A10 - Reliability and Safety Analysis

Year: 2024 Semester: Spring Team: 2 Project: MOUSE

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Assignment Evaluation: See the Rubric in the Brightspace Assignment

1. Reliability Analysis

The components in this design that are most likely to fail are the ESP32-S3-WROOM-1-N4 microcontroller, LD1117S33TR low drop-out voltage regulator, TPSM86838RCGR buck converter, and TB6612FNG dc motor driver. The ESP32-S3-WROOM-1-N4 microcontroller was selected as a component likely to fail due to its extremely high complexity and large number of I/O pins. The LD1117S33TR low drop-out voltage regulator was selected because it may run at a high temperature to produce a 3.3V output from a 5V input. The TPSM86838RCGR buck converter was selected because it is a complex switching voltage regulator to produce a 5V output from an 18.5V input. The TB6612FNG DC motor driver was selected due to the high temperatures it may experience while powering two DC motors, often applying enough current to overcome the motor’s stall current.

For calculating the failures per 106 hours for the ESP32-S3-WROOM-1-N4, the equation [5] is utilized. When calculating the failures per 106 hours for the voltage regulators, LD1117S33TR and TPSM86838RCGR, and motor driver, TB6612FNG, the equation [5] is utilized. All values used in the equation are found in MIL-HDBK-217F [5]. These equations were selected based on the classification of each of the devices. When calculating the mean time to failure (MTTF) in hours, the equation is used.

Device: ESP32-S3-WROOM-1-N4 [1]

|  |  |  |  |
| --- | --- | --- | --- |
| Parameter name | Description | Value | *Comments regarding choice of parameter value, especially if you had to make assumptions.* |
|  | Die complexity | 0.56 | 32-bit processor used in microcontroller |
|  | Temperature coefficient | 0.98 | Based on maximum operating temperature (85°C) |
|  | Package failure rate | 0.019 | 40 pins, SMT |
|  | Environment factor | 4.0 | GM, installed on wheeled vehicle |
|  | Quality factor | 10 | Commercial product |
|  | Learning factor | 1 | In production for more than 2 years |
| Entire design: |  |  |  |
|  | Failures per 106 hours | 6.248 |  |
| MTTF | Hours to failure | 160051.216 | Approximately 18.27 years |

*Table 1. Reliability Analysis for ESP32-S3-WROOM-1-N4*

Device: LD1117S33TR [2]

|  |  |  |  |
| --- | --- | --- | --- |
| Parameter name | Description | Value | *Comments regarding choice of parameter value, especially if you had to make assumptions.* |
|  | Diode type | 0.0020 | Assumed voltage regulator uses Zener diodes |
|  | Temperature coefficient | 5.1 | Based on maximum operating temperature (125°C) |
|  | Electrical stress factor | 1.0 | Voltage regulator |
|  | Package failure rate | 1.0 | Metallurgically bonded contacts (soldered) |
|  | Quality factor | 8.0 | Assumed worst quality, no military grade rating |
|  | Environment factor | 9.0 | GM, installed on wheeled vehicle |
| Entire design: |  |  |  |
|  | Failures per 106 hours | 0.7344 |  |
| MTTF | Hours to failure | 1361655.773 | Approximately 155.44 years |

*Table 2. Reliability Analysis for LD1117S33TR*

Device: TPSM86838RCGR [3]

|  |  |  |  |
| --- | --- | --- | --- |
| Parameter name | Description | Value | *Comments regarding choice of parameter value, especially if you had to make assumptions.* |
|  | Diode type | 0.0010 | Switching regulator |
|  | Temperature coefficient | 6.7 | Based on maximum operating temperature (150°C) |
|  | Electrical stress factor | 1.0 | Voltage regulator |
|  | Package failure rate | 1.0 | Metallurgically bonded contacts (soldered) |
|  | Quality factor | 8.0 | Assumed worst quality, no military grade rating |
|  | Environment factor | 9.0 | GM, installed on wheeled vehicle |
| Entire design: |  |  |  |
|  | Failures per 106 hours | 0.4824 |  |
| MTTF | Hours to failure | 2072968.491 | Approximately 236.64 years |

*Table 3. Reliability Analysis for TPSM86838RCGR*

Device: TB6612FNG [4]

|  |  |  |  |
| --- | --- | --- | --- |
| Parameter name | Description | Value | *Comments regarding choice of parameter value, especially if you had to make assumptions.* |
|  | Diode type | 0.0030 | Assumed device uses Schottky diode |
|  | Temperature coefficient | 3.0 | Based on maximum operating temperature (85°C) |
|  | Electrical stress factor | 1.0 | Applied voltage is same as rated voltage |
|  | Package failure rate | 1.0 | Metallurgically bonded contacts (soldered) |
|  | Quality factor | 8.0 | Assumed worst quality, no military grade rating |
|  | Environment factor | 9.0 | GM, installed on wheeled vehicle |
| Entire design: |  |  |  |
|  | Failures per 106 hours | 0.648 |  |
| MTTF | Hours to failure | 1543209.877 | Approximately 176.166 years |

*Table 4. Reliability Analysis for TB6612FNG*

Overall, the device in our system most likely to fail is the microcontroller ESP32-S3-WROOM-1-N4. The components studied, which are the most stressed and likely to fail in our system, have a maximum failure rate of 6.248 failures/106 hours giving a minimum mean time to failure of over 18 years which is beyond the amount of time our device is expected to operate. The best way to reduce the time to failure for our product would be creating a system to stabilize the circuit within the moving vehicle could also work to improve the reliability of our system. Ensuring the simplest possible components that meet the necessary requirements would also improve the failure rate.

1. Failure Mode, Effects, and Criticality Analysis (FMECA)

The design for MOUSE is divided into five functional blocks with the schematics for these blocks shown in *Appendix A*. The first functional block is the power circuit which includes the DC Voltage Regulator, 5V to 3.3V LDO, and coulomb counter shown in *Figures A1-A3* from *Appendix A*. The second functional block is the microcontroller which includes the ESP32-s3 and its supporting hardware shown in *Figure A4* and *Figure A5* from *Appendix A*. The third functional block is for sensing which includes the PIR sensors and stepper motor shown in *Figure A6* and *Figure A7* from *Appendix A*. The fourth functional block is the movement system which consists of the two motor drivers and four motors shown in *Figure A8* from *Appendix A*. The fifth and final functional block is the shift register and LED network shown in *Figure A9* of *Appendix A*.

When completing the FMECA worksheets in *Appendix* B, three levels of criticality were used. The chosen levels of criticality were low, medium, and high. High criticality refers to any components that, if they failed, could cause bodily harm to a user. Such failures could have causes such as becoming hot enough to burn a user or causing MOUSE to physically run into someone. Medium criticality refers to any components that if they failed would cause MOUSE to lose core functionality, such as losing the ability to reliably detect movement. Low criticality refers to the failure of any components that would cause MOUSE to lose some functionality that would be inconvenient to the user; however, MOUSE could still be used if these components failed. High criticality components are intended to have a failure rate of 10-9 or less. Low criticality refers to anything that may is unlikely to cause bodily harm to a user but will cause the device to no longer be usable. Medium and low criticality components are intended to have a failure rate of 10-6 or less. The assumptions made are that there will be no contamination or damage to traces, pads, or other physical elements of the PCB or wires on MOUSE. It is also assumed that users read the user manual before utilizing MOUSE, and only utilize MOUSE in the way it was intended.

3.0 Sources Cited:  
[1] “ESP32-S3-WROOM-1 ESP32-S3-WROOM-1U,” Espressif Systems https://www.espressif.com/sites/default/files/documentation/esp32-s3-wroom-1\_wroom-1u\_datasheet\_en.pdf (accessed Mar. 25, 2024).

[2] “LD1117,” STMicroelectronics https://www.st.com/en/power-management/ld1117.html (accessed Mar. 25, 2024).

[3] “TPSM86838RCGR,” Texas Instruments https://www.ti.com/lit/ds/symlink/tpsm86838.pdf?ts=1711414346062&ref\_url=https%253A%252F%252Fwww.ti.com%252Fproduct%252FTPSM86838%252Fpart-details%252FTPSM86838RCGR (accessed Mar. 25, 2024).

[4] “TB6612FN,” Toshiba Corporation https://toshiba.semicon-storage.com/info/TB6612FNG\_datasheet\_en\_20141001.pdf?did=10660&prodName=TB6612FNG (accessed Ma. 25, 2024).

[5] “Military Handbook Reliability Prediction of Electronic Equipment,” *Department of* Defense. Washington DC, MIL-HDBK-217F, Notice 1, 2 January 1990

Appendix A: Schematic Functional Blocks

A diagram of a circuit

Description automatically generated

*Figure A1. Coulomb Counter*

A diagram of a circuit

Description automatically generated

*Figure A2. DC Voltage Regulator*

A diagram of a circuit

Description automatically generated

*Figure A3. 5V-3.3V LDO*

A computer diagram of a computer

Description automatically generated

*Figure A4. Microcontroller*

A diagram of a computer

Description automatically generatedA diagram of a circuit

Description automatically generated

*Figure A5. USB and USB to UART for ESP32*

A diagram of a circuit

Description automatically generated

*Figure A6. Stepper Motor*

A diagram of electrical wiring

Description automatically generated

*Figure A7. PIR Sensors*

A computer diagram of a circuit board

Description automatically generated

*Figure A8. DC Motor Drivers and Motors*

A diagram of a circuit board

Description automatically generated

*Figure A9. Shift Registers and LED Network*

Appendix B: FMECA Worksheet

Subsystem A: Power Circuit

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Failure No.** | **Failure Mode** | **Possible Causes** | **Failure Effects** | **Method of Detection** | **Criticality** | **Remarks** |
| A1 | High 5 Voltage on board | Failure of U1 or supporting circuitry | Potential damage to U2, U6, U8, U10, U11-U13; unpredictable | Observation | High | Supporting circuitry involves all capacitors and resistors required to make U1 work shown in *Figure A2* of Appendix A |
| A2 | Low 5 Voltage on board | Failure of U1, U23, D14 or supporting circuitry | No longer able to reliably move; unpredictable | Observation | Medium | Supporting circuitry involves all capacitors and resistors required to make U1 and U23 work shown in *Figures A1-A2* of *Appendix A* |
| A3 | High 3.3 Voltage on board | Failure of U6, C4, C5, U1, U23 or supporting circuitry | Potential damage to U3 or PIR sensors | Observation | High | Supporting circuitry involves all capacitors and resistors required to make U1 and U23 work shown in *Figures A1-A2* of *Appendix A* |
| A4 | Low 3.3 Voltage on board | Failure of U6, C4 or C5 | Unable to power U3 or PIR sensors | Observation | Medium |  |

*Table B1. Subsystem A Power Circuit*

Subsystem B: Microcontroller

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Failure No.** | **Failure Mode** | **Possible Causes** | **Failure Effects** | **Method of Detection** | **Criticality** | **Remarks** |
| B1 | Reset triggered for microcontroller | Failure of SW2 (stuck on), R4 or C7 | Microcontroller unintentionally restarts, stopping all functionality | Observation | Low |  |
| B2 | Loss of output signals through GPIO pins | Failure of software, U3, R1, R2, C14, C1-C3, 3.3V high or low | No longer able to control peripherals on MOUSE | Observation | Medium |  |

*Table B2. Subsystem B Microcontroller*

Subsystem C: Sensing

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Failure No.** | **Failure Mode** | **Possible Causes** | **Failure Effects** | **Method of Detection** | **Criticality** | **Remarks** |
| C1 | PIR sensor not able to return data to microcontroller | Failure of PIR sensor, 3.3V high or low, R5-R8, or physical connection | MOUSE will no longer be able to detect movement | Observation or check from microcontroller (loss of data) | Medium |  |
| C2 | PIR sensor returns inaccurate data to microcontroller | Failure of PIR sensor or physical connection | MOUSE will no longer be able to detect movement | Observation or check from microcontroller (continuous data) | Medium |  |
| C3 | Loss of stepper motor control | Failure of U2, D8, D9, D15-18, R19-22, C8 | No longer able to detect movement on all sides of MOUSE with single PIR sensor | Observation | Medium |  |

*Table B3 Subsystem C Sensing*

Subsystem D: Movement

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Failure No.** | **Failure Mode** | **Possible Causes** | **Failure Effects** | **Method of Detection** | **Criticality** | **Remarks** |
| D1 | Continuous motor drive or no drive | Failure of U8, U10, D5-D8, C12, C13, C24, C25, C18-C21, R10, R11, R15-18, or mechanical connection to motors | No longer able to move in controlled manner | Observation | High | Could case erratic movement or loss of movement |

*Table B4. Subsystem D Movement*

Subsystem E: Shift Register and LED Network

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Failure No.** | **Failure Mode** | **Possible Causes** | **Failure Effects** | **Method of Detection** | **Criticality** | **Remarks** |
| D1 | LED network no longer working | Failure of U11-U13, D27-D50, C9, C11, C15 or R37-60 | LEDs no longer display accurate information or any information | Observation | Low |  |

*Table B5. Subsystem E Shift Register and LED Network*