Engineers of Catan

Final Report

ECE 445

Hannah Hasken - Adam Blackburn

TA: Ryan Corey

Prof: P. Scott Carney

Project 8

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Contents

1.0 Introduction

1.1 Statement of Purpose

We chose to create an electronic version of the board game, “Settlers of Catan”. This board allows players to move through the game faster and to make sure that there are no missed resources during distribution. It also speeds up the initial game setup process.

We selected this project because there is nothing similar available, and it presents some unique challenges with regards to piece detection and board design, due to the game's unique reconfigurable layout and pieces. We also felt that we could produce a functional, easy-to-use, and nice-looking final device that would be a worthwhile goal.

1.2 Goals

- Develop a modular board system that can be easily expanded and assembled
- Recreate very similar gameplay to the actual board game
- Have an easy-to-use interface for players that doesn’t require additional learning

1.3 Benefits

- Resources automatically totaled for players at the beginning of each turn
- Automatically generate the board configuration.
- Built-in random-number dice.
- Makes resource distribution easier for players
- Speeds game play

1.4 Functions

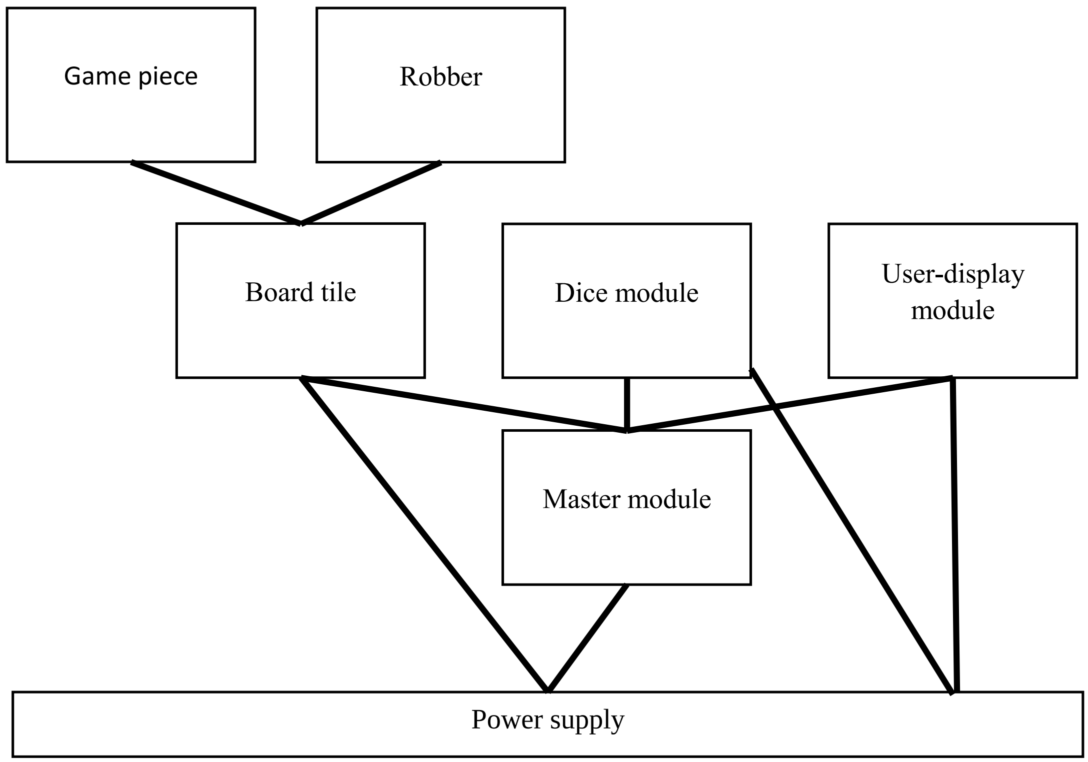
- Bright LEDs to display board layout and 7-segment displays to indicate number on each tile
- Automatic randomized board layout for each game
- Identify individual pieces (type and owner)
- Easy to read resource information for each player

1.5 Features

- Automatic board layout
- Easy-to-use resource counting feature
- Intuitive gameplay
- Contains all pieces for a 4 person game

2.0 Design

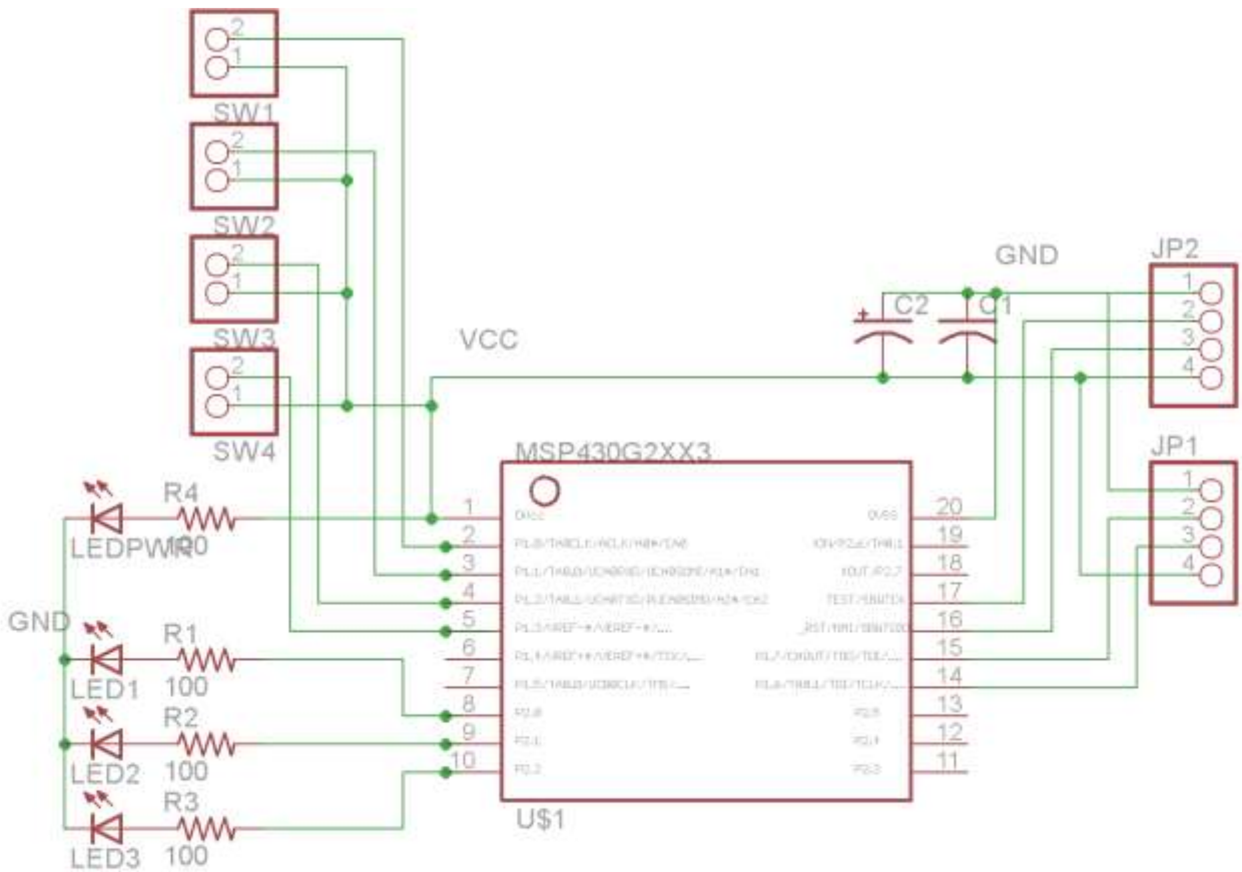
2.1 Block Diagram



2.2 Block Descriptions

2.2.1 Master Module

The master module contains the game logic and is responsible for controlling the board tiles, dice module, and user-display modules. The master module is connected to the other modules via an I^2C bus.



2.2.2 Board Tiles

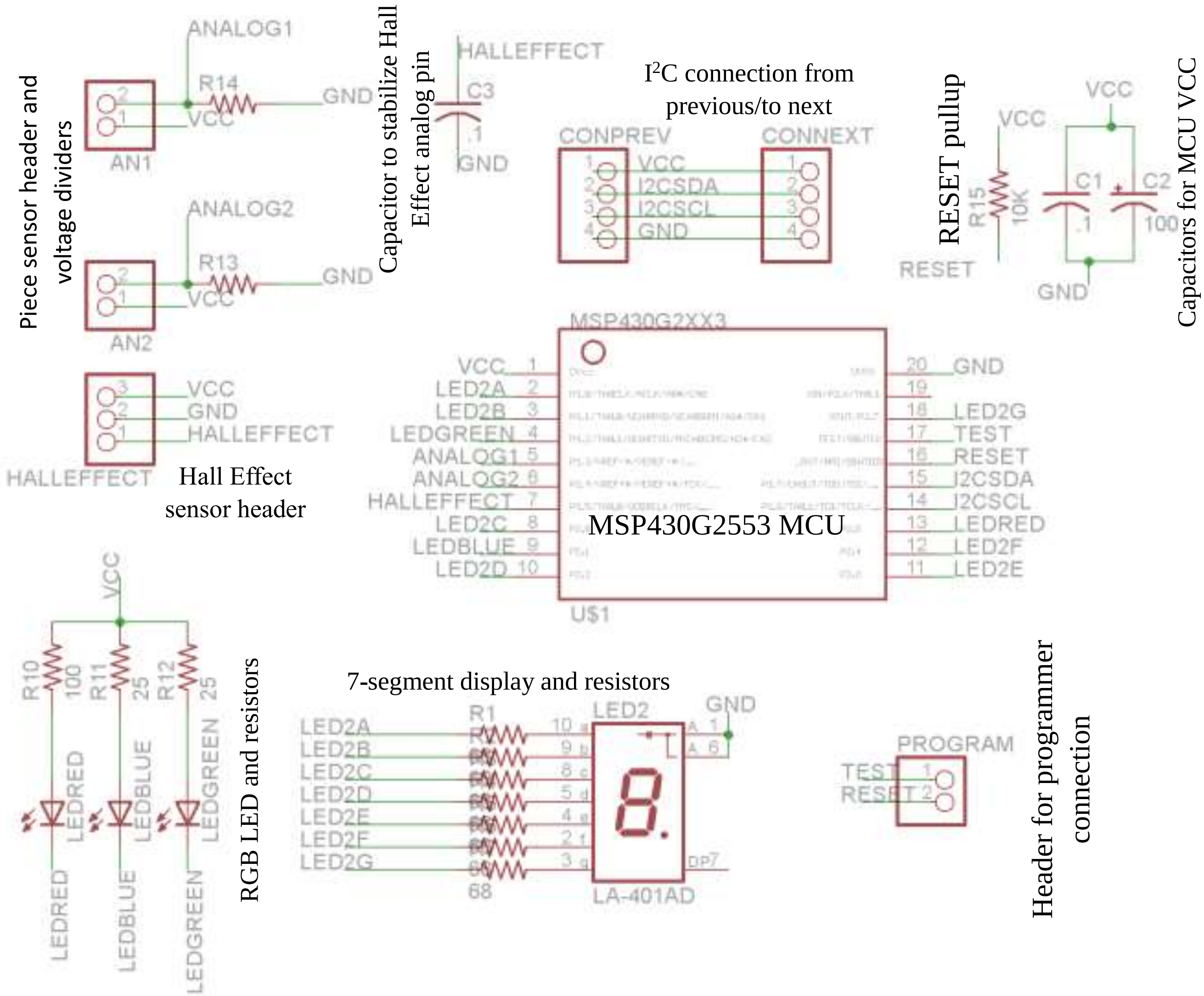
In the traditional Settlers of Catan, the board is made up of several (19) tiles that are laid out and used to construct a unique board for each game. Each tile also gets a token with a number from 2 to 12. Our version has those tiles assembled, but the logic in each cell allows the layout of the board to be randomly generated. This allows the same gameplay as the traditional version. Each tile includes an RGB LED to change the color, two piece sensors, a Hall Effect sensor for detection of the robber, and a 7-segment display to show its number.

In the board game, the tiles are hexagons. The board tiles PCBs are rectangles for easier assembly, but the plastic cover on the game gives the illusion of hexagon tiles.

The board tile PCBs are connected to each other via the CONPREV and CONNEXT headers. This allows only one connection to the master module but allows access to the entire string of board tiles. This minimizes the connections between parts and simplifies assembly since each of the board tile modules only have to be connected to the new and previous modules in the series. This modular design would also allow re-use of our design to make boards of different shapes or larger boards by simply adding more board tile PCBs and updating the master module.

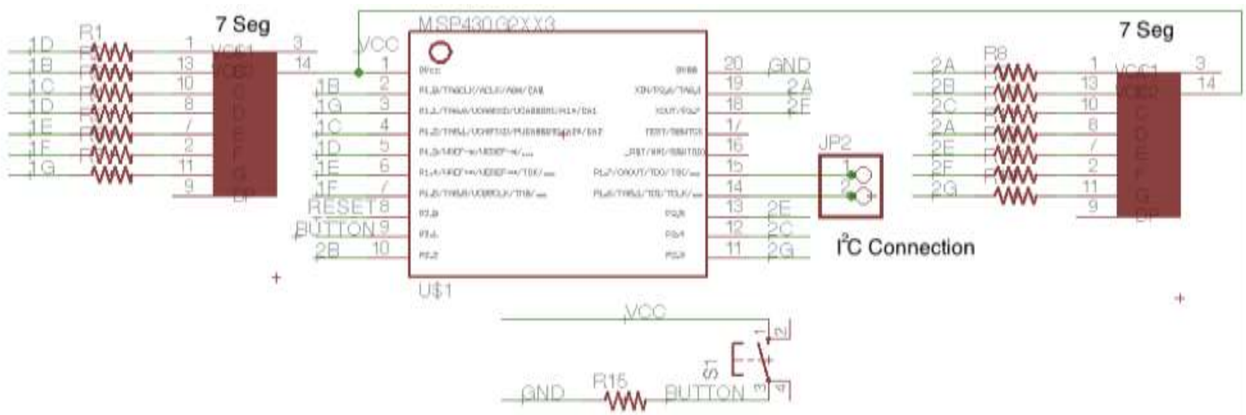
The tiles are identical and connected via an I^2C bus to allow individual addressing and two-way communication with only two wires.

The board tiles are controlled by the master module via the I^{2}C bus.



2.2.3 Dice Module

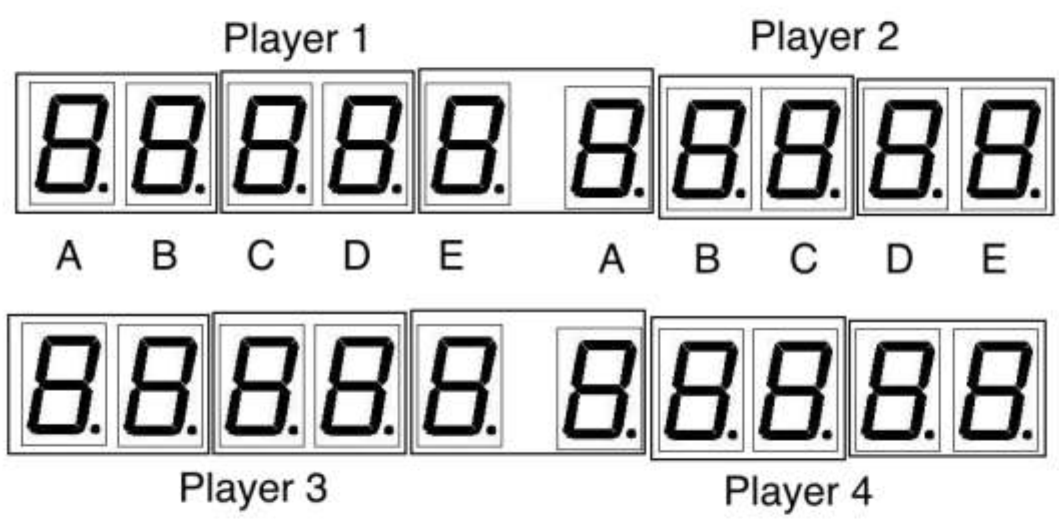
The dice module consists of two digital "dice", a button to “reset”, and a button to “roll” them. The numbers are generated by a random number generator and displayed via LEDs. The module then sends the numbers to the master module via the bus. This simulates rolling the dice for each turn.



2.2.4 User-display Module

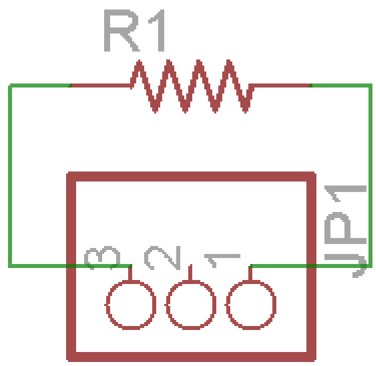
The user display module displays the number of resources collected after each dice roll, while taking into account the position of the robber. These are displayed using 7-segment displays. The master module updates the displays via the I^{2}C bus. This allows players to easily decide which resources to collect after each dice roll.

The same circuit used for the dice is used for the user-display module, sans buttons, simply repeated 10 times. The grouping for the 7-segment displays is illustrated below.



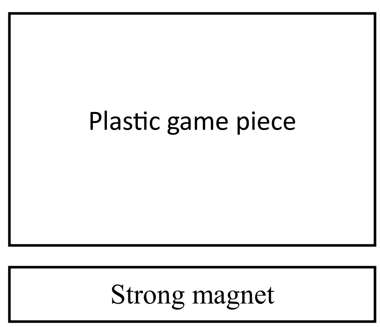
2.2.5 Game Pieces

The standard game pieces consist of different valued resistors inside of 3D printed pieces. This allows the board tiles to identify the type of piece, as well as which player the piece belongs to by measuring the voltage drop in a voltage divider. This allows automatic totaling of the points for easy resource distribution. The pieces allow a simple, intuitive gameplay similar to the normal game.



2.2.6 Robber

The robber is a 3D printed plastic game piece with a powerful magnet on the base, which activates the Hall Effect sensor in each board cell in order to allow the board to sense the piece location. This allows the robber to be used in the same way as the normal game.



3.0 Requirements and Verification

3.1.1 Master Module

Requirements	Verification
1. Receive data at master module via I^2C	▪ Connect the CONNEXT header to the CONPREV header on the board tile or a test microcontroller with a test program. Attach the power cable to the master module. Using a logic analyzer attached to the I^2C bus, verify that the I^2C signals are correct when the master module or test program sends data to the board tile.
2. Send data from master module via I^2C	▪ Connect the CONNEXT header to the CONPREV header on the board tile or a test microcontroller with a test program. Attach the power cable to the master module. Using a logic analyzer attached to the I^2C bus, verify that the I^2C signals are correct when the master module or test program sends data to the board tile.
3. Module must provide an internal voltage of 3.3V ± 0.1V for use by the microcontroller.	▪ Connect a 5.0 ± 0.1V power source to the 5V pin in the CONNEXT header and attach the ground to the GND pin in the CONNEXT header. Use a multimeter to verify that the MSP430 VCC pin has 3.3V ± 0.1V.
4. Pull-up resistors must provide 3.3V ± 0.1V to the I2C bus when all connected inputs are in high-impedance mode.	▪ Using a multimeter, verify that the voltage on the I^2C bus is 3.3V ± 0.1V when the microcontroller inputs are in high-impedance mode.
5. Switches must provide 3.3V ± 0.1V at the input of the microcontroller.	▪ Using a multimeter in continuity mode without connecting the board tile to power, attach one lead to the 3V3 trace and the other to the input pin on the microcontroller. Press the button. When pressed, there should be very low resistance (<5Ω)
6. LEDs must function when provided grounded via the microcontroller.	▪ Connect a 5.0 ± 0.1V power source to the 5V pin in the CONNEXT header and ground to the GND pin in the CONNEXT header. Using a

	microcontroller test program, verify that the LEDs illuminate when the pin is in output mode and is grounded.

3.1.2 Board Tile

Requirements	**Verification**
1. Receive data at board tile via I^2C	▪ Connect the CONPREV header to the header on the master module or a test microcontroller with a test program. Attach the power cable to the master module. Using a logic analyzer attached to the I^2C bus, verify that the I^2C signals are correct when the master module or test program sends data to the board tile.
2. Send data from board tile via I^2C	▪ Connect the CONPREV header to the header on the master module or a test microcontroller with a test program. Attach the power cable to the master module. Using a logic analyzer attached to the I^2C bus, verify that the I^2C signals are correct when the master module or test program sends data to the board tile.
3. Voltages at pins in the CONPREV header must show up at the same pin in the CONNEXT header	▪ Attach a 5.0 ± 0.1V source to the VCC pin in the CONPREV header and verify that the same pin in the CONPREV header shows a 5.0± 0.1V voltage.
4. RGB LED in tile must be visible in a brightly-lit room	▪ Connect a 5.0 ± 0.1V power source to the 5V pin in the CONPREV header and attach the ground to the GND pin in the CONPREV header. Load the LED brightness test program onto the microcontroller via the PROGRAM header. Verify that the LED can be seen when covered by ¼” white plastic in a brightly-lit room.
5. 7 segment display must be visible in a brightly-lit room.	▪ Connect a 5.0 ± 0.1V power source to the 5V pin in the CONPREV header and attach the ground to the GND pin in the CONPREV header. Load the 7-segment test program. Verify that the 7-segment display counts through all numbers from 0 to 10 and is visible

	when uncovered in a brightly-lit room.
6. Must detect standard game pieces when connected	▪ Connect a 5.0 ± 0.1V power source to the 5V pin in the CONPREV header and attach the ground to the GND pin in the CONPREV header. Attach a game piece containing a 1000 ohm resistor to the connector. Verify that the voltage at the ANALOGX junction is 1.65 V ± 0.05V. In addition, use a multimeter to ensure that the correct voltage appears at the analog input pin on the microcontroller.
7. Hall Effect sensor must detect magnet magnetic field through 1/4” plastic.	▪ Connect a 5.0 ± 0.1V power source to the 5V pin in the CONPREV header and attach the ground to the GND pin in the CONPREV header. Place robber piece on board tile near Hall Effect sensor. Verify with a multimeter that the voltage output from the Hall Effect sensor changes when the robber piece is placed near the sensor. In addition, use test code on the microcontroller to verify that the voltage read on the analog input pin changes when the robber is placed or removed.
8. Tile must provide an internal voltage of 3.3V ± 0.1V for use by the microcontroller.	▪ Connect a 5.0 ± 0.1V power source to the 5V pin in the CONPREV header and attach the ground to the GND pin in the CONPREV header. Use a multimeter to verify that the MSP430 VCC pin has 3.3V ± 0.1V.

3.1.3 Dice Module

Requirements	**Verification**
1. Pin wiring in hardware matches pin designations in software	▪ Ensure the power is on ▪ See if all numbers display properly on the 7-segment display. ▪ Check wires and leads with multimeter.
2. Must send information (about generated numbers) serially	▪ Connect the CONPREV header to the header on the master module or a test microcontroller with a test program. Attach the power cable to the master module. Using a logic analyzer attached to the I^2C bus, verify that the I^2C signals are correct when the test program sends data.

3.1.4 User-display Module

Requirements	Verification
1. Must receive information (about earned resources) via I^2C	▪ Connect the CONPREV header to the header on the master module or a test microcontroller with a test program. Attach the power cable to the master module. Using a logic analyzer attached to the I^2C bus, verify that the I^2C signals are correct when the test program sends data.
2. Pin wiring in hardware matches pin designations in software	▪ Ensure the power is on ▪ See if all numbers display properly on the 7-segment display. ▪ Check wires and leads with multimeter.

3.1.5 Game Pieces

Requirements	Verification
1. Must be durable enough to withstand many plug/unplug cycles	▪ Plug/unplug the piece 100 times. Ensure no visible damage or wear is apparent.
2. Must fit snugly in the board	▪ Ensure that pieces fit firmly and flush with the surface and don't move when the board is shaken
3. Resistance must appear at the jack terminals	▪ Using a multimeter, measure the resistance at the terminal on the 3.5mm jack and ensure that it matches the resistance of the resistor placed inside the piece.

3.1.6 Robber

Requirements	Verification
1. Magnet must be powerful enough to cause a noticeable voltage change in the Hall Effect sensors when place ¼" above the sensor	▪ Connect the output from the Hall Effect sensor to a multimeter and measure the voltage change when the magnet is placed above the sensor on ¼" plastic. Ensure that it is at least 0.15V difference when the piece is placed versus when it is not.

3.2 Tolerance Analysis

The component that most affects the performance of the project is the I^2C bus. If the capacitance of the bus is too high, it will not work, and none of the components will be able to function. This can be corrected with an I^2C buffer IC, but it is preferable not to use a buffer if not required.

In order to function, the bus must have a capacitance of less than 400pF, according to the specification. We will measure the bus capacitance when the unit is assembled to determine if it meets the specification.

We will run the test with a function generator and oscilloscope to determine the input capacitance. We will also add additional capacitance to the bus and test the response of the controller.

3.3 Testing

3.3.1 LED Brightness Testing

A sample RGB LED with a 20mA current was bright enough to be seen through plastic under normal lighting. Ultra-bright LEDs will be fine for this application.

A sample 7-segment display was too small and not bright enough to easily be seen through plastic. A larger, brighter 7-segment display will need to be used in the final product.

3.3.2 I^2C Bus Testing

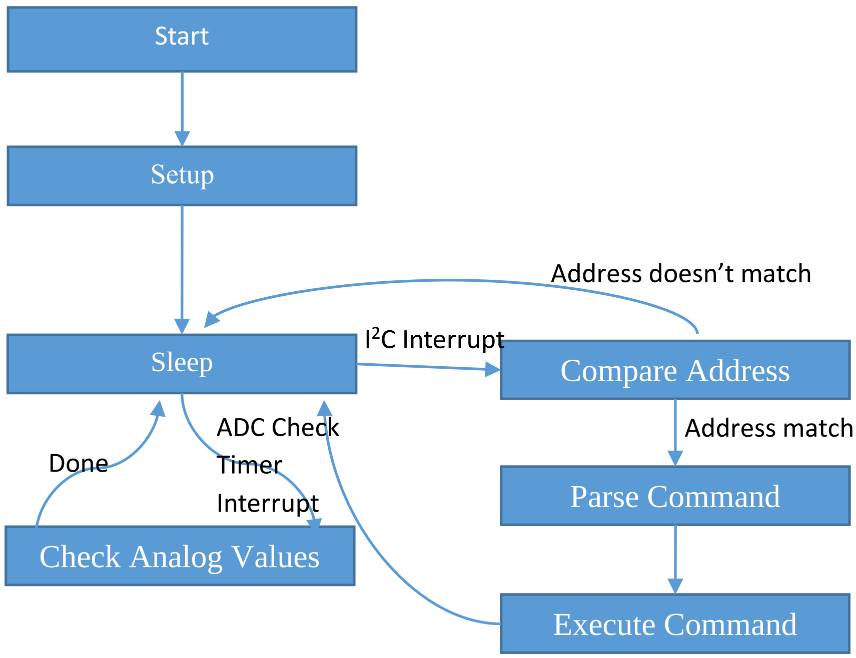
Testing with the MSP430 using the I^2C bus has been performed, and it functions as expected. We will test again with final PCB designs before making all necessary PCBs.

3.3.3 Game Piece Design

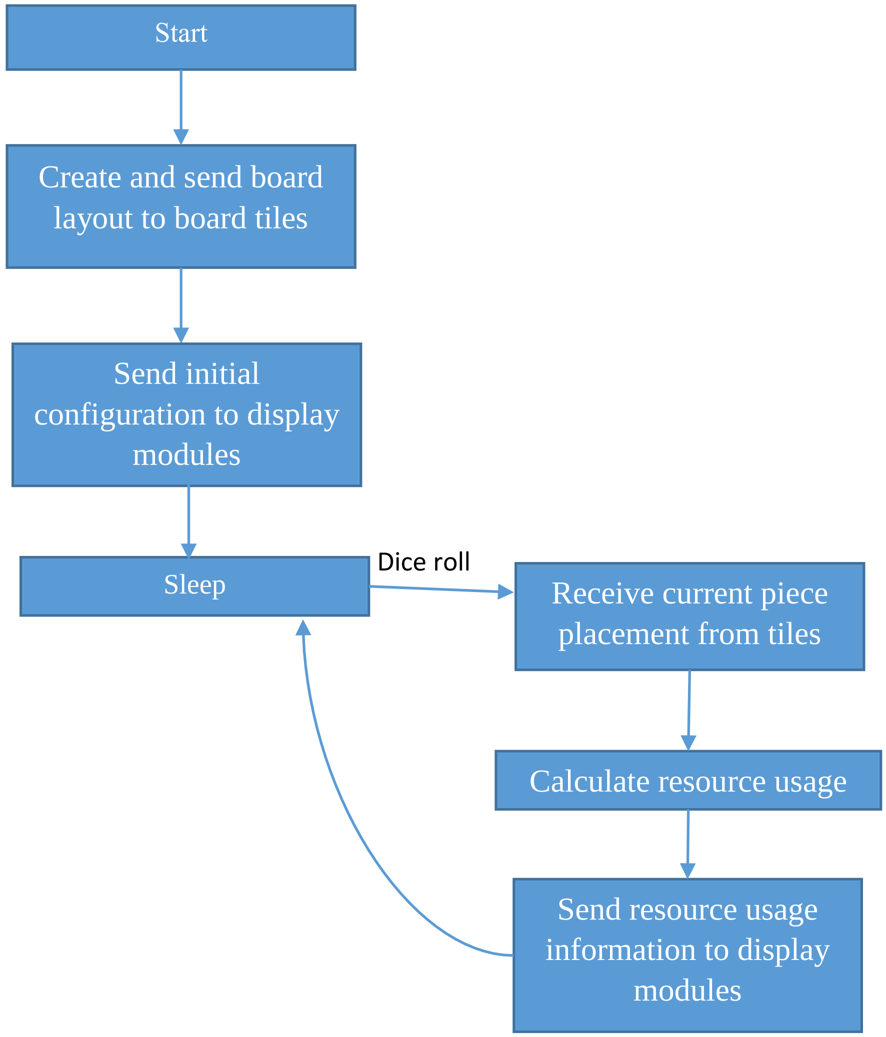
Several plastic game pieces were printed using a 3D printer, and they are durable enough to be used in the final design. They can be sized appropriately to fit the necessary hardware.

3.4 Flowcharts

3.4.1 Board Tile Flowchart



3.4.2 Overall Flowchart



3.5 Simulation

3.5.1 Game Piece Resistor Values

In order to determine which values would make appropriate choices for the game piece resistors.

Using the following parameters,

ADC	10	bits
# Pieces	8	
Divider resistor	1000	ohms
VCC	3.3	V

The following simulation values were obtained:

Piece resistance	Divider voltage	ADC Output	ADC Delta	Acceptable?
0	0.000	0	-	-
100	0.300	93	93	ok
270	0.702	218	125	ok
510	1.115	346	128	ok
750	1.414	439	93	ok
1100	1.729	536	98	ok
1600	2.031	630	94	ok
2400	2.329	723	93	ok
3900	2.627	815	92	ok

This uses an ADC delta of 75 as being the threshold between acceptable and not acceptable. However, all ADC deltas are at least 92, so distinguishing between the values should be no problem, even with noise. The detection circuit will be pulled down to ground when no piece is connected.

4.0 Cost and Schedule

4.1 Labor

Name	Hourly Wages	Hours Invested	Labor Total (x2.5)
Hannah	$40	120	$12000
Adam	$40	120	$12000
Labor Total		240	$24000

4.2 Parts

Part	Part Number	Unit Cost	Quantity	Total
RGB LED		$ 0.45	19	$8.55
Microcontroller	MSP430G2553	$ 1.33	30	$39.90
7-Segment Display	COM-08546	$ 0.86	41	$35.26
Hall Effect Sensor	785-SS42R	$ 0.99	19	$18.81
Linear Regulator	LM3940	$ 0.33	5	$1.65
RCL, etc.				$40.00
Jack plug (male)	3.5 mm plug			$20.00
Panel jack (female)	3.5 mm jack			$20.00
Acrylic Sheet	8505K15	$ 72.13	1	$72.13
Board Frame		$ 100.00	1	$100.00
Power Supply	5VDC 6AMP	$ 30.00	1	$30.00
PCB			36	$200.00
Game Pieces	3D Printed		52	$50.00
Part Total				$636.30

4.3 Grand Total

Section	Total
Labor Total	$24000.00
Part Total	$636.30
Grand Total	$24636.30

5.0 Conclusion

5.1 Accomplishments

We both feel that our project was very successful. Besides creating several working PCB designs, we were able to build approximately 44 of them and connect them into a working project. While the individual PCBs were not complicated, the issues we had while constructing were related to the large number of parts and connections between them. Fortunately, we were able to overcome the difficulties and get the project working. It has been very reliable and hasn't had any issues since we finished building it.

Our other accomplishment was the design of the frame, PCBs, and the top cover. Since these were made by individual processes, it was a great success in the end when they all fit together perfectly. This really improved the final product; it is durable, looks nice, and is easy to use.

5.2 Uncertainties

We are fairly confident in our design and product, but there are a few aspects of the final design of which we are uncertain.

We're not sure how much changing the length of the wires we used for the I^2C bus affects the capacitance of the I^2C bus and if it pushes it too far past the limit. We used a bus expander to increase the limit from 400pF to 4000pF and the project has no issues functioning with this configuration.

We are also uncertain about the quality of the power supply solution we used. The power supply is a 5V, 6A supply and we use several 3.3V linear regulators to provide 3.3V power. Both the linear regulators and the 120VAC to 5V transformer get very warm, so there is almost certainly room for improvement in this area.

5.3 Discussion of Ethical Considerations

We upheld IEEE code of Ethics and Academic Honesty. We made sure our game is safe for mature audiences to use; however, the relatively small board pieces could be a choking hazard for young children. The official game is advised for ages 10 and up. Since we do not plan on selling our board for profit, we avoid running into Intellectual Property regulations.

The proper precautions for wiring and soldering were used.

There are many small pieces in our project, so any concerns regarding small parts should be considered with our project. This includes small children and animals accidentally swallowing the pieces.

Our project has several wires that connect the pieces. While these are insulated and contain low voltages (less than 5V), the proper care should be taken when dealing with them.

The main concern with our project is the 120VAC to 5V transformer. We mounted this transformer in a grounded metal box. This will prevent loose wires from accidentally causing damage from high voltages.

5.4 Future Work / Alternatives

As a future modification, adding a small embedded Linux system like a Raspberry Pi with networking capability would provide the base for several interesting features. Software could be developed to allow users to record games and stream them live over the Internet via a website, develop custom games (different tiles/resource distribution than default), or maybe even a multiplayer game via the Internet.

Connecting the embedded system to a computer monitor would allow game setup via a mouse or keyboard as well as a user interface for creating a new game. This would make it easier for users to configure the game.

We would like to publish the PCB designs and MSP source code online for other Settlers of Catan fans to build or modify. Since people who are interested in Settlers of Catan also tend to be interested in projects like this, we believe it would be well-received by the community.