SUPERCAPACITOR MODULE FOR ILLINI-ROBOMASTER ROBOT

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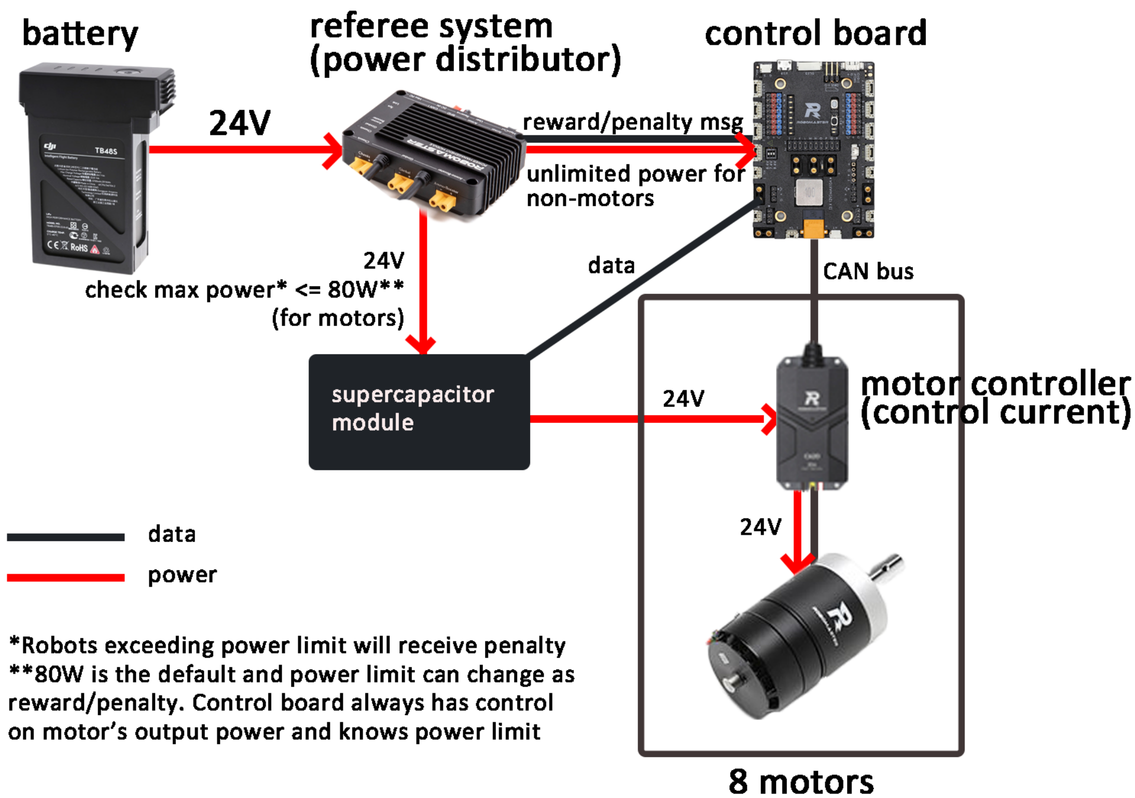
Contents

1. Introduction

Our project is to create a module to store excess power when not needed, and provide it when it is needed. We plan to achieve this using supercapacitors.

1.1 Problem

Illini-Robomaster (iRM) is an RSO at UIUC competing in the Robomaster robotics competition. During a match, robots will be penalized when motors exceed the power limit, but the monitoring system (referee system) is only checking the power output from the battery. To maximize available power for the motors and achieve greater mobility, we need a device to store and release energy. Existing solutions are either prohibited by the competition rules, too large to fit in our mobile robot, or sold at an unacceptable price by our competitor universities.



Visual aid. Note that the control board is the master control board on the robot, not on the module.

1.2 Solution

We propose a supercapacitor module to supply power in addition to the battery. It should be capable to store energy from the battery when the robot is running on low power and release energy when the robot needs it. Thus, we have more power available.

The supercapacitor module consists of a supercapacitor array and a control module. It should keep track of the current power stored and responds to requests from the master board by changing the power pathway of motors between by the battery or by the capacitors, and changing the behavior of the capacitor between charging and discharging.

1.3 High Level Requirements

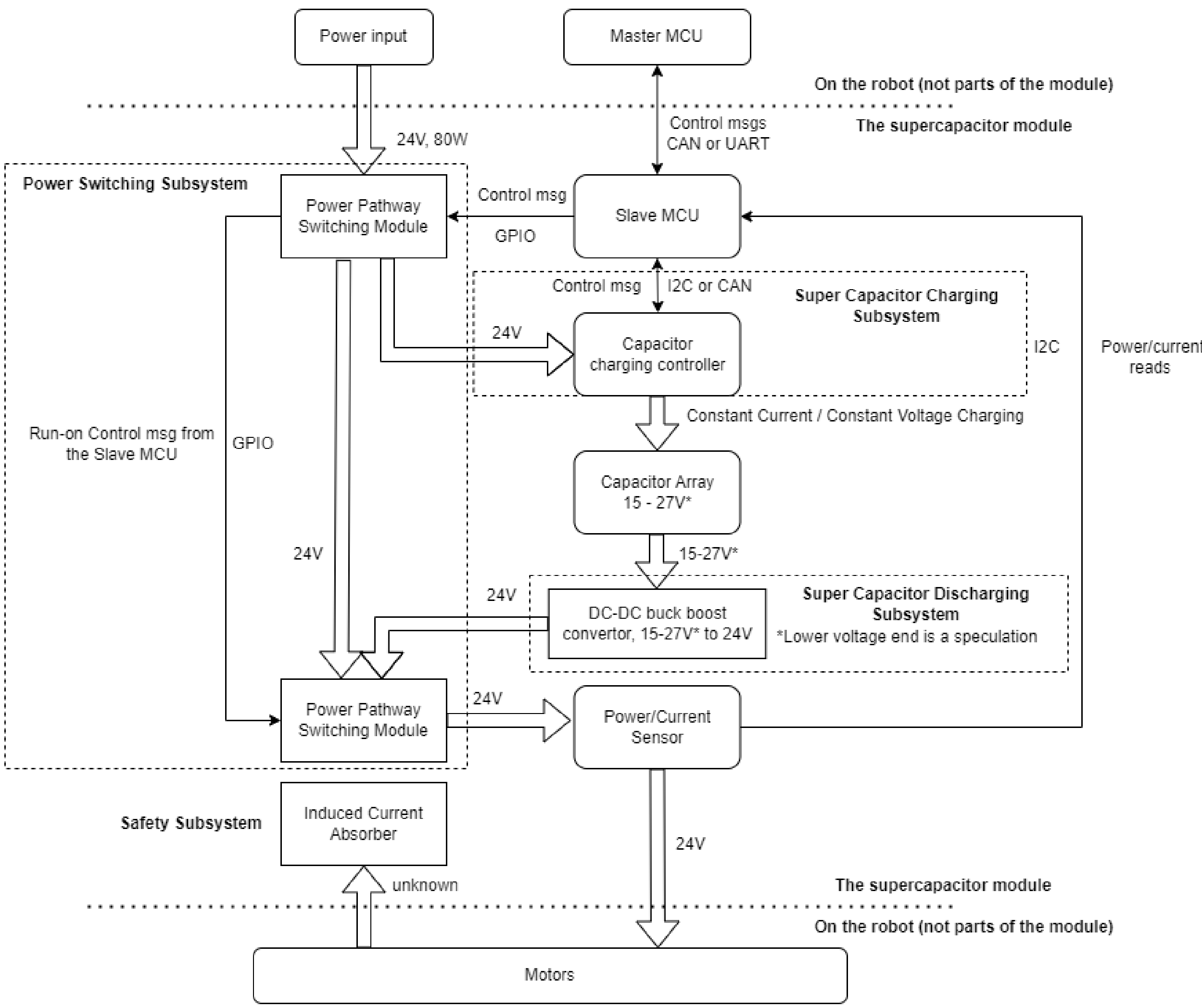
When the energy required by the motors is less than the source power limit of 80W, the module should supply the motors with enough power (as requested) and use the remaining current to charge the capacitor.

When the energy required by the motors is more than 80W and the capacitors have energy, the module should power the motors with 24V, same as the battery, and the current required by the motors.

When the energy required by the motors is more than 80W but the capacitors don't have energy, the module should direct all power from the battery to the motor and make sure the capacitors are not charging to take up power.

2 Design

2.1 Block Diagram



Block Diagram of the entire module
Legend:
Thick arrows: Power

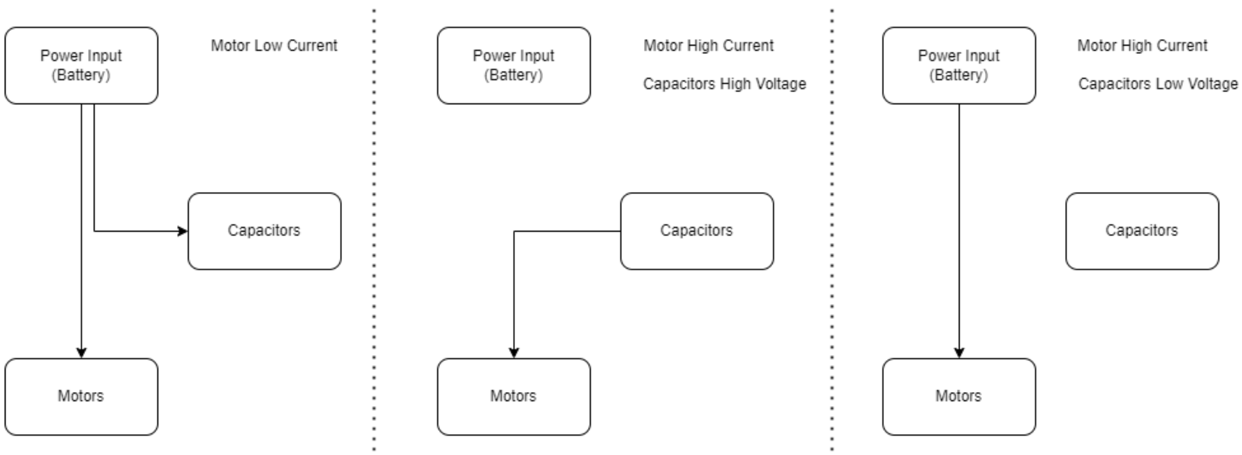
Thin arrows: Data
Rounded Rectangles: Off-the-shelf products
Angled Rectangles: Customized circuits

2.1.1 Power Switching Subsystem

Switching power pathway for the motors given the requests from the master MCU and current state.

The switching should be controlled by the slave MCU and unexpected ways of power pathway (for example, powering motors with battery and discharging capacitors together) should be prohibited. The subsystem should not decrease the voltage of its output by more than 2V or consume more than 1W.

For this subsystem, we use BJT as switches whose GATEs are controlled by the MCU. We plan to rely on software to ensure incorrect combinations of GATEs cannot be turned on together. There are 3 different pathways that make 3 valid configurations:



We place one BJT on each pathway whose GATE is controlled by MCU GPIO.

Requirements	**Verification**
The switching system can switch to all 3 patterns of connections: battery to motors; battery to motor and battery to capacitors; and capacitors to motors	Apply threshold voltage to corresponding gates Then, measure connectivity with a multi scope. Confirm that only the required path is closed.

The switching system's responding time should be less than 2ms (minimal control cycle for motors)	Measure the voltage on the gates and the output with an oscilloscope Apply different voltages to the gates, and compare the time delay. 95% of the tests must have a delay < 2ms
The switching system must sustain a large current (10A±1A)	Apply 10A current with a current source to each of the configurations for at least 10 seconds. Then go over the previous 2 tests. If both pass, then we consider this as a pass.

2.1.2 Supercapacitor Charging System

Charge the supercapacitor with current from the battery. Controlled by the slave MCU and is coupled with the switching subsystem.
For this subsystem, we choose BQ24640 as an off-the-shelf supercapacitor charging chip. It can charge the supercapacitor from 2.1V to 26V and has constant voltage and constant current charging modes. A PWM pin on the chip is used to control the charging current of the capacitor so we can control the power distributed to charging when the voltage is constant.

Requirements	**Verifications**
The charging subsystem can charge the capacitors with the set current	Set a voltage by replacing resistors at the current control pin. Then, measure the output voltage of the charging subsystem and compare it with the expected value. Confirm that the difference is less than ±4% for 95% of the tests

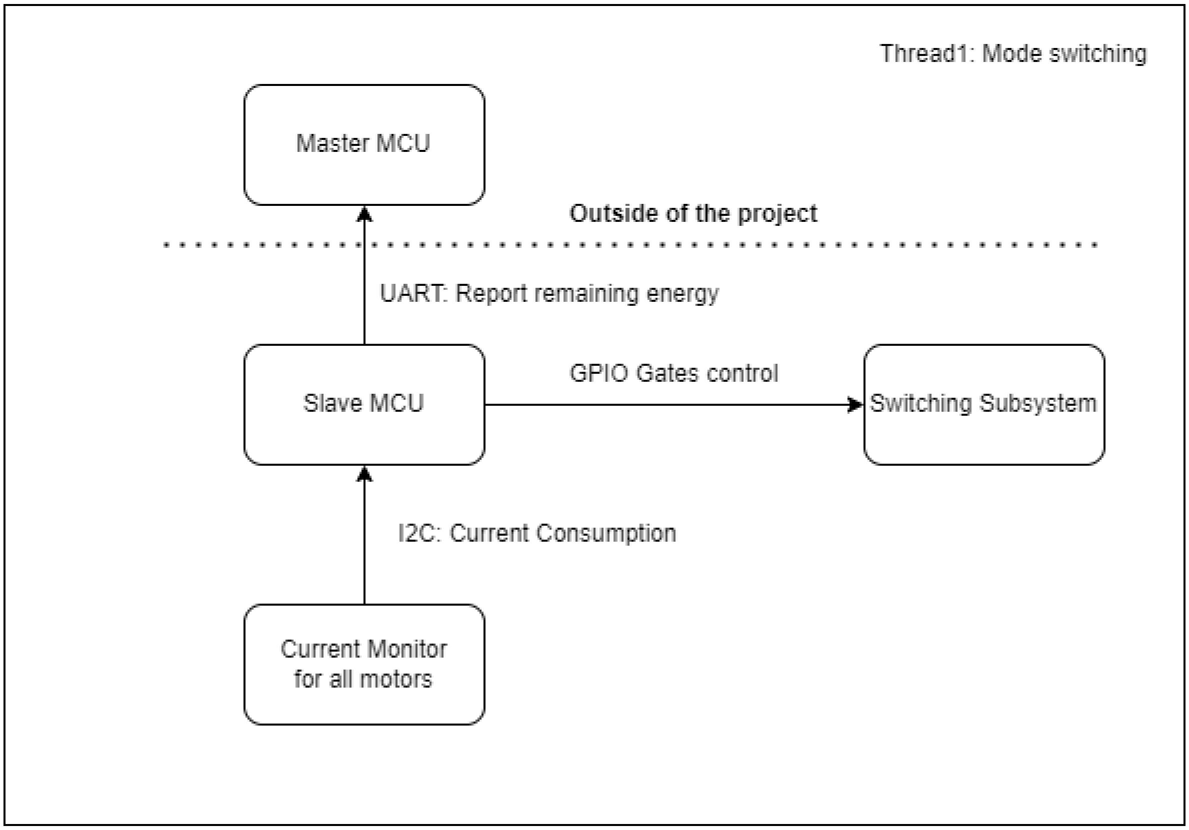
2.1.3 Supercapacitor Discharging System

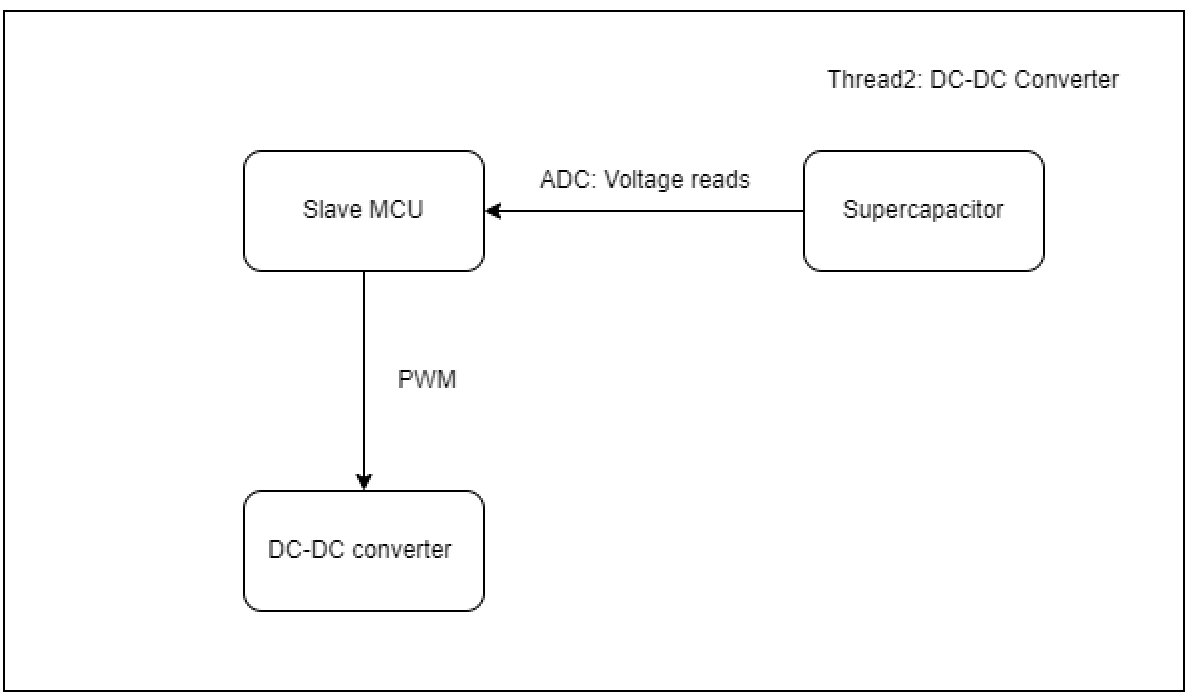
Release energy from the battery, controlled by the slave MCU and is coupled with the Power switching subsystem.

For this subsystem, we will use the MP4247 non-inverting buck boost converter, which can convert a range of input voltages to a requested output voltage, in our case 24V. This chip takes I2C signals to set the output voltage and other parameters. Along with the surrounding circuitry, this will make up our discharging system, leading back to the power switching subsystem to deliver power to the robot.

Requirements	**Verifications**
The DC-DC converter should convert variable input voltage to stable output voltage (+/- 0.5V)	Connect a power supply to the input of the discharging subsystem. Then, scan the voltage of the power supply from 27V to 10V with a step of 0.1V Confirm that the voltage output is in the range of 24±0.5V for 95% of the tests
The DC-DC must sustain a large current (10A±1A)	Apply 10A current with a current source to each of the configurations for at least 10 seconds. Confirm no critical thermal effect (> 125°C) Then go over the previous test. If it pass, then we consider this as a pass.

2.1.4 Software





Detailed API

2.2.4 Tolerance Analysis

The maximum energy allowed by the rules in the capacitors is 2000J (nominal). We plan to use 10 2.7V 50F capacitors, which results in ½ CU^2 = 1822.5J at 27V. Average attacking window lasts for 5s and consumes 100W of power. So we want the capacitor module to release at least 500J of energy, and the ending voltage is 23V, which is higher than the minimum voltage our supercapacitor charging chip can support (2.1V for BQ24640). If power is drawn for longer, at a steady 100W from supercapacitors the current rapidly increases. If we draw power down to 15V in a longer attacking window, the current will go up to 6.67 A.

2.3 Safety

When motors stop, the induced current will flow back to the supercapacitor module. We need to make sure the induced current is safely handled.

Requirements	**Verifications**
It's hard to define "safe" so we will use the following rule of thumb: everything should still work after the induced current is released and we don't smell anything burning.	N/A
This subsystem should not force motors or the supercapacitor module to stop working to avoid the induced current.	N/A

For this subsystem, we choose LM74670-Q1 chip as an off-the-shelf diode rectifier. Since energy efficiency is not important for the robot during the competition, we choose to waste the induced current safely with a rectifier.

3. Cost and Schedule

3.1 Cost

The total cost for parts as table shown below is $45.31. With an additional $7 in shipping and 10% on tax, the final result is $56.85 We can expect a salary of $40/hour * 7 weeks * 20 hours/week = $5600 in labor cost. This comes out to be a total cost of $5656.85

Name	Description	Price	Quantity	Total Price
SIS412DN	MOSFET for supercap charger chip	0.59	2	1.18
BQ24640	supercapacitor charge controller	5.19	1	5.19
INA219	digital current monitor	2.97	1	2.97
LM74670	smart diode rectifier controller	2.76	1	2.76
STM32G474	MCU for the board	12.35	1	12.35
MP4247	buck boost converter	3.81	1	3.81
AMS1117	Voltage regulator for MCU	0.62	1	0.62
LM5050	MOSFET controller	2.15	2	4.30
MCP4018	Digital Potentiometer	0.72	1	0.72
Capacitors	SMD 0805 capacitors	0.1 (average)	36	3.60
Inductors	SMD 0805 inductors	0.1 (average)	2	0.20
Resistors	SMD 0805 resistors	0.1 (average)	22	2.20
LED lights	indicate power status	0.15	3	0.45
SK1045	Schottky diode for supercap charging	0.85	1	0.85

BAT54	Schottky diode for supercap charging	0.16	1	0.16
SMAJ28CA	DC-DC output voltage regulator (fuze)	0.32	1	0.32
4 pin header	pinout from the MCU	0.16	6	0.96
XT30 connector	connectors for the power	1.9	4	7.60
CSD19531	MOSFET for power switching	2.21	4	8.84
Total	-	-	-	59.08

3.2 Schedule

Week	Task	Person
2.27 - 3.5	Order parts	Haoyuan
	Initial PCB design	Haoyuan
3.6 - 3.12	Verify power switching module + programming	Haoyuan
	Verify DC-DC converter module + programming	Shaurya
3.13 - 3.19	Verify safety module	Haoyuan
	Verify charging module + programming	Shaurya
3.20 - 3.26	Test the entire system	Shaurya
	Second PCB design	Haoyuan
3.27 - 4.2	Assemble	Everyone
4.3 - 4.9	Integrate to the real robot	Everyone
4.10 - 4.16	Finalize everything	Everyone

4. Ethics and Safety

As the use of supercapacitors is allowed and already regulated by rules in the competition, there are no known ethical concerns about using such a module on the robot. The safety concerns mostly revolve around storing large amounts of power in our module, as all the surrounding power sources are already determined safe and provided to us by Robomaster. We are limiting the capacitor voltage to reduce the danger present, and only charging the capacitor to a safe amount of energy stored, as ruled by Robomaster. Induced current from the motors can also damage our hardware, so we will have a subsystem dedicated to dealing with it.

Additional safety concerns exist, not during the use of this device, but during our testing. Precautions need to be taken to keep ourselves safe and to confirm the power stored in our device is no more than expected. We intend to use the proper lab equipment and safety procedures, and monitor the power stored in the supercapacitors at all times. We also intend to start testing with lower power to stay safe and ensure everything functions properly.

5. References

[1] *IEEE Code of Ethics,* IEEE Xplore, accessed 29 March 2023.