Component Analysis

Year: 2024 **Semester:** Spring **Team:** 1 **Project:** Dungeon Crawler Board
Creation Date: February 1, 2024 **Last Modified:** February 1, 2024

Member 1: Landon Carre **Email:** lcarre@purdue.edu
Member 2: Neil Brown **Email:** brow1950@purdue.edu
Member 3: Jackson Luna-McCrocklin **Email:** jlunamcc@purdue.edu
Member 4: Grace Whitaker **Email:** gwhitake@purdue.edu

Assignment Evaluation: See Rubric on Brightspace Assignment

1.0 Component Analysis:

The main hardware components of our Dungeon Crawler Board include a microcontroller, LEDs, an LCD, Hall Effect Sensors, Keypad, and voltage regulator. The microcontroller will run the main game through the LEDs, LCD, and Keypad, and control the LEDs based on decoded map and character info and Hall Effect sensing. The LEDs will display map information, character positioning, and character movement during gameplay. The LCD will display basic information and settings for starting the game and detailed character and game information for the DM during gameplay. The Hall Effect sensors will detect magnetic character tokens so the microcontroller can determine character positions. The Keypad will allow the DM to enter information about dice rolls and character status. Finally, the voltage regulator will be used to distribute various levels of voltage to different areas of the PCB. Information about these components is found below.

1.1 Analysis of Component 1: Microcontroller

Two microcontrollers were considered. The STM32F405VGT6TR [1] is the ultimate choice the team has chosen. It is important that many GPIO pins are available. This is used for devices such as the lighting system, the hall effect matrix system, and the keypad. Including 3 SPIs allows for an LCD peripheral to display gameplay status. The STM32F405 also comes equipped with a USB OTG that will allow users to port initialization board information from a computer to the gameboard to display maps. I2C is an addition valued for its ability to interface with I2C IO Expanders to increase the number of IO pins while also allowing interruptions. This will help aid the design and control of a Hall effect sensing matrix to track player movement. Although not quite as many timers equipped with PWM are needed, up to 17 timers can be used for PWM to control the planned 16 WS2812B pixel rows in the lighting matrix. Memory was also considered to potentially store default initialization data or store loaded data from the USB OTG.

It is compared against a similar microcontroller in the family, the STM32407Vx [2] category controller. The two are very similar and cover all the needs of the project. The STM32F405 is cheaper than STM32F407 and does not come equipped with the unnecessary Camera interface making it the better choice for our project. We chose to compare the two because the team is currently prototyping with the STM32F407 development board until later design stages.

Feature	STM32F405VG [3]	STM32F407Vx [3]
Data Bus Width	32 bit	32 bit
Max CPU Freq.	168 MHz	168 MHz
SPI	3	3
GPIOs	72	82
USB OTG FS	Yes	Yes
I2C	3	3
Operating Voltage	1.8V-3.6V	1.8V-3.6V
Flash Memory	1Mbyte	1Mbyte
SRAM	192+4 Kbytes	192+4 Kbytes
Timers With PWM	Up to 17	Up to 17
Camera Interface	No	Yes
Price	$13.54	$14.11
Choice	CHOSEN	

STM32F405VG vs STM32F407Vx

1.2 Analysis of Component 2: LEDs

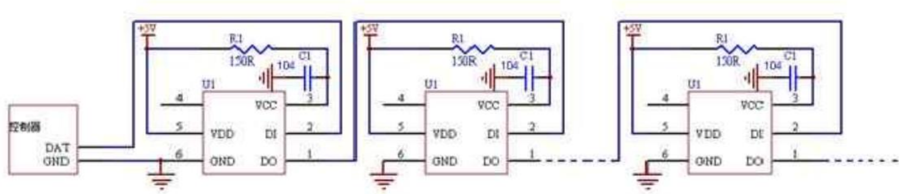
The Dungeon Crawler Board gameplay is facilitated through lighting displays. The game board, separated in a hex matrix, uses lights beneath the board to display gameplay effects such as movement, combat, and the game map. Determining the type of lighting used was crucial to determining how the board electronics would be assembled.

The first method considered was to use simple RGB LED lamps [4]. This is a part that the whole team is familiar with and has used before. However, there were some concerns. The Dungeon Crawler Board requires a full LED matrix to underlight the entire hex matrix board surface. Additionally, it is necessary that a number of LEDs are able to be powered on simultaneously. It is possible for this to be done, but at least 32 different output pins would be needed to wire a matrix that would allow LED lamps to be turned on via row and column selection. It also might have been necessary to multiplex through selected rows or columns to a non-detectable frequency to manage power consumption. Each RGB has a current draw of 20mA per color resulting in an a total max current drawn of 60mA per LED lamp.

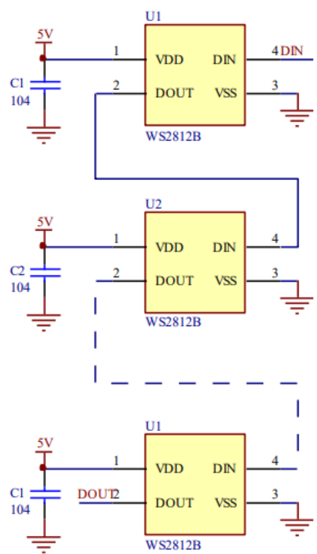
A different solution to gameplay lighting was visited. Using neopixel lights like the WS2812 [5] provides a different path to controlling lighting. Each pixel contains RGB LEDs and can be wired serially. WS2812 pixels can be wired together with the power supplied in parallel while a data-in and data-out line wired in serial format. Using the DMA and PWM a single data line can send 24 bit segments to each WS2812 pixel on a single data line. This allows the entire lighting matrix required by the Dungeon Crawler Board to be controlled through only 16 output pins. The ability to simply wire the pixels together in series also allows for much easier design and production of the lighting system. Like the LED lamps described above, 20mA is required for each color in each pixel, resulting in a max current draw of 60mA per pixel.

The WS2812B [6] is ultimately the final component that will be used for the Dungeon Crawler Board lighting system. The WS2812B is an upgrade component of the WS2812. The WS2812B has better brightness and color uniformity than the WS2812. The WS2812B also has better heat dissipation. Finally, the WS2812B has a more simplified straight-forward structure that will allow for easier circuit design [7].

The differences in structures and resulting serial wiring can be seen below.



WS2812 wired in series



WS2812B wired in series

It should be noted that there is a key difference in the power supply voltage when comparing WS2812 and WS2812B [7]. WS2812B has the lower supply voltage needed making it a more ideal choice. It should also be noted that most specifications in each datasheet are identical. Some specification comparisons can be seen in the chart below.

	Power Supply Voltage (V)	Current Per Pixel (Max) (mA)	Data Speed (Kbps)
WS2812B [6]	+3.5~+5.3	60	800
WS2812 [5]	+6.0~+7.0	60	800

WS2812 and WS2812B Datasheet Comparison

1.3 Analysis of Component 3: LCD

The LCD used in the project is to display prompts and game information to the DM and players, which will help progress the game. The LCD should use SPI, be small enough to fit onto the board, but still big enough to display enough information on screen so that text is readable without requiring lots of scrolling. Since the hexes will be lit in color, the screen should also be in color so that information can be provided on the type of hex based on its color. It should not draw too much power since it will be on the for the entirety of the gameplay. Touchscreen LCDs should be avoided since a keypad is used in the project and requires more programming.

The ILI9341 2.2-inch TFT SPI LCD [8] is a 240x320 color screen. The screen is small enough so it fits onto the board, but also has enough pixels for text to be readable. It allows for up to an 18-bit RGB interface, allowing for over a million possible colors. The LCD takes in 4.5 to 5.5 V. The standard current is 1 µA, so given an average of 5 V used for the LCD, it will require 5 µW for power. This fits well into the limits of a wall outlet. Given that several members already have this part on hand, it will not cost any money to purchase.

The CFAF320480C7-035TN 3.5-inch TFT SPI LCD [9] is a 320x480 color screen. The screen is slightly larger than the previous but is still small to fit onto the board, while having enough pixel density for the text to be readable. It also allows for up to an 18-bit RGB interface, allowing for over a million possible colors. The LCD takes in 2.8 to 3.4 V. Using a typical voltage of 3.2 V and a typical current of 120 mA, the LCD uses 0.384 W, which once again fits well into the limits of a wall outlet. The price of the LCD is $47.41 plus tax [10].

Features	**ILI9341** [8]	**CFAF320480C7-035TN** [9]
Average Voltage	4 V	3.2 V
Average Current	1 µA	120 mA
Average Power	5 µW	0.384 W
Communication Protocol	SPI	SPI
Size	2.2-inch	3.5-inch
Resolution	240x320	320x480
Color	Up to 18-bit	Up to 18-bit
Price	NA	$47.41+

Though the first LCD is smaller, given that it consumes less power and is on hand, it will be used in the project. Also, one group member already has extensive experience programming and customizing the display for that LCD. In every other capacity, the two LCDs are comparable. If the first LCD is not up to the satisfaction of the group, due to either size or poor documentation, it is possible to use the second one as a replacement.

1.4 Analysis of Component 4: Hall Effect Sensors

The Hall Effect sensors in the project are used to detect magnetic character tokens for the gameplay, which will act as an indicator for movement and position. Since the board is 256 hexes, with the desired dimension of each hex being roughly 25 mm across (almost an inch), the sensors need to be small enough to fit under each hex, strong enough to detect the magnets through the acrylic top, without being too strong such that it detects tokens on neighboring hexes. Since 256 sensors will be needed, it is also best if it does not take much voltage or current to power.

The AH9246 [11] Hall Effect sensor is a small magnetic sensor that outputs a digital high or low signal in response to detecting a magnetic field. It is omnipolar, meaning that it can detect positive or negative fields, which in turn allows for the magnet to be in no particular orientation for the sensor to work. The sensor takes in 2.5 to 5 V. The average supply current is 8 µA, given that most of the time it is in sleep mode. Using a typical draw of 3 V, each sensor takes 24 mW on average, or 6.144 mW for the entire board. This is well under the typical power draw of a wall outlet. The sensor at maximum size is 1.620 mm by 4.150 mm by 3.130 mm, fitting into our bounds of desired hex size. Purchasing 100 at a time for 300, the total price of the part is $117.09 [12] plus possible additional costs such as shipping, tariffs, and tax.

The SS49E [13] Hall Effect sensor is a small magnetic sensor that outputs a linear analog signal in response to detecting a magnetic field. This means an ADC will have to be used for each sensor to convert the signal so it is readable for the program. The datasheet does not specify whether or not it is omnipolar. The sensor takes in 4.5 to 6 V. The average supply current is 4.2 mA, which means that it is not in sleep mode at any point in its cycle. There is no typical draw for voltage listed, so the midpoint of 5.25 V will be assumed. This makes the average power draw to be 22.05 mW for each sensor, and 5.6448 W for the entire board. While still well below the average power draw for an outlet, it takes more power than the previous sensor by a substantial margin. The size of the sensor is 1.52 mm by 4 mm by 3 mm, which fits within the bound of the desired hex size. Purchasing 100 at a time for 300, the total price of the part is $63.30 [14] plus tax.

Feature	AH9246	SS49E
Average Voltage	3 V	5.25 V
Average Current	8 µA	4.2 mA
Average Power	24 mW	22.05 mW
Total Power	6.144 mW	5.6448 W
Digital Signal	Yes	No
Fits Within Hex	Yes	Yes
Total Price	$117.09+	$63.30+

Since the magnet used for the token did not come listed with a magnetic rating, testing was done with the first sensor to see if the magnetic strength would satisfy the desired dimensions of the hexes. Testing showed that the sensor was strong enough to detect the magnet through the acrylic top, as well as not interfering with neighboring hexes. Though the first sensor does cost more, given that it outputs a digital signal, and the second sensor takes in more power and has less information in its datasheet, the AH9246 Hall Effect sensor has been chosen for the project.

1.5 Analysis of Component 5: Keypad

The keypad in this project is used to respond to prompts from the LCD display. This will include action selection, game settings, dice rolls, and character damage. This information will then be stored on the microcontroller to keep track of character movement and status. Since the input types will primarily be selection and number values, we need a keypad with numbers and at least a few additional buttons for non-numerical selections. While searching for parts, two main types of numerical keypads appeared: standard matrix keypads and membrane matrix keypads. The three products considered were the Adafruit 4x4 Matrix Keypad [15], the 4x4 Parallax Matrix Membrane Keypad [16], and the Adafruit 3x4 Matrix Keypad [17].

The 4x4 Matrix Keypad [15] module from Adafruit is a keypad with 16 buttons that requires 8 microcontroller pins to scan the keypad field. Its contact rating is 20 mA, 24 VDC [21], based on typical 4x4 matrix keypads. This keypad closely resembles the keypad from our lab kit, and many keypads on the market follow the same specifications and pinout. The keypad is 69 mm by 65.5 mm. As a result, it is a medium size and will not take up much space on the game board while still being large enough for easy input. The keypad features standard 0-9 numerical values, along with seven other button options that can be used for different selection types. The larger button size will provide more tactile feedback to the user, which will increase the likelihood of correct inputs. Also, due to the thickness of the keypad and its mounting on a standard board, it will be sturdy when placed. However, we will need to put more thought into the wiring and placement of the keypad in relation to the microcontroller. This keypad is $5.95 on Adafruit, which is very inexpensive since we only need one for the board.

The 4x4 Matrix Membrane Keypad [16] from Parallax is a keypad with 16 buttons that uses 8 pins to access the 4x4 matrix. Its maximum voltage rating is 24 VDC [22], and max current rating is 30 mA. The pad's dimensions are 69 mm by 76 mm, and it comes with an 8-pin connection cable that is 88 mm long. The larger dimensions will take up a little more space, but it could help with readability for the DM and players. Also, the longer cable allows for more flexibility in the final placement of the keypad, and we would not have to wire the keypad ourselves. In addition, it comes with an adhesive backing which would help secure the keypad to the game board. A downside to this keypad, however, is its membrane material. This material does not allow for as much tactile feedback and could lead to more input errors. Otherwise, the keypad's thin design, visual appeal, and ease of placement make this device appealing. It is $9.95 on Parallax, which is more expensive than a standard keypad.

The 3x4 Matrix Membrane Keypad [17] from Adafruit is a keypad with 12 buttons and uses 7 pins for scanning the buttons. The keypad still features standard 0-9 numerical values, but only has two additional buttons. Using this keypad could simplify the option choices, but we would need to account for this limit when designing the prompt system. This keypad looks very similar to the Parallax membrane keypad and has an adhesive backing and an 85 mm long cable for connecting pins. Its dimensions are 70 mm by 77 mm, which is similar in size to the 4x4 Membrane Keypad from Parallax. This keypad would face the same input issues as the Parallax membrane keypad, and it is $3.95 on Adafruit.

The main differences between these products are matrix size and style. All the keypads need a small amount of power, which is good considering we want to save more for the microcontroller and LEDs. For our basic functionality, the matrix size would directly affect the prompts and possible inputs. All the keypads feature standard numerical values, but we may want additional buttons for menu selections. For this reason, we decided that it would be best to stick with a 4x4 matrix so we can have several options available to users. Between the standard and the membrane, we decided to use the standard keypad. This keypad is sturdier and provides more tactile feedback to the players. In addition, if we wish to move it, we will not have to worry about removing adhesive backing. The Adafruit 4x4 Matrix Keypad is like the keypad in our lab kit, so we will stick with the keypad we already have. This will allow us to prototype and build faster as we will not need to worry about ordering products, and we have previous experience working with this keypad.

Keypad	**Adafruit Standard 4x4** [15]	**Parallax Membrane 4x4** [16]	**Adafruit Membrane 3x4** [17]
Dimensions (mm)	69 x 65.5	69 x 76	70 x 77
Max Voltage (VDC)	24	24	24
Max Current (mA)	20	30	30
Price	$5.95	$9.95	$3.95
Buttons	16	16	12
Pins	8	8	7

1.6 Analysis of Component 6: Switching Regulator

For this project, power will be supplied to the game board from a 5V AC to DC converter which is connected to the wall outlet. The 5V of electricity will be used to power the LED strips found on the game board. However, while the LEDs take 5V, the microcontroller that is being used only takes in 3.3V of electricity and 5V will result in a damaged chip. As a result, it is essential that the 5V input is properly converted to 3.3V so that the microcontroller is not damaged. Finding a module that can deliver constant power across the board will be important for a properly functioning PCB. The only current intensive component found in this project is the LED strips that consume 60mA. Since this is run on 5V power, occurring before the drop to 3.3V, there are not high current requirements for the output from the voltage regulator. The two components being considered for this function are the Pololu D24V22F3 [18] and the LM2574M-3.3/NOPB [19].

A switching regulator is ideal for the goal that is being achieved here due to its high efficiency. Other types of regulators, specifically linear regulators, are inefficient compared to switching regulators because there is significant energy loss as heat [20]. This is something that needs to be avoided to keep the temperature of the PCB at a reasonable level and maintain power in the system to be used for other components. The one disadvantage of a switching regulator is that it can generate noise which can interfere with other components [20]. Since this project does not have any sensitive components or analog signals, any noise generated by the switching regulator will not be an issue for the PCB. If the stretch PSDR of an audio signal being produced is implemented, it will be placed on the opposite side of the board to prevent any of this noise from interfering with the signal.

To determine what specific switching regulator to use, two viable options are considered below:

Feature	**Pololu D24V22F3** [18]	**LM2574M-3.3/NOPB** [19]
Output Voltage	3.3 V	3.3 V
Input Voltage	4 V – 36 V	4 V – 40 V
Max Output Current	1.4 A – 2.6 A	500 mA
Efficiency	85% - 90%	72% (Vin = 12 V)
Supply Current	1 mA	5 mA
Switching Frequency	~400 kHz	58 kHz
Price	$11.95	$3.11

Both options are great modules for switching regulators. They can both convert an input voltage in the desired range to 3.3 V, which is a high efficiency compared to linear regulators. When comparing the two components, both have strengths in some areas compared to others. However, the areas where the D24V22F3 excel are more important compared to the LM2374M. The LM2374M is cheaper and can accommodate a higher input voltage, but the difference in price is not drastic, and a high input voltage is not necessary for this project. Although the D24V22F3 is more expensive, it can supply more power in the output, is more efficient, and takes less supply current. As a result of these improved functions in the D24V22F3, it makes it worth the price difference, which is why that component will be used for this project.

2.0 Sources Cited:

[1]“STM32F405VGT6TR,” digikey.com. https://www.digikey.com/en/products/detail/stmicroelectronics/STM32F405VGT6TR/5268284 (accessed Feb. 02, 2024).

[2] “STM32F407VG - STMicroelectronics,” STMicroelectronics, 2024. https://www.st.com/en/microcontrollers-microprocessors/stm32f407vg.html#documentation (accessed Feb. 02, 2024).

[3] “STM32F405xx STM32F407xx.” Accessed: Feb. 02, 2024. [Online]. Available: https://www.st.com/resource/en/datasheet/stm32f405oe.pdf

[4] “Shenzhen Fedy Technology Co., LTD FD-5WSRGB-A.” Accessed: Feb. 02, 2024. [Online]. Available: https://cdn-shop.adafruit.com/datasheets/FD-5WSRGB-A.PDF

[5] “WS2812 Intelligent control LED integrated light source.” Available: https://cdn-shop.adafruit.com/datasheets/WS2812.pdf

[6] “WS2812B Intelligent control LED integrated light source Features and Benefits.” Available: https://cdn-shop.adafruit.com/datasheets/WS2812B.pdf

[7] “WS2812 VS WS2812B” Accessed: Feb. 02, 2024. [Online]. Available: https://cdn.sparkfun.com/assets/learn_tutorials/1/0/5/WS2812B_VS_WS2812.pdf

[8] "ILI9341 a-Si TFT LCD Single Chip Driver 240RGBx320 Resolution and 262K color Specification Preliminary a-Si TFT LCD Single Chip Driver 240RGBx320 Resolution and 262K color ILI9341." Accessed: Feb. 02, 2024. [Online]. Available: https://www.elektor.com/amfile/file/download/file/1673/product/8639/

[9] Crystalfontz.com, 2024. https://www.crystalfontz.com/products/document/4944/CFAF320480C7-035TNDatasheet.pdf (accessed Feb. 02, 2024).

[10] "320x480 3.5" Color TFT from Crystalfontz," Crystalfontz America Inc. https://www.crystalfontz.com/product/cfaf320480c7035tn-320x480-3-5-inch-color-tft-display (accessed Feb. 02, 2024).

[11] "AH9246 NEW PRODUCT ULTRA HIGH SENSITIVITY MICROPOWER OMNIPOLAR HALL-EFFECT SWITCH," diodes.com. https://www.diodes.com/assets/Datasheets/AH9246.pdf (accessed Feb. 02, 2024).

[12] "AH9246-P-B," Digikey.com. https://www.digikey.com/en/products/detail/diodes-incorporated/AH9246-P-B/5418532 (accessed Feb. 02, 2024).

[13] "SS49E Linear Hall Effect Sensor." https://content.instructables.com/ORIG/FHV/BQO4/JVR5YV9R/FHVBQO4JVR5YV9R.pdf (accessed Feb. 02, 2024).

[14] "10pcs 49E Hall Element OH49E SS49E Hall Sensor Hall Effect Sensor New: Amazon.com: Industrial & Scientific," www.amazon.com. https://www.amazon.com/10pcs-Element-OH49E-Sensor-Effect/dp/B07KNKTDFK?source=ps-sl-shoppingads-lpcontext&ref_=fplfs&psc=1&smid=A3KAKSP1F9N2ZH (accessed Feb. 02, 2024).

[15] A. Industries, "4x4 Matrix Keypad," *www.adafruit.com*. https://www.adafruit.com/product/3844 (accessed Feb. 01, 2024).

[16] "4x4 Matrix Membrane Keypad - Parallax." https://www.parallax.com/product/4x4-matrix-membrane-keypad/ (accessed Feb. 01, 2024).

[17] A. Industries, "Membrane 3x4 Matrix Keypad + extras," *www.adafruit.com*. https://www.adafruit.com/product/419 (accessed Feb. 01, 2024).

[18] "Pololu 3.3V, 2.6A Step-Down Voltage Regulator D24V22F3," www.pololu.com. https://www.pololu.com/product/2857 (accessed Feb. 02, 2024).

[19] "LM2671 SIMPLE SWITCHER ® Power Converter High Efficiency 500-mA Step-Down Voltage Regulator With Features," 1998. Accessed: Feb. 02, 2024. [Online]. Available: https://www.ti.com/lit/ds/symlink/lm2671.pdf?ts=1706811888081&ref_url=https%253A%252F%252Fwww.ti.com%252Fproduct%252FLM2671

[20] "What is a Switching Regulator?," *ABLIC Inc.*
https://www.ablic.com/en/semicon/products/power-management-ic/switching-regulator/intro-2/

[21]
"Keypad, 4 x 4, Matrix, Plastic, 20 mA, 24 V," *Newark.com*, 2021.
https://www.newark.com/multicomp/mcak1604nbwb/switch-keypad-4x4-20ma-24v-plastic/dp/24M4378 (accessed Feb. 02, 2024).

[22]
"4x4 Matrix Membrane Keypad 4x4 Matrix Membrane Keypad." Available:
https://www.electronicoscaldas.com/datasheet/Teclado-membrana-matricial-4x4.pdf