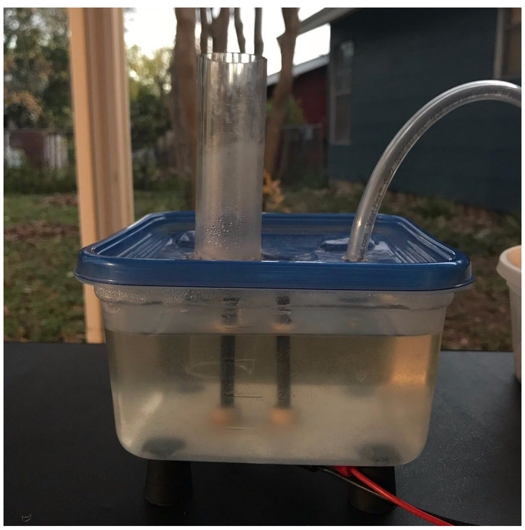

Figure 5. Electrolysis mechanical setup.

Electrolysis Chemical Design

To affect the environment in a timely manner we targeted oxygen production of 200mL/5 minutes. In order to reach this rate of production, using Faraday's Law of Electrolysis was determined that the system required 5A of current. The power supply was 18V, which meant the solution needed to be highly conductive. To achieve this a 20% by mass solution of NaOH and water (resistance ~4 ohms) was used.

Environment Mechanical Design

The environment subsystem consisted of:

- A plastic container to house CO_2 sensor.
- 3 holes at top of container for oxygen input, CO_2 input, and pressure output.

- 2 check valves to ensure 1-way flow for CO_2 input and pressure output.
- 1 hole on side for CO_2 sensor's wires.
- Marbles to keep the container weighted.

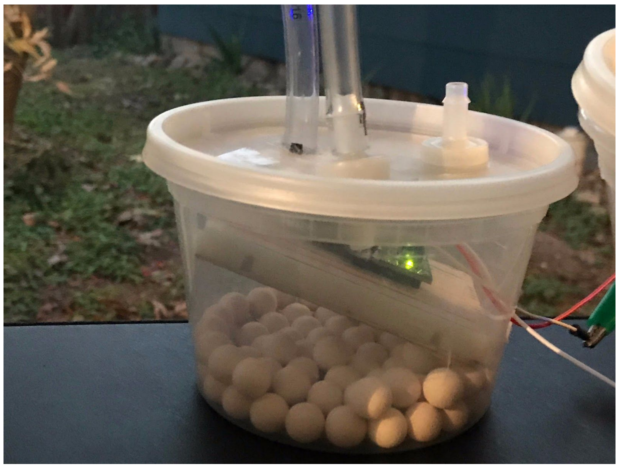

Figure 6. Environment mechanical setup.

3 Software Design

Controller Design

The software for the ECS is responsible for managing the sensor, actuator, and user interfaces. It consists of 7 modules:

- **ECSMain:** Main module initializing the rest of the modules and managing the ECS state machine and system transitions between the states.
- **CO2Sensor:** Interface with CO_2 sensor. Initializes ADC and sample rate, calibrates sensor input, and provides API to main module for getting sensor data.
- **Electrolysis:** Module interfacing with electrolysis system. Provides API to main module for starting and stopping electrolysis.
- **LCD:** Module interfacing LCD hardware to produce UI. Provides API to main module for updating the LCD.
- **Sound:** Module interfacing with speaker system. Creates alarm sound using a square wave. Provides API to main module for starting and stopping alarm sound.
- **Switch:** Module interfacing with switches for modifying soft and hard CO_2 limits.
- **LED:** Module interfacing with LED's for notifying when CO_2 limits have been hit.

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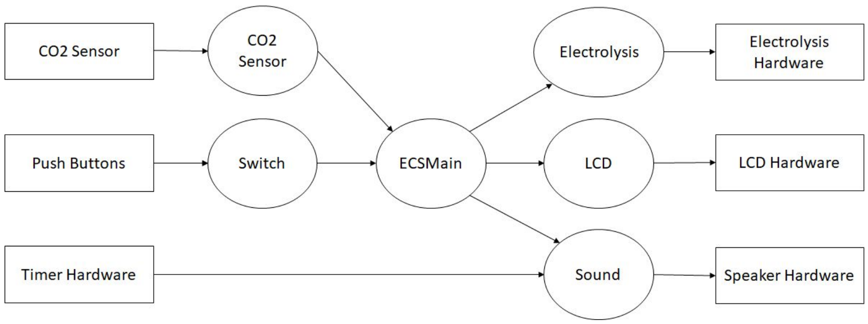

Figure 7. Data flow graph.

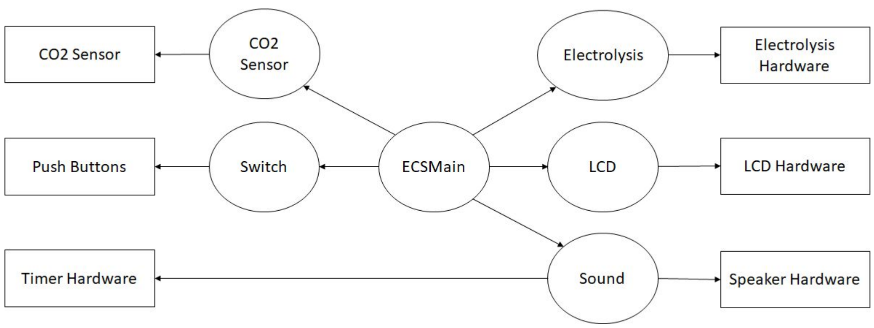

Figure 8. Call graph.

4 Measurement Data

3. 1 Current for each state of system

State	Current Total (A)	Current Sensor (A)	Current Speaker (A)
CO2 Level < Soft Limit	.242	.16	0
CO2 Level >= Soft Limit && CO2 Level < Soft Limit	.244	.16	0
CO2 Level >= Hard Limit	.320	.16	.076

Figure 9. Current measurements without electrolysis.

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3.2 Electrolysis Current Measured For Different Power Sources & Solutions

Power Source	**Solution**	**Current (A)**
2 AA In Series	$NaHCO_3 + H_2O$ (saturated)	.026
9V	$NaHCO_3 + H_2O$ (saturated)	.487
2 9V In Series	$NaHCO_3 + H_2O$ (saturated)	1.062
1 9V	$NaOH + H_2O$ (20% by mass)	1.616
2 x (2 x 9V in series) → 18V	$NaOH + H_2O$ (20% by mass)	5

Figure 10. Current measurements of electrolysis with various solutions and power supplies. Last row is what was used for final system.

3.3 System Cost

Including all materials, the system cost is $112.90.

5 Demonstration

https://www.youtube.com/watch?v=pTkeIjM7VU0&feature=youtu.be

6 Potential Improvements

2 18V (2 x 9V in series) powered the electrolysis subsystem, but current dropped as the batteries were used. Powering the system from the wall would be more sustainable. Additionally, the mechanical setup had some leakage where small amounts of air could enter and leave the environment, resulting in an imperfect test. Finally, the sensor required calibration depending on humidity and temperature of the environment, so a calibration mode should be implemented in the software and UI so that calibration does not need to be done manually.