Steel Wire-Rope Inspection Tool

Group 9:
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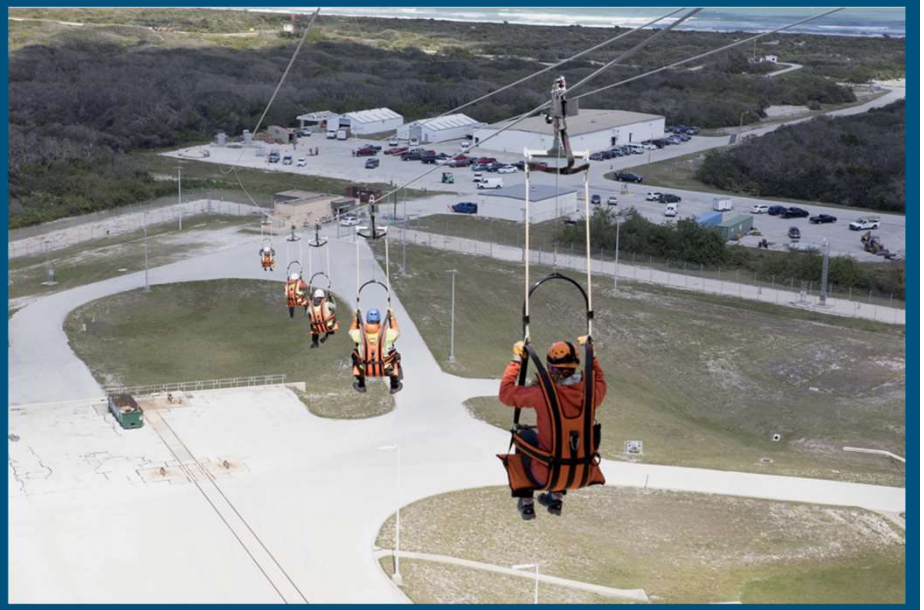
Sponsor: United Launch Alliance

Introduction

- United Launch Alliance developed Emergency Egress System in 2017.
- The egress cables are situated on level 12 of the Crew Access Tower (CAT), 172 feet above the Space Launch Complex 41 pad deck at Cape Canaveral Air Force Station.
- Allows the crew to evacuate the CAT quickly to a landing zone more than 1,340 feet from the launch vehicle.



Motivation

- Current Inspection Methods Costly and Time-Consuming
- Tasked with Designing and Implementing a device that can be installed on the cable traveling across the length of the cable while inspecting for broken wires or other deformities.
- The device should be capable of being installed, operated, and removed by a single person.

Goals and Objectives

Device shall be used to perform a visual scan of each of 4 emergency egress system cables to detect possible damage to cables.

1) Device should at a minimum provide video recorded feed of entire cable diameter and length.

2) Device can provide additional sensor scan data (i.e. Hall Sensor) to provide greater fidelity data.

3) The objective of the inspection is to look for signs of damage that would jeopardize the safety of a person transition the cable during a training exercise or prior to a mission. This would include:

a. Foreign objects on the cables (FOD)

b. Broken strands that are a protrusion to the cable – trolley path of transition.

c. Broken strands of the cable in general.

d. Signs of electrical damage from arc (i.e. lightning strike)

e. Excessive corrosion

Operation Requirements

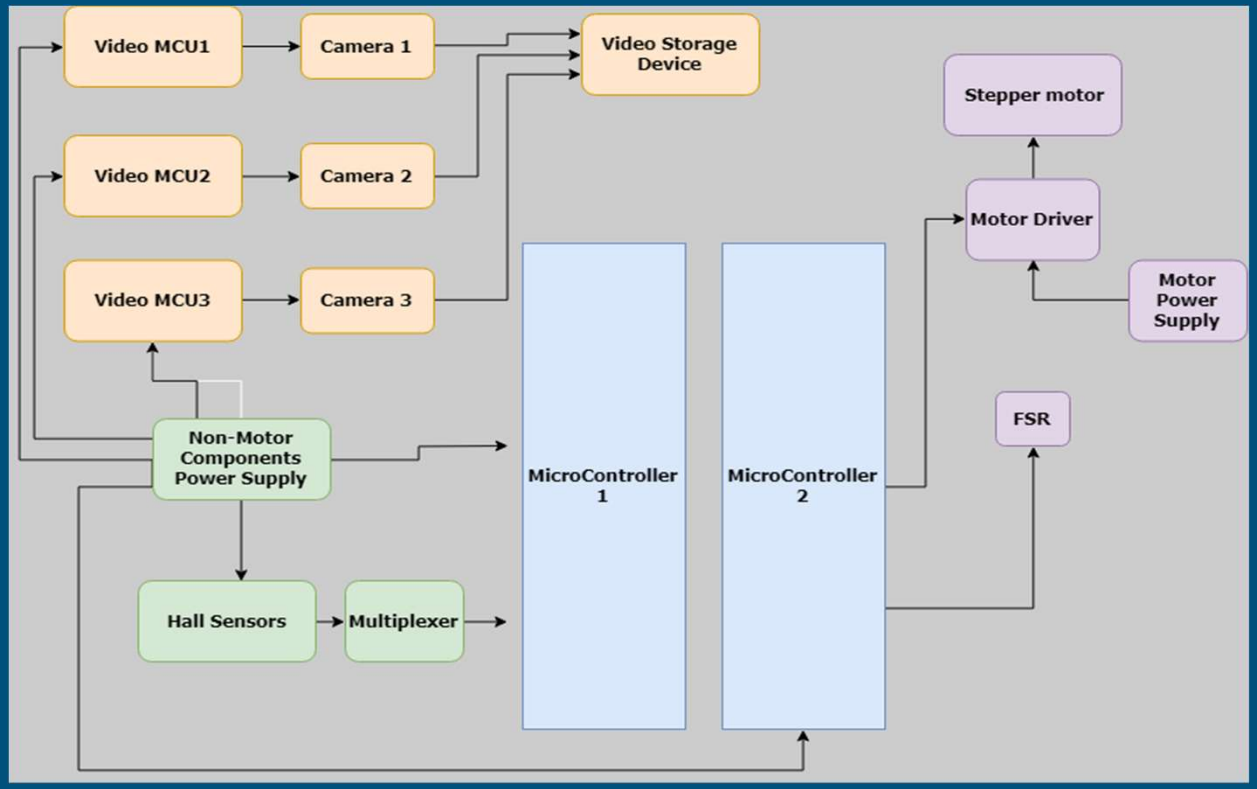
1) Device will be required to descent the length of each cable, no ascent required.
2) Maximum desired window of time to complete all scans (all cables) is 4 hours.
3) Required to be able to upload and store the data for each cable individually for future comparison purposes. Upload of data to be done after all four cables are inspected per session.

Egress Cable Specifications	
Length	1319 ft.
Average Grade	14%
Cable	IWRC 6X19 Steel Wire Rope
Cable Thickness (Diameter)	3/4''

Expected Benefits

- Less recurring costs of man hours to complete task
- More scheduling opportunities to perform task due to decreased personnel and time requirements
- Decreased risk for operating personnel
- System can be implemented for other Wire-Ropes such as in Zip-Lines, Ski Lifts, or other Cable Lift mechanisms.

Overall Block Diagram



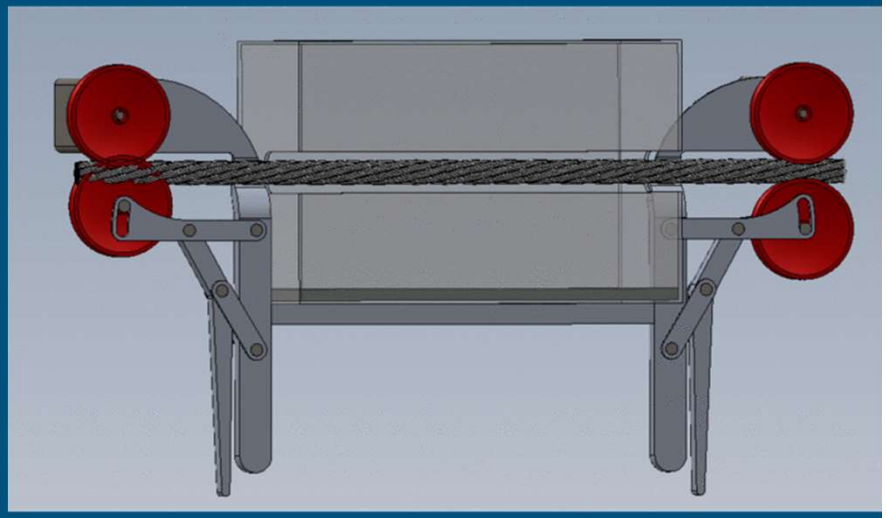
Mechanical Involvement

3 Mechanical Engineering Senior Design Groups whose primary focus areas are:

- Chassis
- Cable Grip and Mounting
- Device Construction
- Meeting Torque and Operation needs to ascend cable

Electrical/Computer focus:

- Motor Controls
- MicroController
- Sensors (Visual & Electromagnetic)
- Power Needs



Motor

Step Angle: 1.8°
Holding Torque: 425oz.in
Rated Current: 4.2A
Operating Voltage: 24-48V
Weight: 1.8kg

Desired Speed : 0.868 ft/s
Desired Torque: 384 oz.-in.

23HS45-4204S NEMA23 Stepper Motor

Motor Driver

DM542T Digital Stepping Motor

- Anti-Resonance provides optimal torque
- Overvoltage and overcurrent protection
- Lower Noise
- Ideal choice for high requirement applications

Stepper Driver Specifications	
Input Voltage (V)	20-50
Output Current	1-4.2A
Microstep(Steps/rev.)	400-25600
Max Pulse Input (kHz)	200
Pulse Width (us)	2.5
Weight (kg)	0.21

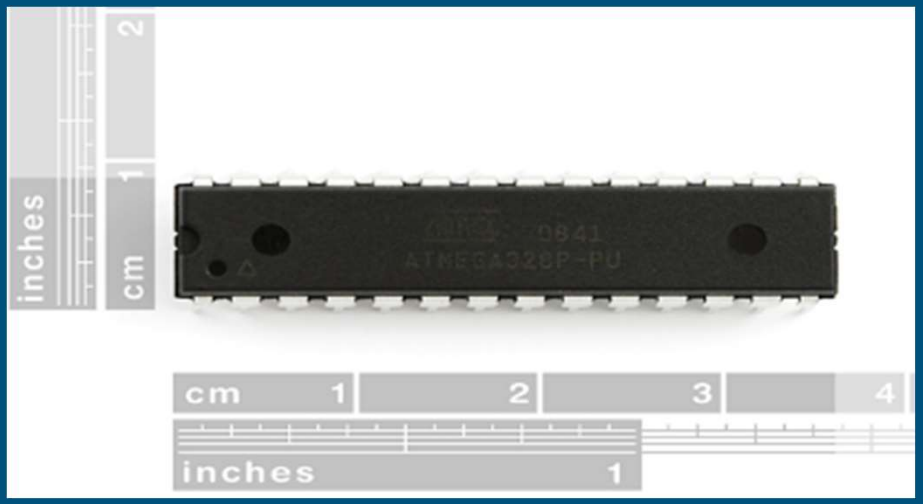
MicroController Selection

Features	ATmega328/P	MSP430G2553	ATmega2560
Pin Count	32	20	100
Flash Memory (KB)	32	16	256
CPU Speed (MHz)	8	16	16
Supply (Operating) Voltage	1.8-3.6V	1.8-5.5V	1.8-5.5V
Analog I/O Pins	6in/0out	8in/0out	16/0
Digital I/O Pins	9	8	54
Cost (USD per unit)	$2.01	$2.41	$12.35

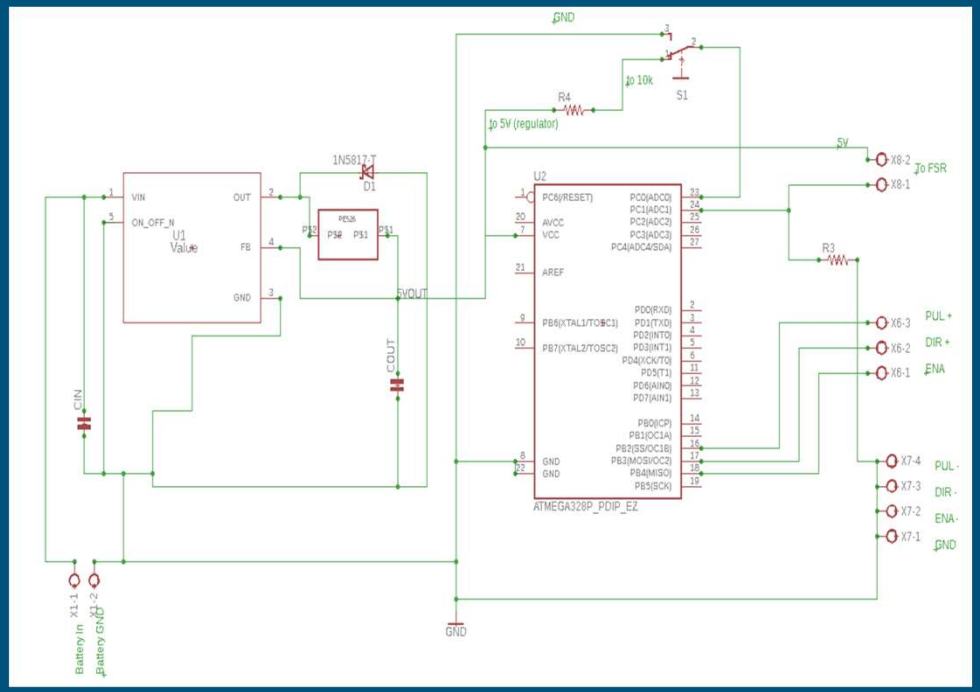
MicroController Selection

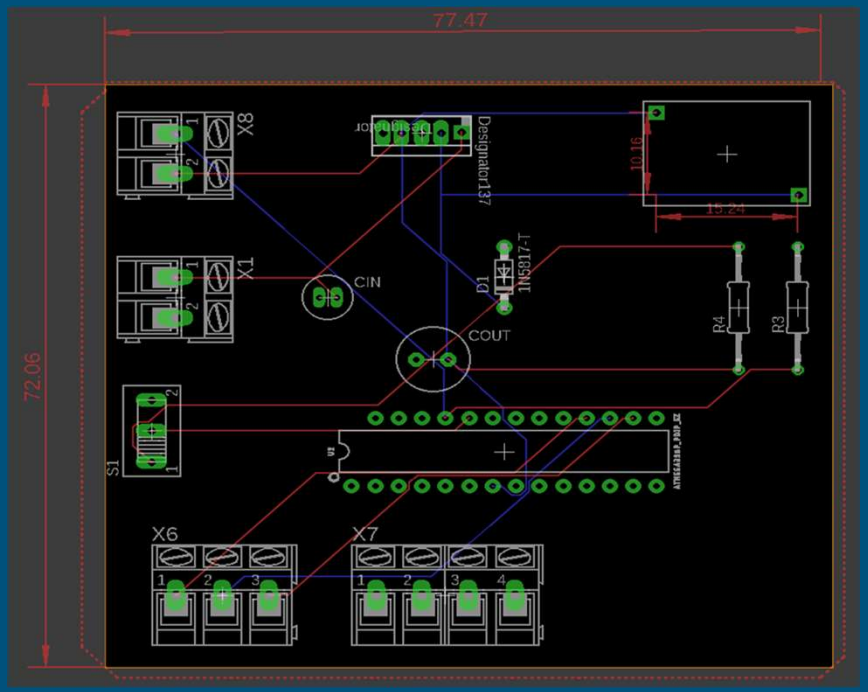
ATMega328P

- Familiarity
- Well-Documented
- Dual In-line Package

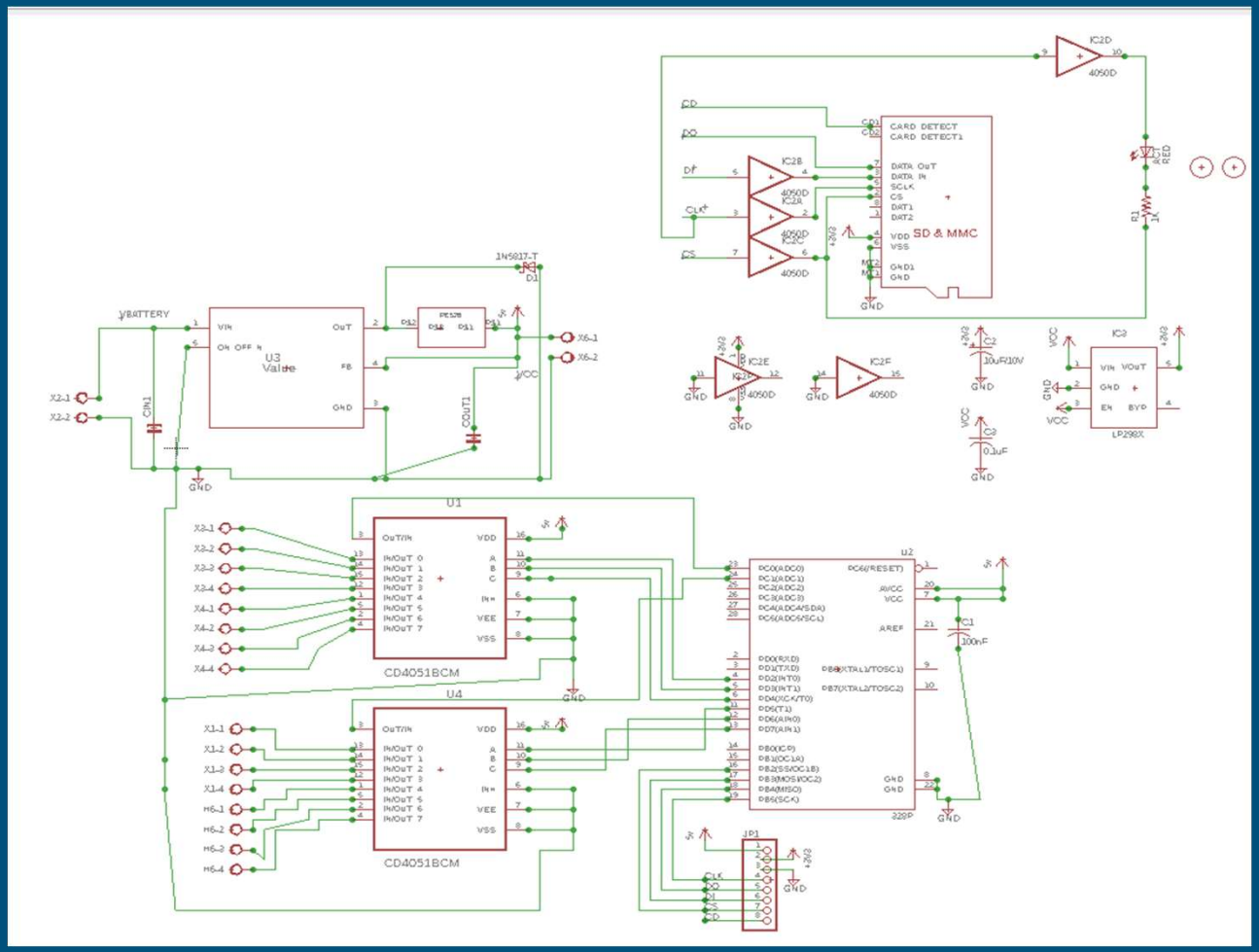


Motor Control Circuit

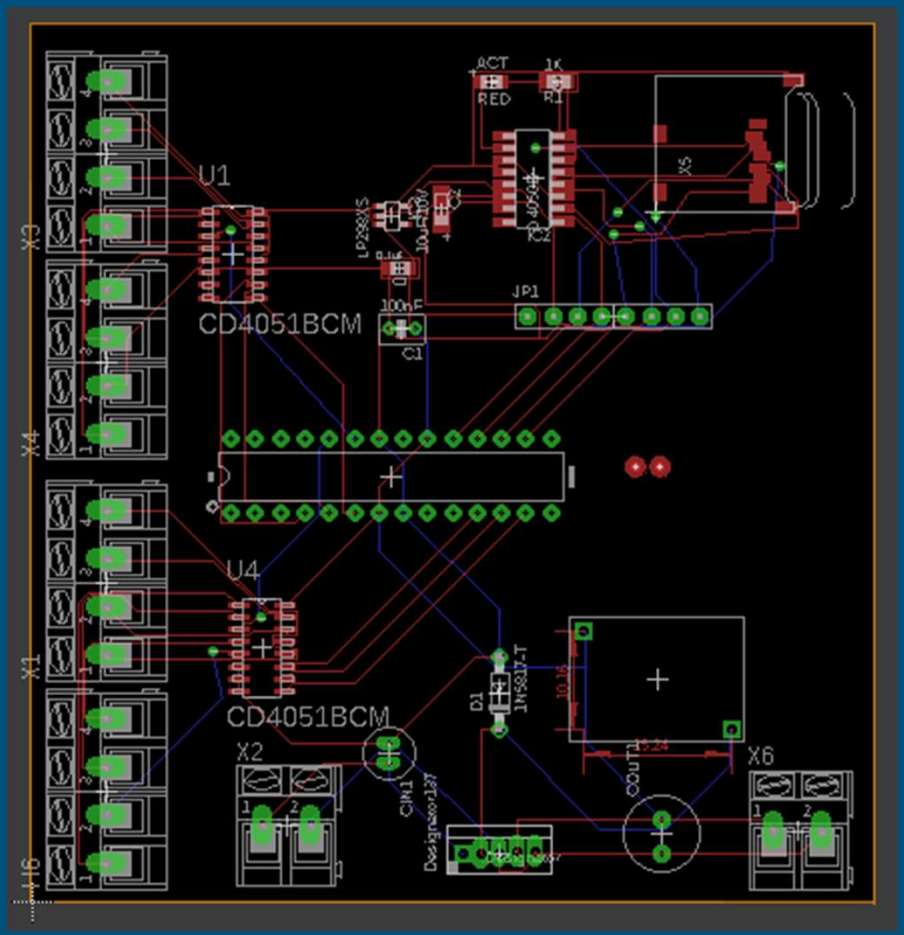




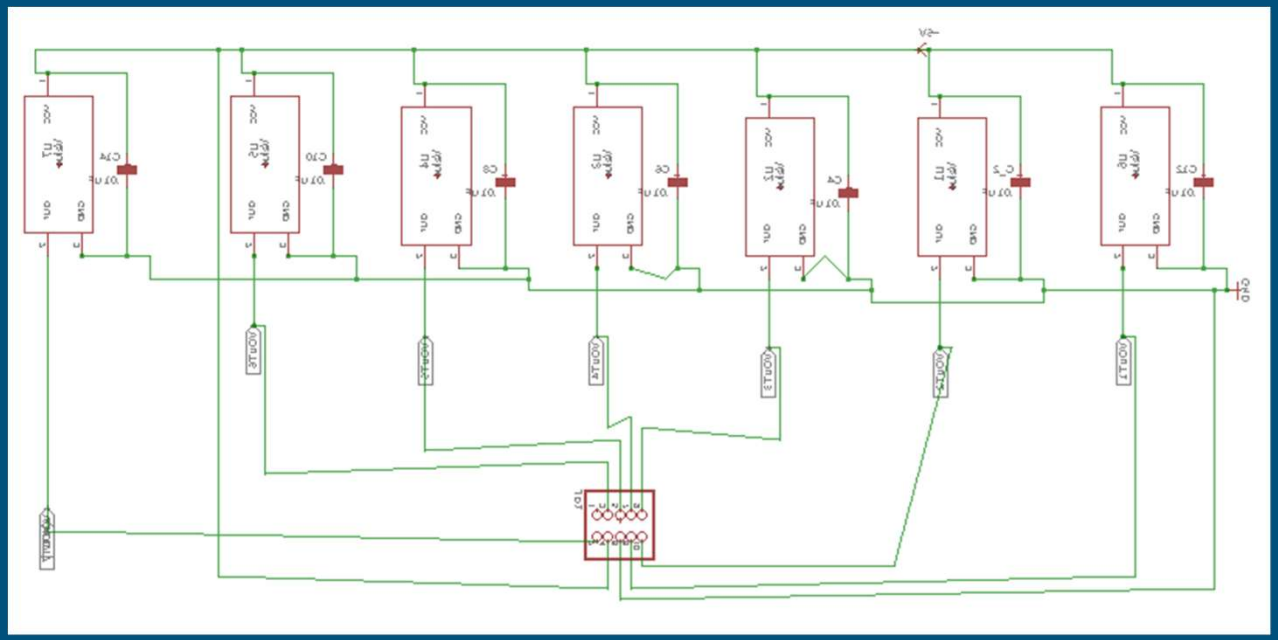
Hall Sensor MCU Schematic



Hall Sensor MCU Board



Hall Sensor Array Schematic



Battery (Non-Motor Components)

Battery:	LiFePo 18500	LiFePo4 18650	Lectron Pro Lipo Battery
Number of Cells	4 cells	6 cells	6 cells
Operating Voltage	7.4 V	9.6 V	22.2 V
Capacity	2.8 Ah	3.0 Ah	5.2 Ah
Dimensions	4.2" x 1.5" x 0.9" (LxWxH)	2.1" x 1.9" x 3.1" (LxWxH)	5.35" X 1.77" x 2.01" (LxWxH)
Weight	4.4 oz	10.2 oz	23.25 oz
Charging Time	3 hr	3 hr	2.5 hr
Price	$40.00	$46.95	$85.00

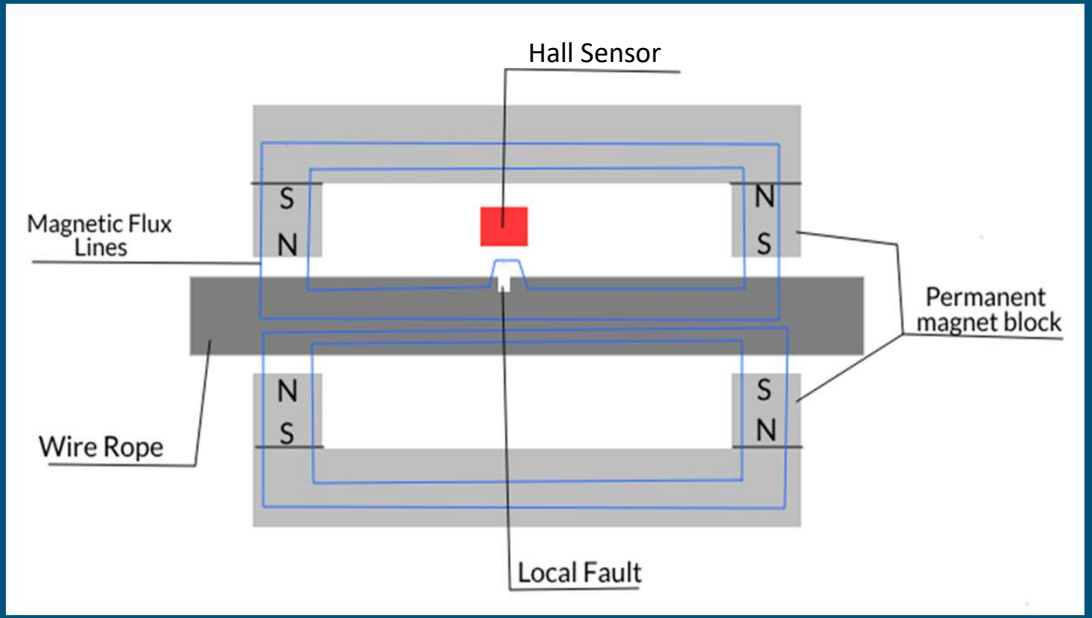
Voltage Regulation

Regulator:	TPS7B6950	LMR14010	LM2575
Type of Regulator	Linear	Switching	Switching
Operating Voltage	5.5 – 40 V	4 - 40V	4 - 40 V
Regulated Output	5 V (fixed)	.765 - 30 V	5 V (fixed)
Max Output Current	0.150 A	1 A	1 A
Efficiency	~25%	~80%	~77%
Dropout Voltage	450 – 800 mV	0.2 - 0.5 V	0.7 - 1.4 V
Shutdown Temperature	175 °C	170 °C	125 °C
Manufacturer	Texas Instruments	Texas Instruments	Texas Instruments

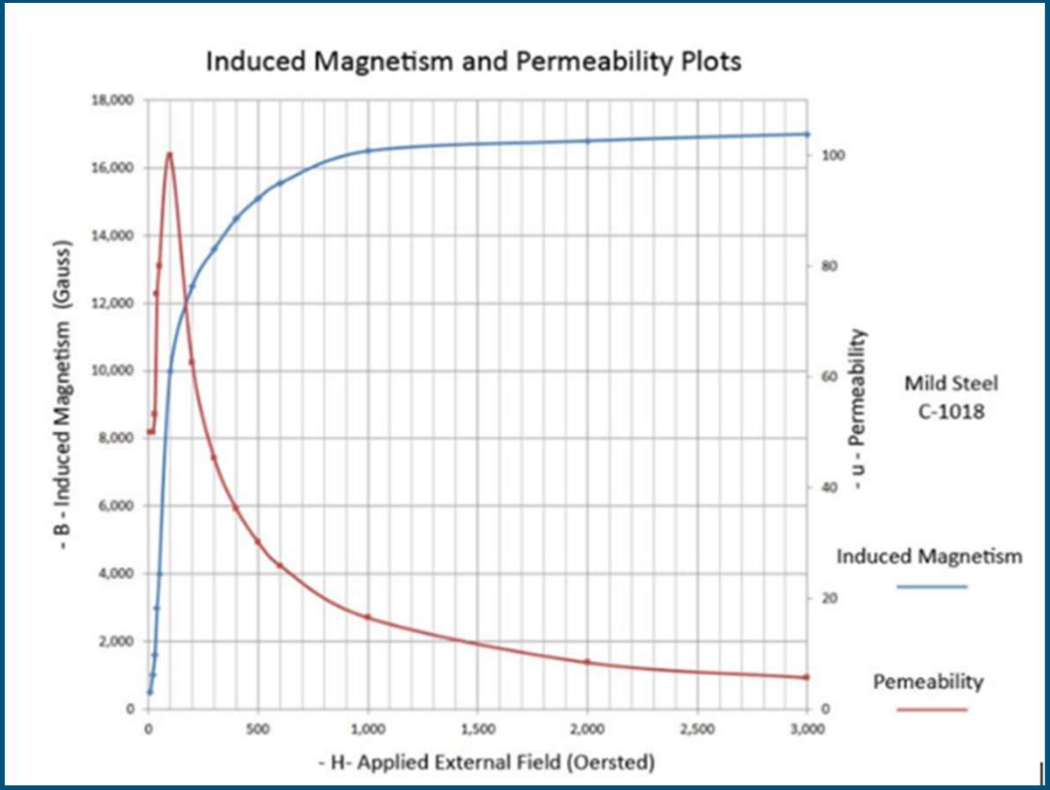
Magnetic Flux Leakage

The detection and identification of breaks or faults in a ferromagnetic material by sensing "leaked flux"

1. Magnetic saturation of the material to be tested.
2. Selection and arrangement of the sensing elements
3. Movement of the magnetizing and sensing elements along the surface of the material.

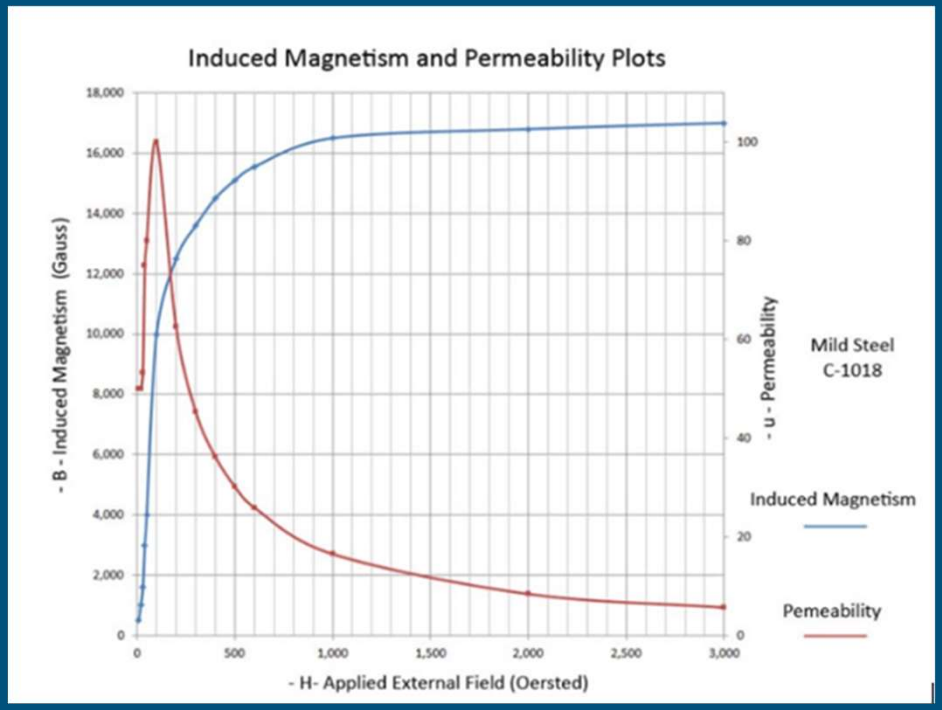


Magnetic Saturation of the Wire Rope

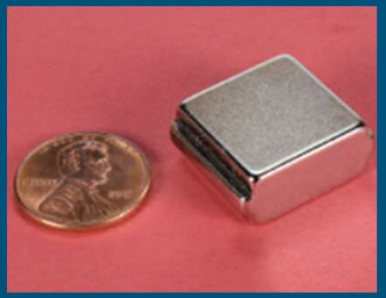


Methods of saturation:	
Coil magnetization	**Permanent Magnet magnetization**
Field strength can be adjusted to appropriate strength	Strong rare Earth magnets are capable but fixed
Cumbersome and complicated to implement	Much easier to implement and arrange

Magnetic Saturation of the Wire Rope



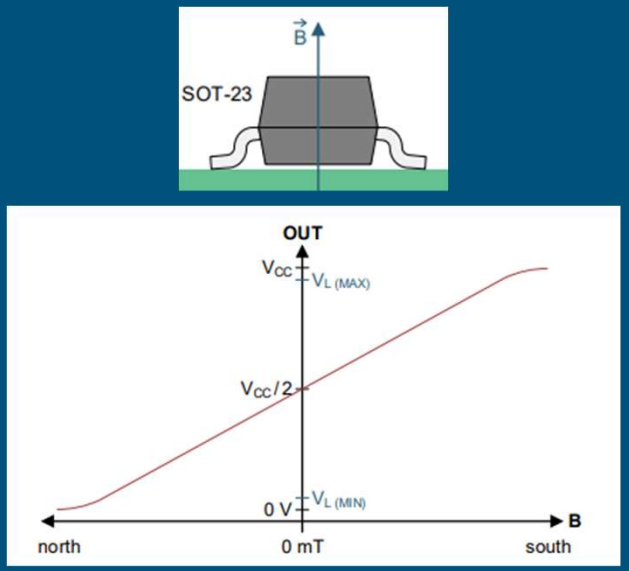
SBCC6-OUT Nickel plated Neodymium magnet	
Surface Field:	4260 Oersted
Dimensions:	3/4" L x 3/4" W x 3/8" T
Weight:	0.965 oz.
Price:	$7.50 each

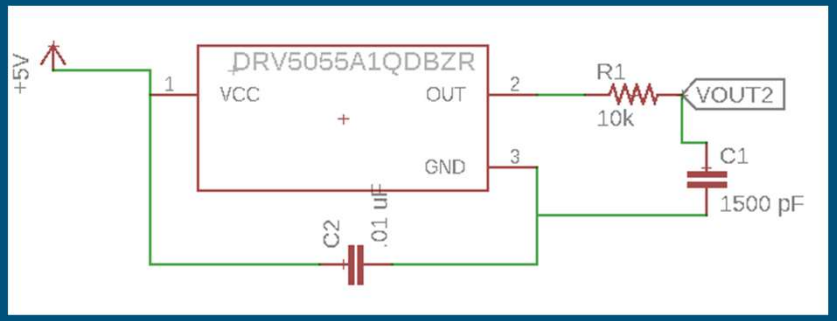


Hall Sensor Selection: DRV5055

Hall Sensor:	DRV5055	DRV5056-Q1	SS495
Magnetic Sensitivity	12.5 -100 mV/mT	23.8 – 210 mV/mT	32.15 mV/mT
Operating Supply Current	6 - 10 mA	6 - 10 mA	7 mA
Propagation Delay Time	10 µs	10 µs	n/a
Input-Referred Noise	0.12 mT_{pp}	0.12 mT_{pp}	n/a
Polarity	Bipolar	Unipolar	Bipolar
Quiescent Offset	$V_{CC}/2$	0.60 V	$V_{CC}/2$
Standard Industry Package	Surface-Mount SOT-23	Surface-Mount SOT-23	Board-Mount TO-92
Manufacturer/Availability	Texas Instruments / yes	Texas Instruments / pending	Solid State Sensors / yes

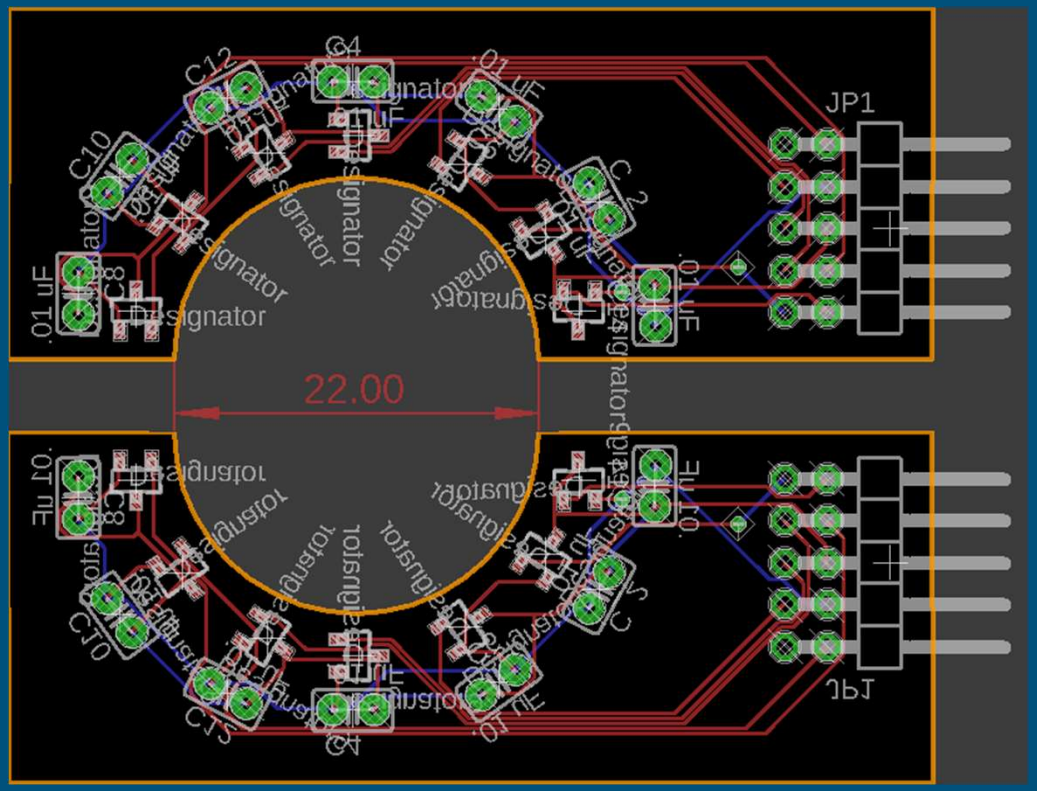
DRV5055-A1-QDBZR





Magnetic response of the DRV5055

Hall Sensor Array Board



MultiPlexer

Multiplexer:	CD4051B	74HC4052
Analog Signal Range	≤ 20 V_{PP}	-5 V to +5 V
Supply Voltage	5 V	5 V
Propagation Delay Time Signal Input to Output	30 ns	15 ns
Propagation Delay Time Address-to-Signal OUT	450 ns	30 ns
Channels	8 to 1	Dual 4 to 1
Manufacturer/Availability	Texas Instruments / yes	Nexperia/ yes

Video & Storage System

- Sponsors want a quality video that can be looked through after the tool has inspected the cables so they can visually check for any major damages.
- The device needs to have removable storage that they can remove from the device and connect to a computer and have a basic technician without specialized training look at the data output.
- To achieve complete coverage of the wire cable there will be three visual sensors spaced equidistantly around the circumference of the cable.

Microcontroller

- Taking video and storing it is a very resource intensive process
  - Requires strong processor and memory space
  - A single 1080p frame has 2,073,600 pixels
- Originally was using an Arduino Uno with the ATmega328p but testing showed it was not strong enough for our needs
- Switched to a Sitara AM3355 with a Beaglebone Black as it was the strongest processor
- The Raspberry Pi with a Broadcom BCM2837B0, was the final choice after issues with the Beaglebone

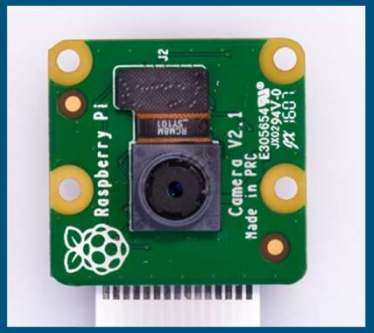
Features	ATmega328/P	Sitara AM3358	Broadcom BCM2837B0
Core Size	8-bit AVR	32-bit RISC	64-bit ARM v8
Max clock Frequency	20 MHz	1 GHz	1.4 GHz
Supply Voltage	1.8-3.6	1.8-3.3	5V DC
General Purpose I/O Pins	21	4 x 32 (Pins can have multiple configurations depending on modes set)	40

Visual Sensors

- Need a sensor with enough resolution to get a clear video image
- Needs to have a frame rate and shutter speed quick enough to capture entire wire
  - Shutter speed affects motion blur
  - Frame rate affects amount of cable captured per frame

	CMOS OV5642 Camera Module	Logitech C920	Raspberry Pi Camera Module V2
Output Formats	8-bit compression data, 8/10-bit raw RGB data	JPEG , YUV h.264	JPEG , GIF, BMP, PNG, YUV420 h.264
Shutter Style	Rolling shutter	Rolling shutter	Rolling shutter
Max Image Transfer Rate	5 megapixel (2592×1944): 15 fps (and any size scaling down from 5 megapixel)	15 megapixel 1080p30 720p60	8 megapixel 1080p30 720p60 640 × 480p60/90
Price	$40	$50	$25

- The OV5642 Camera Module was the original choice as it allowed the use of multiple cameras with an Arduino and were able to be used with the Beaglebone as well
- After issues with the Beaglebone the Logitech C920 was considered along with the Raspberry Pi camera, the pi camera was the final decision due to its quality and ease-of-use with the Raspberry Pi



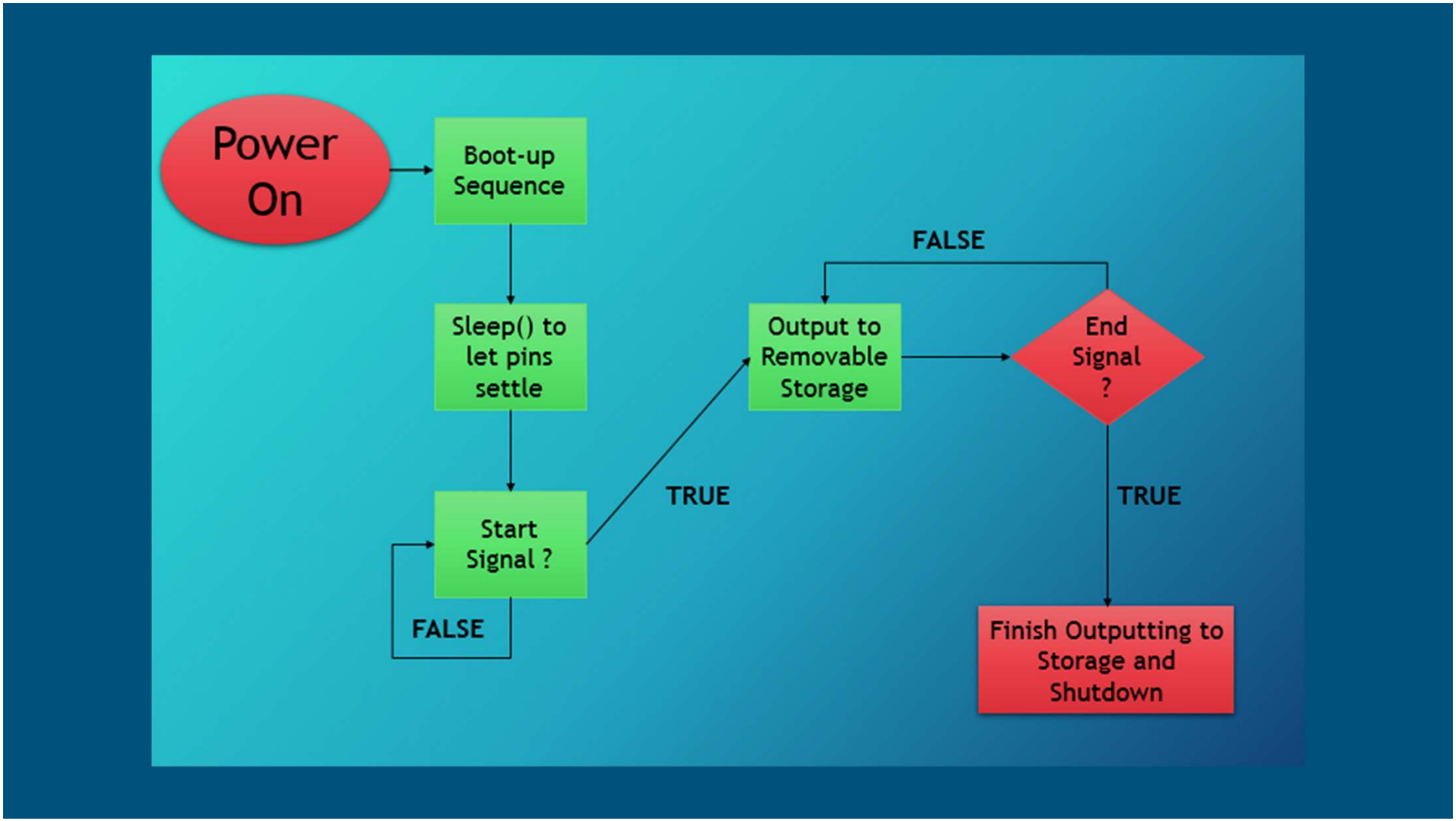
Storage Drive

- Need space to store high quality video and sensor readings for four cables
- Must be able to survive impacts or vibration
- Rules out almost all Hard Disk Drives, need to use a Solid State Drive

	LaCie Rugged Mini	ioSafe Rugged Portable SSD	StarTech Rugged Hard Drive Enclosure
Capacity	1/2/4 TB	500 GB/ 1TB	Variable
Storage Type	HDD	SSD	HDD or SSD
Interface	USB 3.0	USB 3.0	USB 3.0 SATA for drive
Drop Height	4ft	20ft	13ft
Other Resistances	Rain/Pressure	Crush/Water/ Chemical Environmental/ Altitude	Vibration/Humidity Salt Spray/Dust
Price	1TB - $100	500 GB - $650	$50*

Video Software Flow

- Three Raspberry Pi’s with cameras to control
- One main start button for all cameras
- Three main stages:
  - Boot Sequence
  - Video Output
  - Shut down
- One end signal that shall cause all video to finish outputting and finish writing to file
- Make use of different LED’s to inform user what stage it is in


Power On
Boot-up Sequence
Sleep() to let pins settle
Start Signal ?
FALSE
TRUE
Output to Removable Storage
FALSE
End Signal ?
TRUE
Finish Outputting to Storage and Shutdown

Administrative Content

Budget

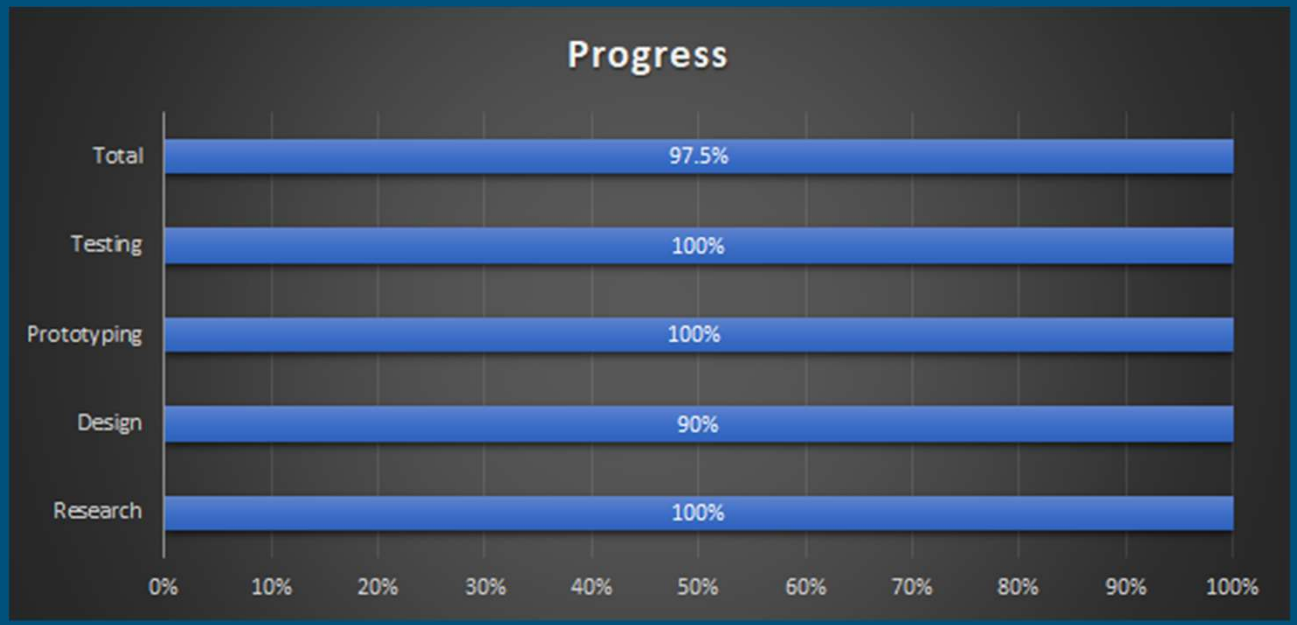
Subsystem	Item	Quantity	Vendor	Estimated Cost
Motor	23HS45-4204S NEMA23 Stepper Motor	1	Amazon	$39.00
	DM542T Digital Stepper Driver	1	Amazon	$4.86
	Mounting Brackets	1	Home Depot	$3.99
	ATMega328P-PU Microcontroller	1	Atmel	$2.01
	Motor Battery Powerizer LiFePO4 (24V 10Ah)	1	Powerizer	$299.0
	Switch	1	Amazon	$8.50
	Miscellaneous electrical components (resistors, chips, capacitors, wires, etc.)	-		$15
Hall Effect Sensor	Hall Effect Sensor	6	Texas Instruments	$1.83 x 6 =$10.98
	Video/Hall Sensor Li-Ion 18500 Battery Pack	1	AA Portable Power Corp	$40.00
Visual Sensor	Arducam OV5642 Camera Module	3	RobotShop.com	$29.99x3 =$90.00
	Raspberry Pi	3	Amazon	$39.00x3 = $117
Additional Costs	PCB(s)	4	JLCPCB	$21x4 =$44.00
	Shipping, Taxes, and other miscellaneous fees.	-	-	$50
Total Estimated Cost				**$724.34**

Financing

Financing is to be provided by the United Launch Alliance.

Work Distribution

Group Member	Motor/Controls	Power	Visual Sensor	Hall Sensor
Friedrich S.	P	S		
Paul J.			P	
Ellis C.		P		P


Progress
Total
Testing
Prototyping
Design
Research
97.5%
100%
100%
90%
100%
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%

Difficulties

- Coordination with 3 Mechanical Teams all implementing different designs.
- Sponsor Requirements Changes
- Shorter Summer Semester

Questions?