Reliability and Safety Analysis

Year: 2018 **Semester:** Fall **Team:** 07 **Project:**Handi_glove
Creation Date: September 17, 2018 **Last Modified:** November 2, 2018

Member 1: Yaodong Shen **Email:** shen234@purdue.edu
Member 2: Jia En Chua **Email:** chuaj@purdue.edu
Member 3: Yao Chen **Email:** chen1748@purdue.edu
Member 4: Carol Lo **Email:** lo40@purdue.edu

Assignment Evaluation:

Item	Score (0-5)	Weight	Points	Notes
Assignment-Specific Items				
Reliability Analysis	5	x2	10	
MTTF Tables	5	x3	15	
FMECA Analysis	4.5	x2	9	
Schematic of Functional Blocks (Appendix A)	5	x2	10	
FMECA Worksheet (Appendix B)	4.5	x3	13.5	
Writing-Specific Items				
Spelling and Grammar	4	x2	8	
Formatting and Citations	3	x1	3	Please do not change the layout of pages
Figures and Graphs	5	x2	10	
Technical Writing Style	4	x3	12	
Total Score			90.5	

5: Excellent 4: Good 3: Acceptable 2: Poor 1: Very Poor 0: Not attempted

Comments:
~~*Comments from the grader will be inserted here.*~~

Please check the comments.

1.0 Reliability Analysis

Components that are most likely to fail in our project are TPS54332 switching power regulator, STM32L152ZET6 microcontroller and TPS56528 switching power regulator. The model used to determine the failure rate was found in the Military Handbook (MIL-HDBK-217f) [1]: $\lambda_P = (C_1 \pi_T + C_2 \pi_E) \pi_Q \pi_L$ and mean time to failure (MTTF) in years: MTTF = $10^6 / (24 * 365 * \lambda_P)$ years.

TPS56528 Switching Power Regulator [2]

TPS56528 switching power regulator is selected to convert 12V from wall to 0.8V for Peltier Cooler and the cooler's operating current is around 3A with a maximum current of 5A. The regulator is estimated to have around 1 to 100 linear MOSFETs. According to Military Handbook, the die complexity is 0.01 and temperature factor for voltage regulator at junction temperature T_J of 85°C is 3.0. The packaging failure coefficient for a 8-pin hermetic surface mount technology is 0.0026 based on the handbook. The environmental factor for mobile device is 4.0, quality factor for commercial part is 10 and learning factor is 1.0 for device which has more than 2 years production period according to the handbook.

Parameter name	**Description**	**Value**	**Comments**
C_1	Die complexity	0.01	Based on the Military Handbook for regulator with 101 to 300 linear MOSFETs
π_T	Temperature coeff.	3.0	Based on the Military Handbook for regulator with T_J of 85°C
C_2	Packaging Failure coeff.	0.0026	Based on the Military Handbook for 8-pin Hermetic SMT
π_E	Environmental Factor	4.0	Based on the handbook for mobile devices, GM.
π_Q	Quality Factor	10	Commercial part
π_L	Learning Factor	1.0	More than 2 years in production
λ_P	Failures rate per	0.404	

	million hours		
MTTF	Mean Time To Failure	282.56 years	

Table 1. TPS56528 Switching Power Regulator Analysis

TPS54332 Switching Power Regulator [3]

TPS54332 switching power regulator is selected to regulate the power input for servo which is utilized to control robotic fingers and motion restraint. It is a 28-V, 3.5A converter that integrates a low-R_{DS} high-side MOSFET. The regulator is estimated to have around 101 to 300 linear MOSFETs. According to Military Handbook, the die complexity is 0.02 and temperature factor for voltage regulator at junction temperature T_J of 150°C is 6.7. The packaging failure coefficient for a 8-pin hermetic surface mount technology is 0.0026. The environmental factor for mobile device is 4.0, quality factor for commercial part is 10 and learning factor is 1.0 for device which has more than 2 years production period according to the handbook.

Parameter name	**Description**	**Value**	**Comments**
C_1	Die complexity	0.02	Based on the Military Handbook for regulator with 101 to 300 linear MOSFETs
π_T	Temperature coeff.	6.7	Based on the Military Handbook for regulator with T_J of 150°C
C_2	Packaging Failure coeff.	0.0026	Based on the Military Handbook for 8-pin Hermetic SMT
π_E	Environmental Factor	4.0	Based on the handbook for mobile devices, GM.
π_Q	Quality Factor	10	Commercial part
π_L	Learning Factor	1.0	More than 2 years in production
λ_P	Failures rate per million hours	1.444	
MTTF	Mean Time To Failure	79.05 years	

Table 2. TPS54332 Switching Power Regulator Analysis

STM32L152ZET6 Microcontroller [4]

STM32L152ZET6 is selected mainly because of its sufficient amount of ADC and PWM channel for the project's need. According to Military Handbook, the die complexity is 0.56 for our 32 bit microcontroller and temperature factor for junction temperature T_J of 85^oC is 5.7. The packaging failure coefficient for the 128-pin SMT microcontroller is 0.0053. The environmental factor for mobile device is 4.0, quality factor for commercial part is 10 and learning factor is 1.0 for device which has more than 2 years production period according to the handbook.

Parameter name	**Description**	**Value**	**Comments**
C_1	Die complexity	0.56	Based on the Military Handbook for 32-bit microcontroller
π_T	Temperature coeff.	5.7	Based on the Military Handbook for T_J of 85^oC
C_2	Packaging Failure coeff.	0.0053	Based on the Military Handbook for 128-pin Hermetic SMT
π_E	Environmental Factor	4.0	Based on the handbook for mobile devices, GM.
π_Q	Quality Factor	10	Commercial part
π_L	Learning Factor	1.0	More than 2 years in production
λ_P	Failures rate per million hours	32.132	
MTTF	Mean Time To Failure	3.55 years	

Table 3. STM32L152ZET6

The overall system of this project is considerably reliable because MTTFs for all three components that are most likely to fail are fairly long. In addition, these components are selected because of their attractive price. The project's reliability can certainly be improved by ~~replace~~ replacing these components with higher pricing solution and that totally depends on the user need.

2.0 Failure Mode, Effects, and Criticality Analysis (FMECA)

Power Modules:
A shorted bypass capacitor on the SS pin will cause the module lost the slow-start feature, which has no influence to the system.

A shorted flyback diode or filtering capacitor on the output will cause a voltage drop. The power consumed on the shorted point may fry the component. This failure is critical to the system. (The diode used in the module is recommended by the regulator datasheet)

Dry out may happens on the capacitors in the -12v power module. The drop of the capacitance will lower the maximum current supply capability, which will not influence the system, since the -12v supply is used for logic operation. The short of the capacitor may cause a voltage drop to the output, the criticality of this failure depends on the magnitude of the voltage drop: A voltage just above the Vth of the H-bridge may fry the H-bridge(High Criticality), and a voltage below the Vth may cause the H-bridge remain open(fail to control the Peltier cooler Low Criticality)

Microcontroller：
The microcontrollers are supposed to have good reliability. However, given decoupling capacitor shorted, the microcontroller might not be able to reprogram again. Also, if input voltage suddenly drops, the capacitors might not be able to provide the power to keep the voltage stable. This will not damage other parts of the circuit board, the user will not need to reprogram the microcontroller. Another pitfall is that even the trivial noise in the circuit caused by perhaps insufficient capacitive decoupling near the MCU or switching the power supplies may causes errors on the UART communication and consequently leads to potential damage to users. Users may experience bi-polar temperature caused by the miscommunication of two microcontrollers. This may induces the temperature feedback system cannot work.

DC Motor Driver Module：
There might be a high possibility of overheating the DC motors in our project due to the fact that users may constantly by using the robotic hand. High ambient temperature comes along with the overheating issue can also damages other components around the motor.

H-Bridge Module:

The H-bridge is an important subsystem of our temperature feedback system. Our temperature feedback system includes a voltage regulator, an H-bridge, and the Peltier cooler. The Peltier cooler works by relying on the polarities of the input voltage. The polarities of the input voltage coming from the output of the H-bridge module. In the case where the H-bridge drives current less than 3A or outputs voltage less than |0.8|V, the Peltier cooler will not heat up or cool down enough for the human skin to detect a change in temperature. This would directly result in the failure of our temperature feedback system. The potential causes of these failures would be either the input voltage to the H-bridge being incorrect or the logic input voltage being incorrect. These two input voltages are the V_{DS} and V_{GS} values of the MOSFETs inside of the H-bridge and will impact the current and output voltage of the system to the cooler.

2.1 Levels of Criticality

The levels of criticality are divided into three levels: Low, Medium and High.

'Low' criticality indicates the failure mode is not harmful to the user and does not damage the rest of functionality that's critical to the user experiences. Low criticality levels are intended to have a failure rate of 10^-6 or less.

'Medium' criticality indicates the failure mode is not harmful to the user but can damage the rest of functionality that's critical to the user experiences. Medium criticality levels are intended to have a failure rate of 10^-7 or less.

'High' criticality indicates the failure mode can be harmful to the user and can damage the rest of functionality that's critical to the user experiences. High criticality levels are intended to have a failure rate of 10^-9 or less.

There are several major hardware components: power modules, DC motor driver module, microcontroller, comparator module and H-Bridge module. We anticipate that the most common failures modes will be high current drawn by the servos, communication lag between the different modules, and mechanical failure of the robot arm chassis.

3.0 Sources Cited:

[1] "Military Handbook,"1 1990. [Online]. Available: http://snebulos.mit.edu/projects/reference/MIL-STD/MIL-HDBK-217F-Notice2.pdf [Accessed 11 5 2014].

[2] Texas Instruments, “Step-Down DC-DC Converter With Eco-Mode,” TPS54332 datasheet, Sept. 2013 [Revised Feb. 2016].

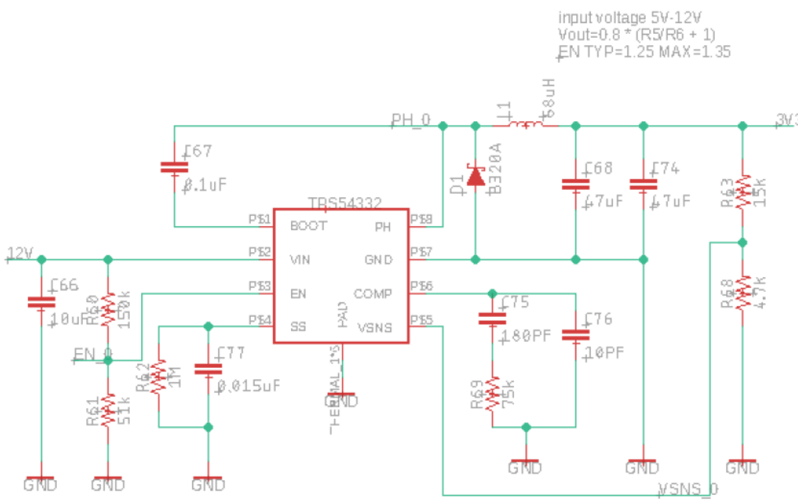
[3] Diodes Incorporated, “30V COMPLEMENTARY ENHANCEMENT MODE MOSFET H-BRIDGE,” DMHC3025LSD datasheet, n.d. [Revised Jan. 2018].

[4] Texas Instruments, “5-A Synchronous Step-Down Converter With Advanced Eco-Mode,” TPS56528 datasheet, Sept. 2013 [Revised Feb. 2016].

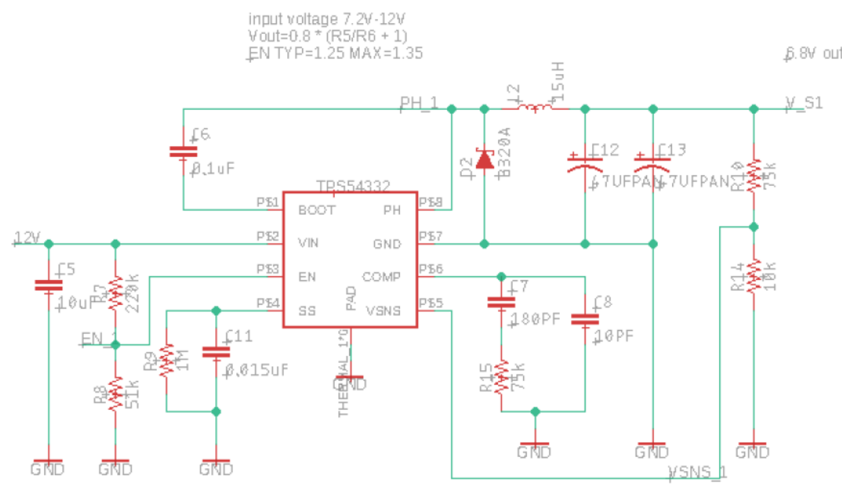
[5] STMicroelectonics, “Ultra-low-power 32-bit MCU,” STM32L151xE STM32L152xE datasheet, Sept. 2013 [Revised Feb. 2016].

[6] AlphaElectrics, “The Five Most Common Faults That Will Happen in AC and DC Motors,” *alphaelectrics.com*, n.d.. [Online]. Available: http://alphaelectrics.com/the-five-most-common-faults-that-will-happen-in-ac-and-dc-motors/. [Accessed Nov. 1, 2018].

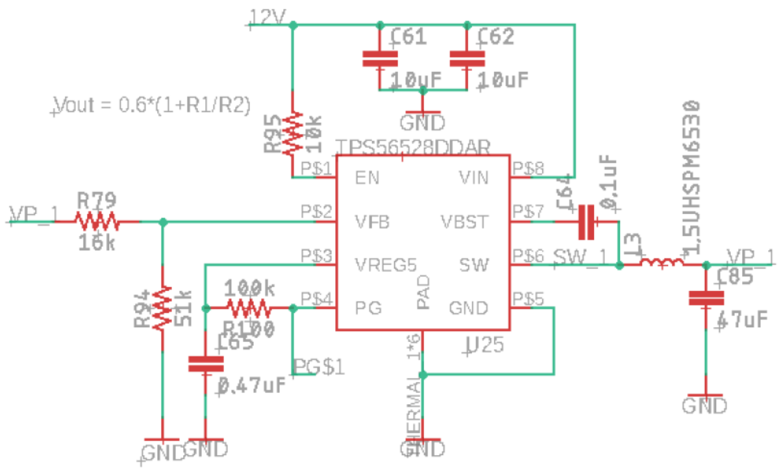
Appendix A: Schematic Functional Blocks



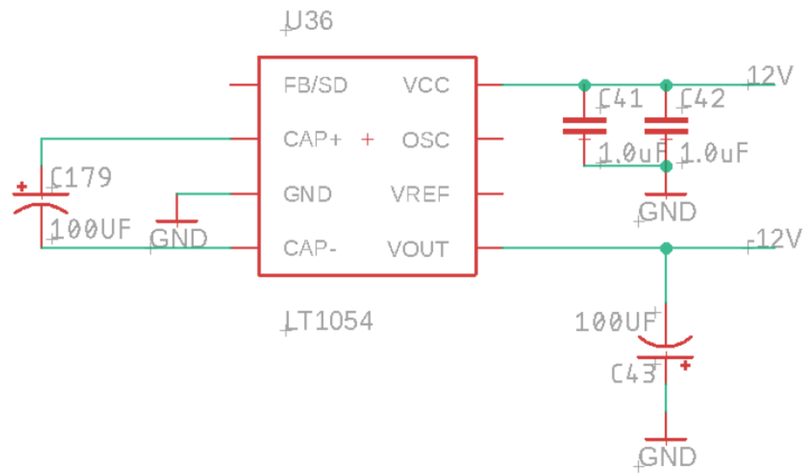
3.3v power module



6.8v power module

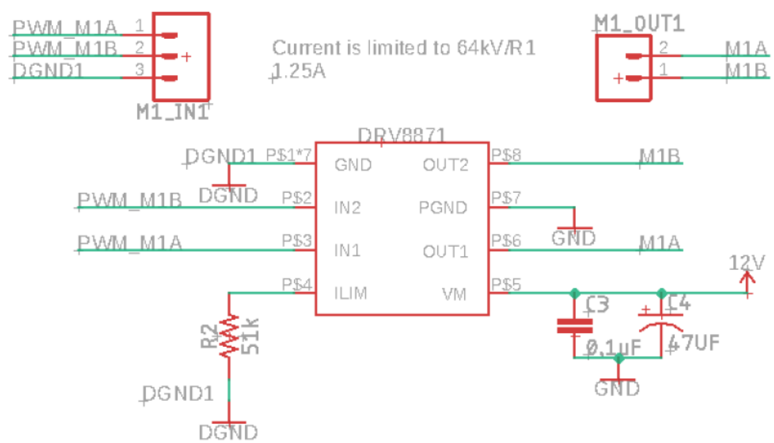


0.8v power module

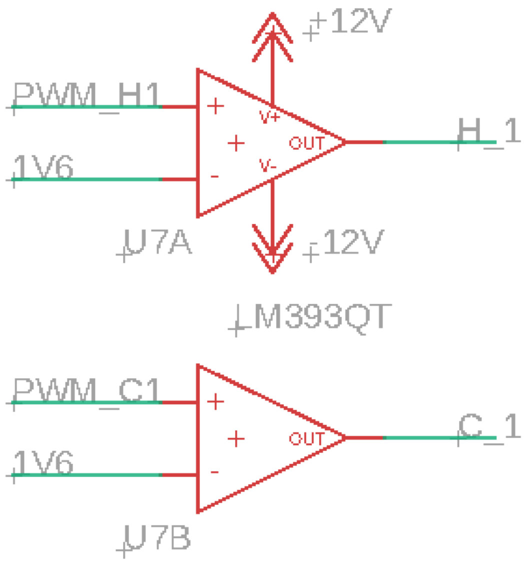


-12v voltage inverter module

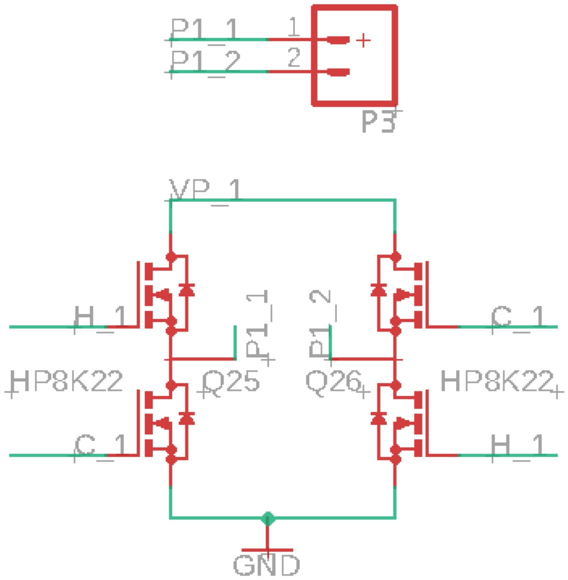
Power Modules



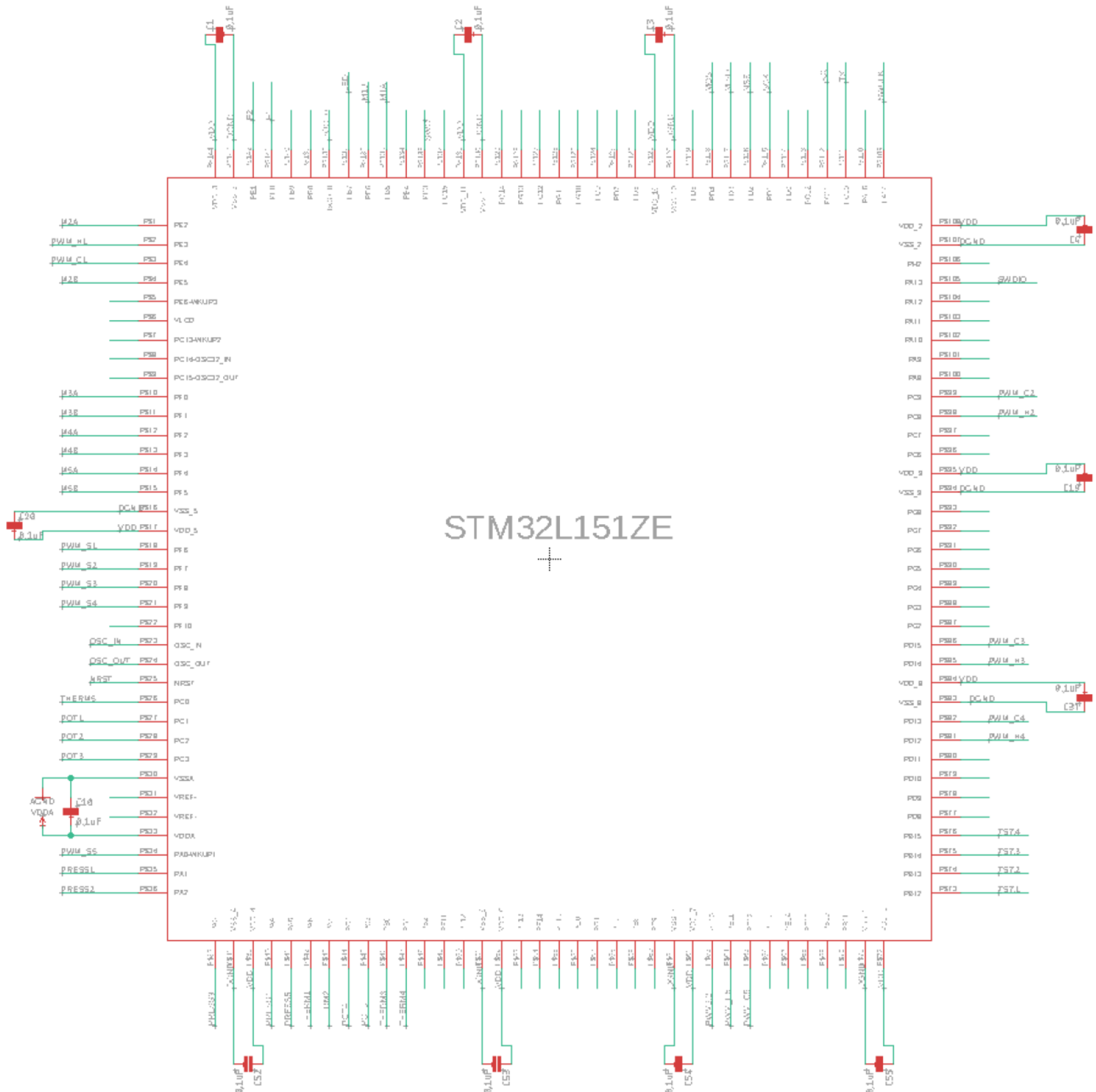
DC Motor Driver Module



Comparator Module



H-Bridge Module


STM32L151ZE

Microcontroller

Sensor Array

Appendix B: FMECA Worksheet

~~*For each group of failures corresponding to one subsystem, make a separate table and **label it with the name of the corresponding subsystem**. Add more rows to this table as necessary to provide a complete analysis.*~~

~~https://engineering.purdue.edu/ece477/Course/Assignments/Example/ReliabilityAndSafetyEx1.pdf~~
~~https://engineering.purdue.edu/ece477/Course/Assignments/Example/ReliabilityAndSafetyEx2.pdf~~

Subsystems A: Power Modules

Failure No.	Failure Mode	Possible Causes	Failure Effects	Method of Detection	Criticality	Remarks
A1	Low 0.8 Voltage on board	Voltage regulator failure, shorted output bypass capacitor	Peltier cooler not responding, or slow responding	observation, multimeter	Medium	
A2	High 0.8 Voltage on board	Voltage regulator failure, feedback resistor open circuit, heavy load on output	Peltier cooler too hot or too cold	observation	High	may damage other components
A3	Low 3.3 Voltage on board	Voltage regulator failure, shorted output bypass capacitor, shorted flyback diode	System stop working, LED dim	observation, multimeter	Medium	

A4	High 3.3 Voltage on board	Voltage regulator failure, feedback resistor open circuit, heavy load on output	System stop working, microcontroller over temperature, LED too bright	observation, multimeter,	Medium	may damage other components
A5	Low 6.8 Voltage on board	Voltage regulator failure, shorted output bypass capacitor, shorted flyback diode	Servos respond slowly, servos stop working	observation, multimeter	Medium	
A6	High 6.8 Voltage on board	Voltage regulator failure, feedback resistor open circuit, heavy load on output	Servos stop working, servos over temperature	observation, multimeter	Medium	may damage other components
A7	Low -12 Voltage on board (absolute value)	Voltage regulator failure, shorted output bypass capacitor, shorted input decoupling capacitors, 12v main power malfunctioning	H-bridges over temperature, Peltier coolers stop working	observation, multimeter	Medium	may damage other components
A8	High -12 Voltage on board (absolute value)	Voltage regulator failure, 12v main power malfunctioning	H-bridge Gate breakdown, comparator breakdown, Peltier coolers remain working, or Peltier coolers	observation, multimeter	High(if cooler remains heating) Medium (else)	low failure rate, may damage other components

			stop working			

Subsystems B: Microcontroller

Failure No.	Failure Mode	Possible Causes	Failure Effects	Method of Detection	Criticality	Remarks
B1	Microcontroller resets	Reset switch is open on pull-up resistor; reset switch is stuck on close; decoupling capacitor is open; unstable supply voltage	Device restarts	Visual observation	low	
B2	Miscommunication between two UART modules	Intense power supplies switching and insufficient capacitive decoupling near MCU pins	Robotic hand and glove are not synchronized. Temperature and pressure feedback does not work	Skin feeling	medium	
B3	Microcontroller is not able to reprogramming	Insufficient capacitive decoupling near MCU pins	Microcontroller is not able to reprogramming	Observation	Low	

Subsystems C: H-Bridge

Failure No.	Failure Mode	Possible Causes	Failure Effects	Method of Detection	Criticality	Remarks
C1	Incorrect/opposite polarities switching	Incorrect pin connection	Opposite intended temperature effect experienced	Visual observation/sensor observation	low	
C2	Less than 0.8V output	Incorrect VGS or VDS fed into H-bridge	Peltier cooler not powered	Visual observation/sensor observation	low	
C3	Less than 3A output	Incorrect VGS or VDS fed into H-bridge	Peltier cooler not powered	Visual observation/sensor observation	low	

Subsystems D: DC Motor Driver Module

Failure No.	Failure Mode	Possible Causes	Failure Effects	Method of Detection	Criticality	Remarks
D1	Overheating	The torque of the motor is too small	Motor overheats and even stop working. Ambient temperature can break other components next to the motor.	Visual observation. Odor detection	low	