Steel Wire-Rope Inspection Tool

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Sponsor: United Launch Alliance

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

Device Requirements

1) Device should be less than or equal to 45 pounds.

2) Device must be easy to install and remove from cable while working overhead and in less than 5 minutes labor by one person.

3) It shall remain secure on the cable during descent and not be able to fall from the cable or get stuck half way down.

4) Device should operate under its own power (remotely). There is not a power source on the tower that can be used

5) Device will be stored when not in use in a climate controlled store room.

6) Device will need to operate in wind conditions up to and including wind gusts of 20 knots.

7) Device will not be operated when lighting is occurring or expected to occur within 5 miles.

8) Device shall be made of corrosion resistant materials.

Operation Requirements

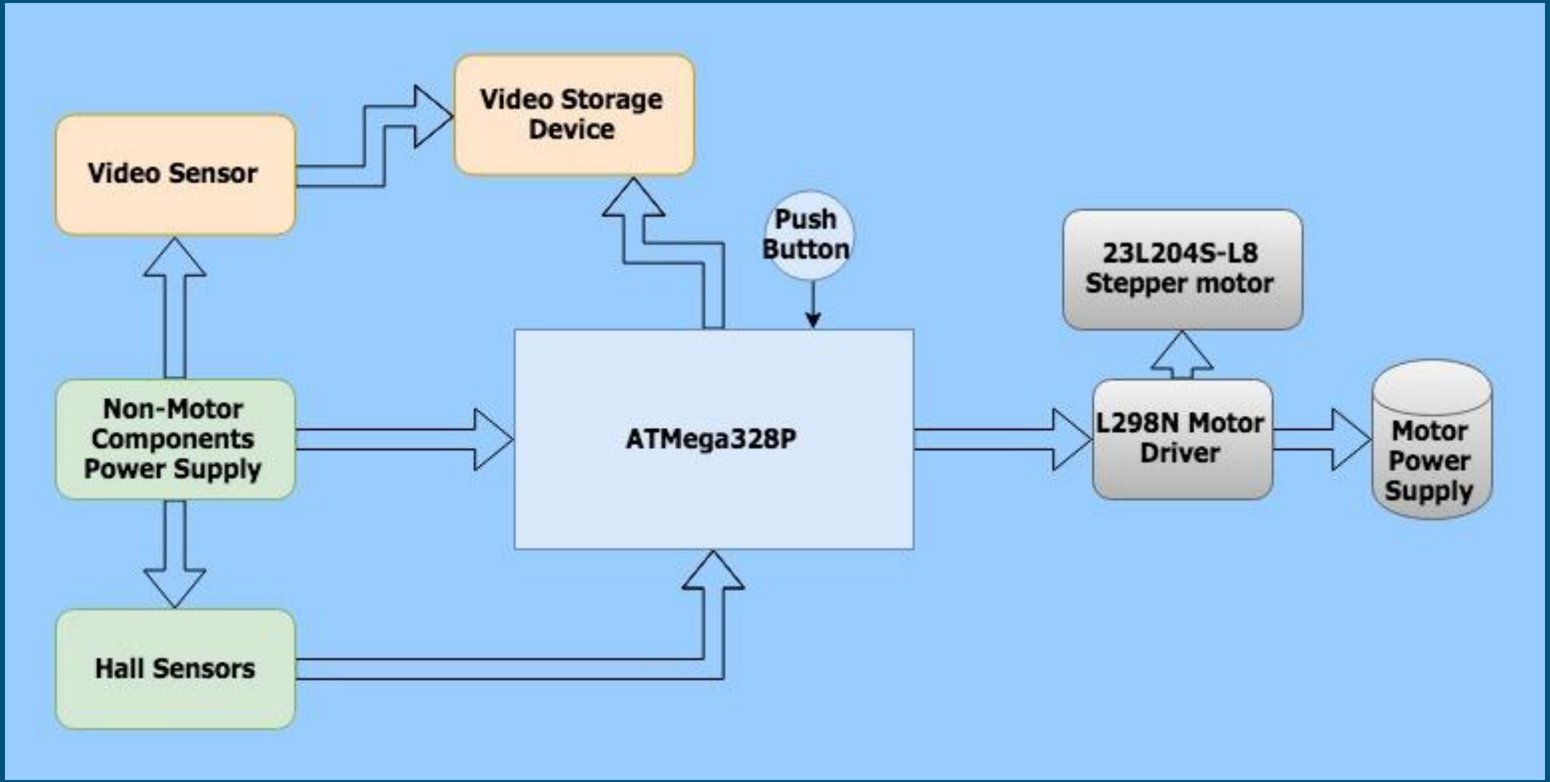
1) Device will be required to descent the length of each cable, no ascent required.
2) Maximum desired window of time to complete all scans (all cables) is 4 hours.
3) Required to be able to upload and store the data for each cable individually for future comparison purposes. Upload of data to be done 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)	¾"
Cable Weight per ft.	1.04 lb./ft.

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
- Meeting Torque and Operation needs to ascend cable

Electrical/Computer focus:

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

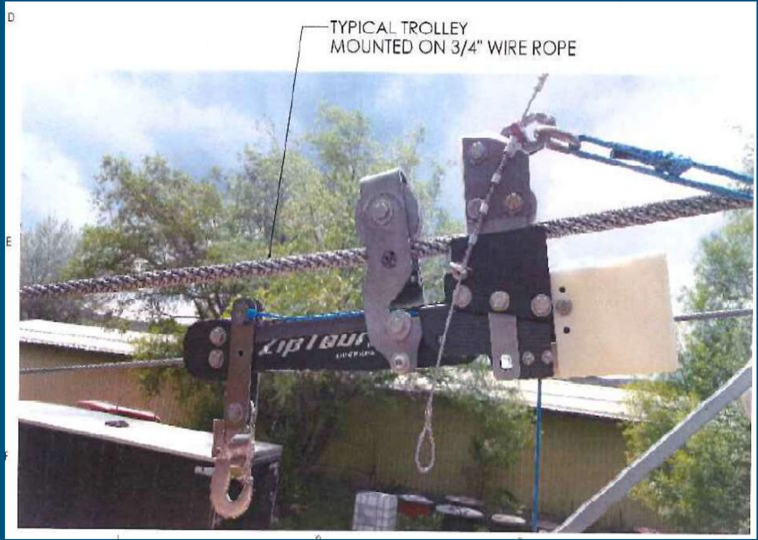


Image Provided by ULA.

Motor

Key Factors:

- Size
- Weight
- Modular
- Torque
  - Desired speed 0.868 ft/s
  - Torque needs to meet desired speed 384 oz.-in.

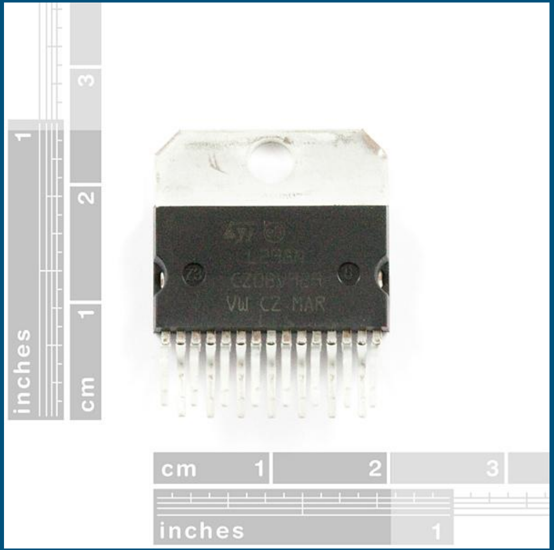
Anaheim 23L204S-L8 High Torque Stepper Motor	
Length	3.1 in
Weight	2.2 lbs.
Torque	226 oz.-in
Step Angle	1.8°
# of Lead Wires	8

Motor Driver

L298 H-Bridge Motor Driver

- High Voltage, High Current, dual full-bridge motor driver.

Maximum Ratings	
Operating Supply Voltage	50 V
Logic Supply Voltage	7 V
Output Current	4A (2A per channel)
Input & Enable Voltage	-0.30 – 7V
Storage and Operating Temperature	-25° - 130° C



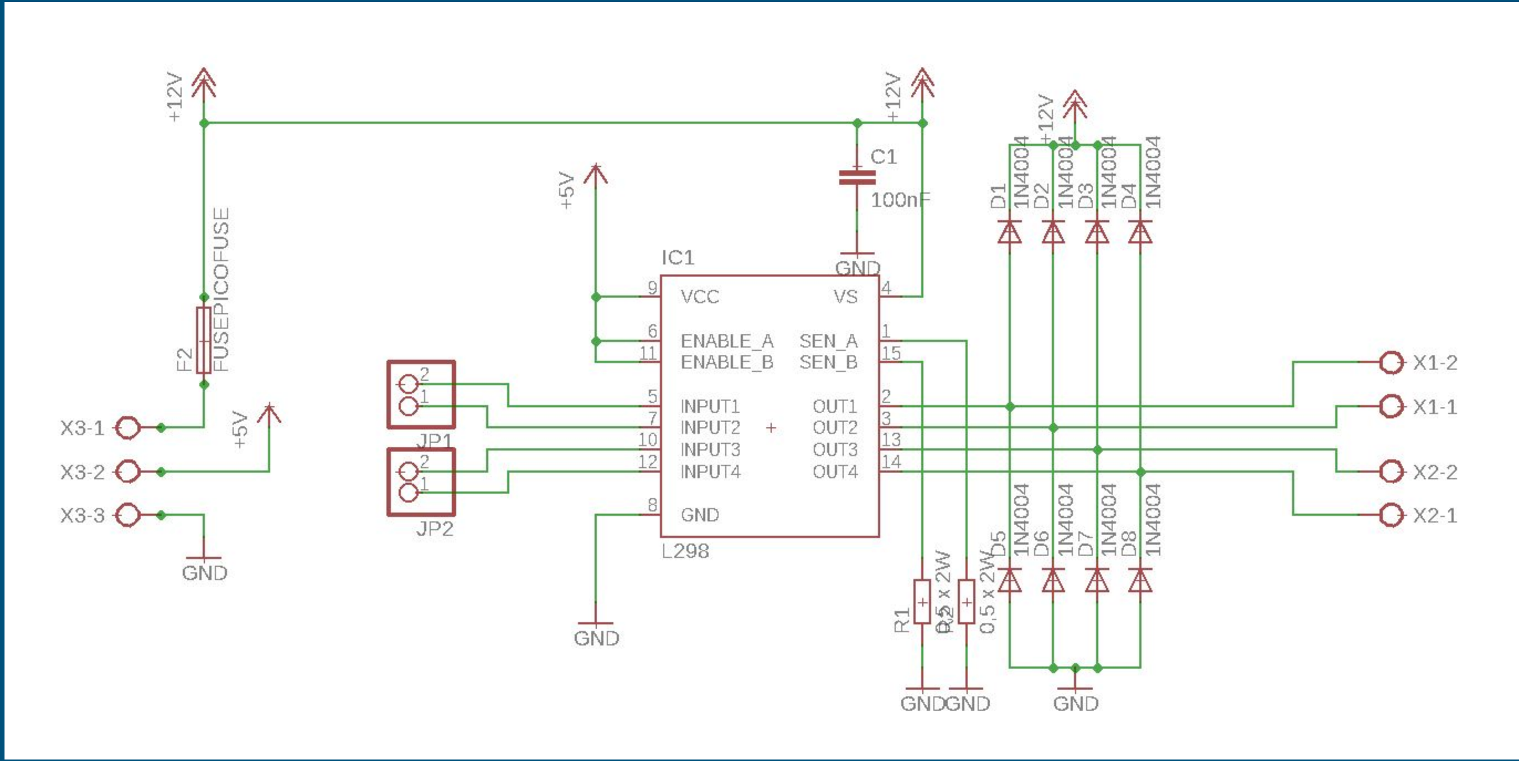
Motor Driver

- The L298 can be configured to act as a motor shield which is then used to drive the Motor.
-
- L298 lacks built in protection diodes, necessary for high-torque motor.
    - 1N4004 Fast Recovery Diodes have to be incorporated in design.

```
//Motor A
const int motorPin1  = 9;
const int motorPin2  = 10;
//Motor B
const int motorPin3  = 6;
const int motorPin4  = 5;
void setup(){

    //Set pins as outputs
    pinMode(motorPin1, OUTPUT);
    pinMode(motorPin2, OUTPUT);
    pinMode(motorPin3, OUTPUT);
    pinMode(motorPin4, OUTPUT);
    //Motor Control - Motor A: motorPin1,motorpin2 & Motor B: motorpin3,motorpin4
    //Turn Motor A clockwise for 2 sec. Modular Nature allows us to enter desired run-time
    analogWrite(motorPin1, 180);
    analogWrite(motorPin2, 0);
    analogWrite(motorPin3, 180);
    analogWrite(motorPin4, 0);
    delay(5000);
    //Turn Motor A counter-clockwise for 2 sec.
    analogWrite(motorPin1, 0);
    analogWrite(motorPin2, 180);
    analogWrite(motorPin3, 0);
    analogWrite(motorPin4, 180);
    delay(5000);
    //Turn Motor B clockwise for 2 sec.
    analogWrite(motorPin1, 0);
    analogWrite(motorPin2, 180);
    analogWrite(motorPin3, 180);
    analogWrite(motorPin4, 0);
    delay(1000);
    //Turn Motor B counter-clockwise for 2 sec.
    analogWrite(motorPin1, 180);
    analogWrite(motorPin2, 0);
    analogWrite(motorPin3, 0);
    analogWrite(motorPin4, 180);
    delay(1000);
    //Stop Motors
    analogWrite(motorPin1, 0);
    analogWrite(motorPin2, 0);
    analogWrite(motorPin3, 0);
    analogWrite(motorPin4, 0);
}
void loop(){
```

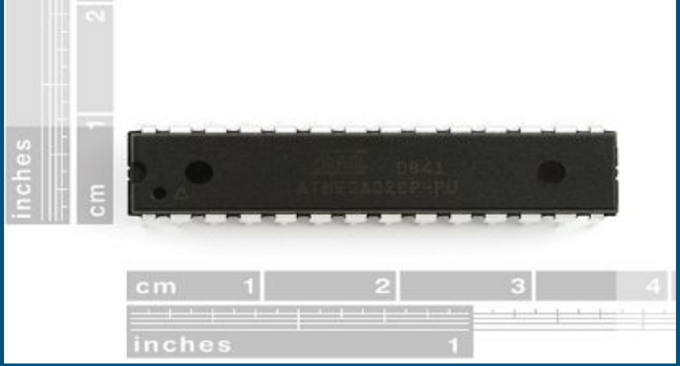
Motor Driver



MicroController Selection

ATMega328P

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



Features	ATmega328P
Pin Count	32
Flash Memory (KB)	32
SRAM (KB)	2
Max Clock Frequency (MHz)	20
Supply (Operating) Voltage (V)	1.8-3.6
General Purpose I/O Pins	21
Power Consumption (Active Mode)	200uA at 1MHz
Cost (USD per unit)	$2.01

Battery (Non-Motor Components)

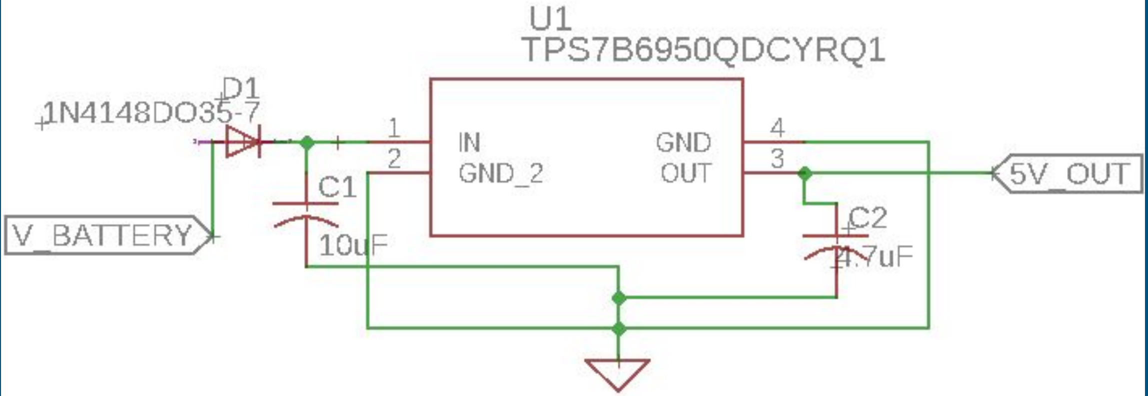
LIFEPO4
18500 VS 18650

- Made of 4 cylindrical 18500 rechargeable cells
- 7.4V - 2.8Ah - 21wh
- Overcurrent protection
- 4.2" x 1.5" x 0.9" (LxWxH)
- 4.4 oz
- 3 hour charging time
- $40.00

- Made of 6 cylindrical 18650 cells
- 9.6 V (working)   11.7 V (peak)
- 3000 mAh
- Overcurrent, overcharge, over drain protection
- 2.1" x 1.9" x 3.1" (LxWxH)
- 10.2 oz
- 3 hour charging time
- $46.95

Voltage Regulation

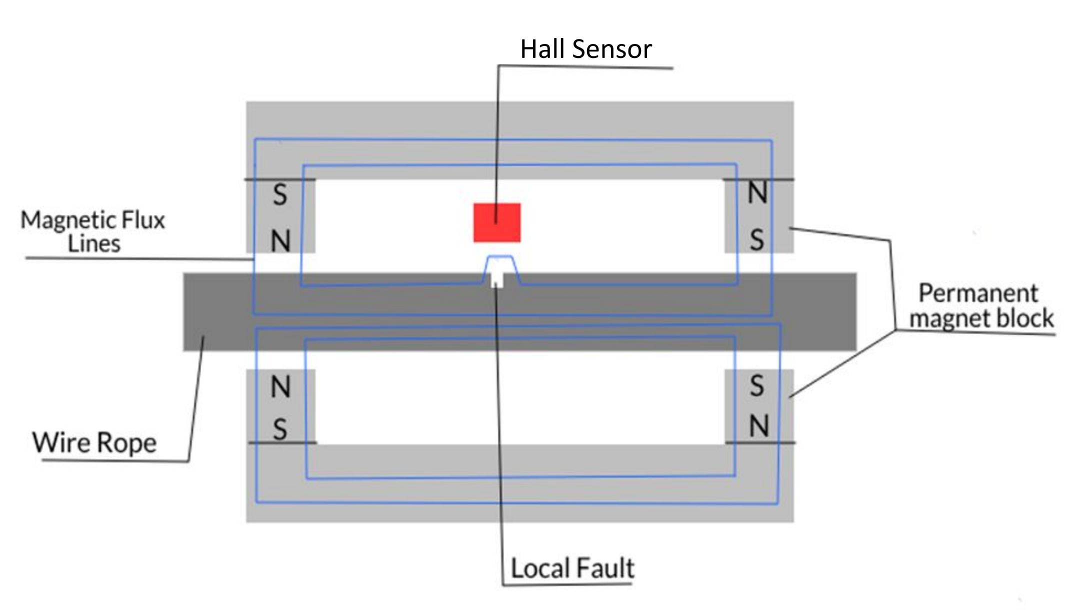
- 4 to 40-V Input Voltage Range
- Maximum Output Current of 150 mA
- 450-mV Typical Low Dropout Voltage at 100 mA Load Current
- Integrated Fault Protection
- SOT-223 has a body size of 6.50 mm by 3.50 mm.
- Line regulation: 10mV
- Load Regulation: 20mV



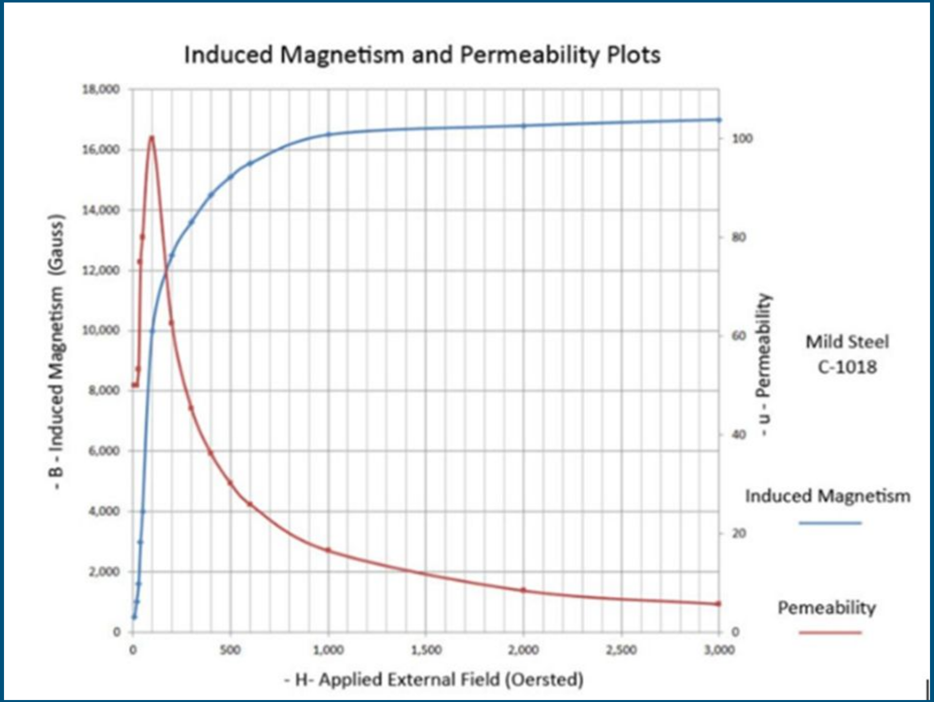
Magnetic Flux Leakage

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.

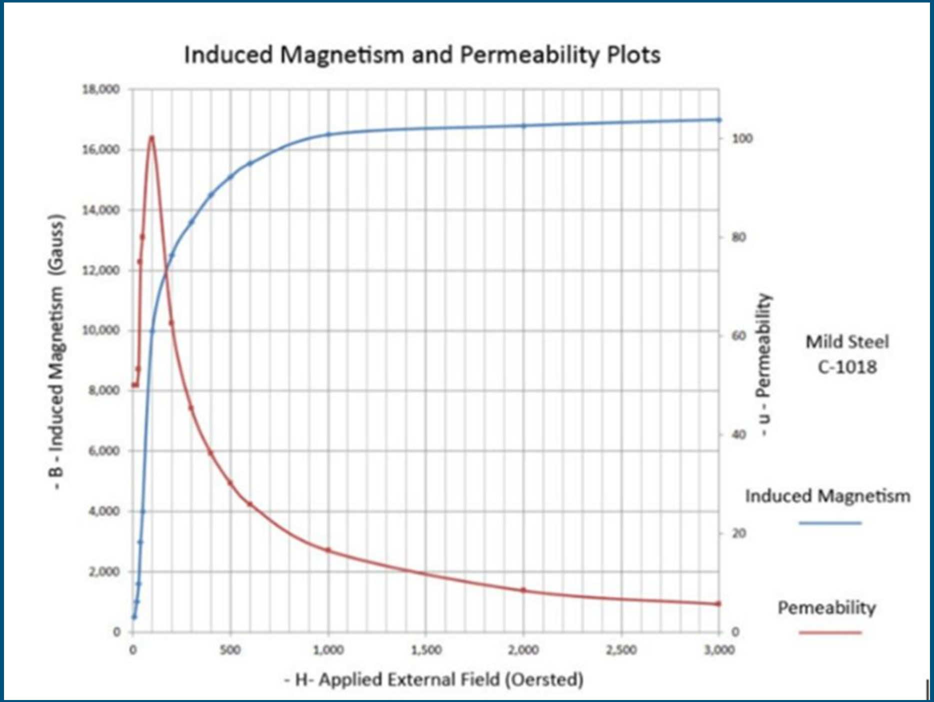


Magnetic Saturation of the Wire Rope



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

Sensor Selection

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-SOT-23

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
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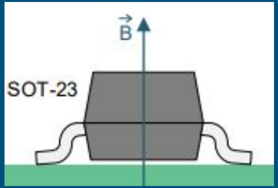
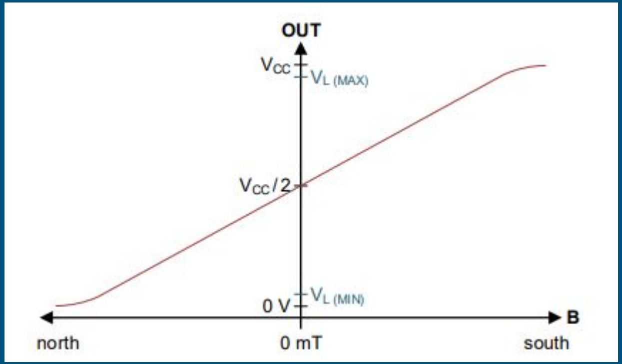
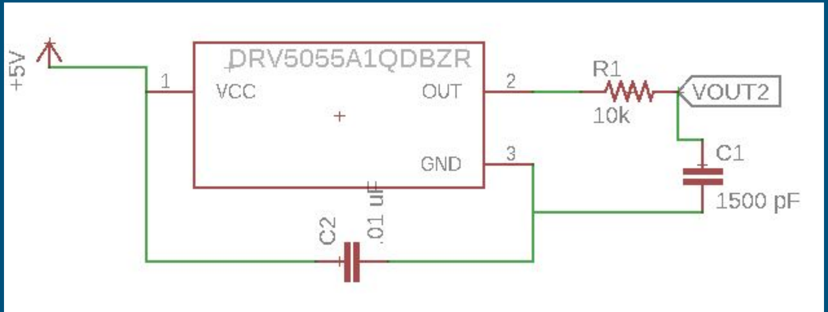
DRV5055-A1-QDBZR

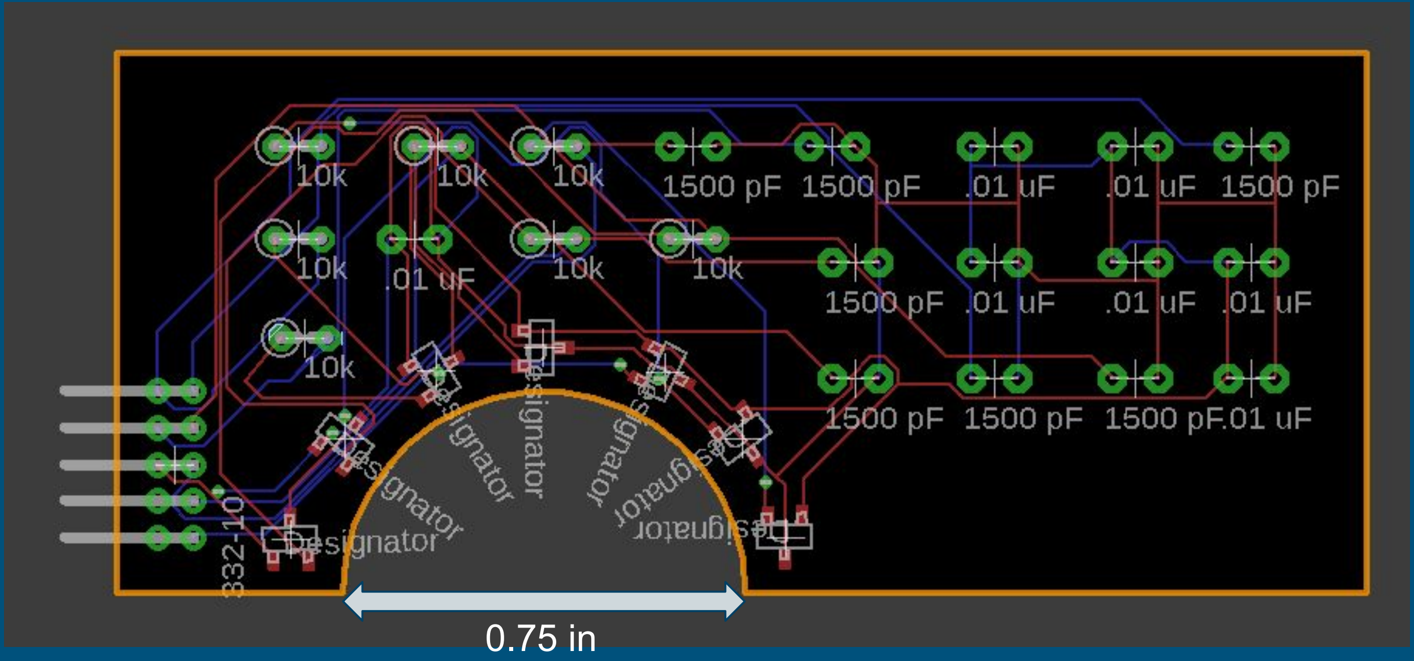




Magnetic response of the DRV5055



PCB


10k
10k
10k
1500 pF
1500 pF
.01 uF
.01 uF
1500 pF
10k
.01 uF
10k
10k
1500 pF
.01 uF
.01 uF
.01 uF
10k
1500 pF
1500 pF
1500 pF
.01 uF
332-10
Designator
0.75 in

MultiPlexer

Multiplexer:	CD4051B	74HC4052
Analog Signal Range	$\leq 20\ V_{PP}$	-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	Dual 4 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.

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 OV5640 Camera Module	CMOS OV5642 Camera Module
Active Array Size	2592 x 1944	2592 x 1944
Power Supply	core: 1.5V +- 5% analog: 2.6 ~ 3.0V I/O: 1.8V / 2.8V	core: 1.5VDC +- 5% analog: 2.6 ~ 3.0V I/O: 1.7 ~ 3.0V
Output Formats	8-bit compression data, 8/10-bit raw RGB data	8-bit compression data, 8/10-bit raw RGB data
Lens size	¼”	¼”
Input clock Frequency	6 - 27 MHz	6 - 27 MHz
Shutter Style	Rolling shutter / frame exposure	Rolling shutter
Max Image Transfer Rate	QSXGA (2592×1944): 15 fps (and any size scaling down from 5 megapixel)	5 megapixel (2592×1944): 15 fps (and any size scaling down from 5 megapixel)
Pixel Size	1.4 um x 1.4 um	1.4 um x 1.4 um

- With both sensors being functionally about the same, availability became the key factor in determining the two
- The other key factor was that in order to implement multiple visual sensors through one microcontroller it was necessary to use the Arducam 5MP mini which uses the OV5642 visual sensor

Microcontroller

- Taking video and storing it is a very resource intensive process
  - Requires strong processor and memory space
- 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 the development board

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

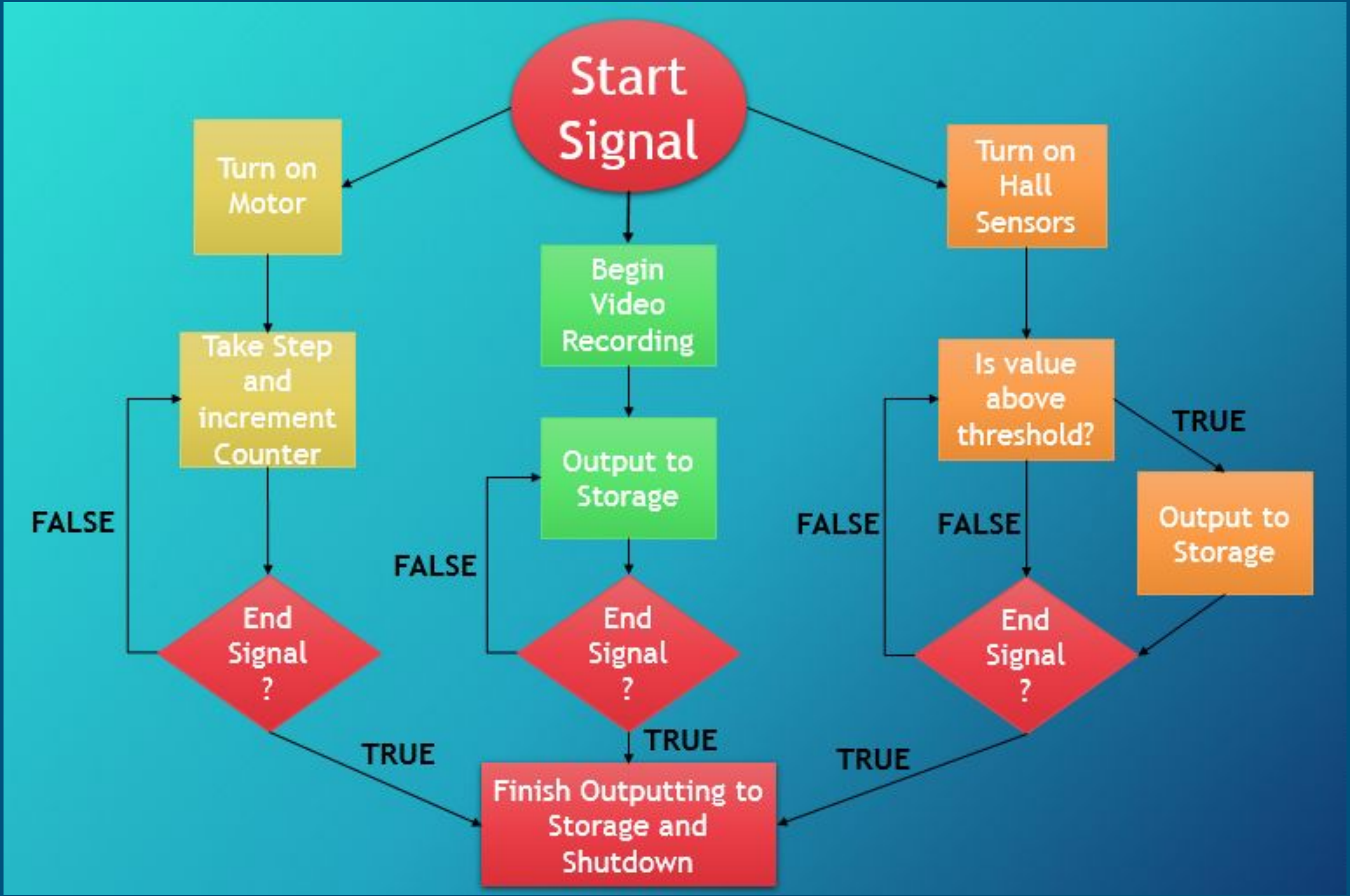
Storage Drive

- 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*

Software Flow

- Three major systems to control Visual, Motor, and Hall sensors
- One main start button for entire device
- Three main tasks to control:
  - Output and store continuous video from start to finish
  - Monitor Hall Sensor output for any spikes and store location of spike
  - Cause stepper motor to move and keep track of how many steps take
- One end signal that shall cause all processes to finish and then power down the device


Start Signal
Turn on Motor
Begin Video Recording
Turn on Hall Sensors
Take Step and increment Counter
Output to Storage
Is value above threshold?
TRUE
FALSE
FALSE
FALSE
FALSE
Output to Storage
End Signal ?
End Signal ?
End Signal ?
TRUE
TRUE
TRUE
Finish Outputting to Storage and Shutdown

Administrative Content

Budget

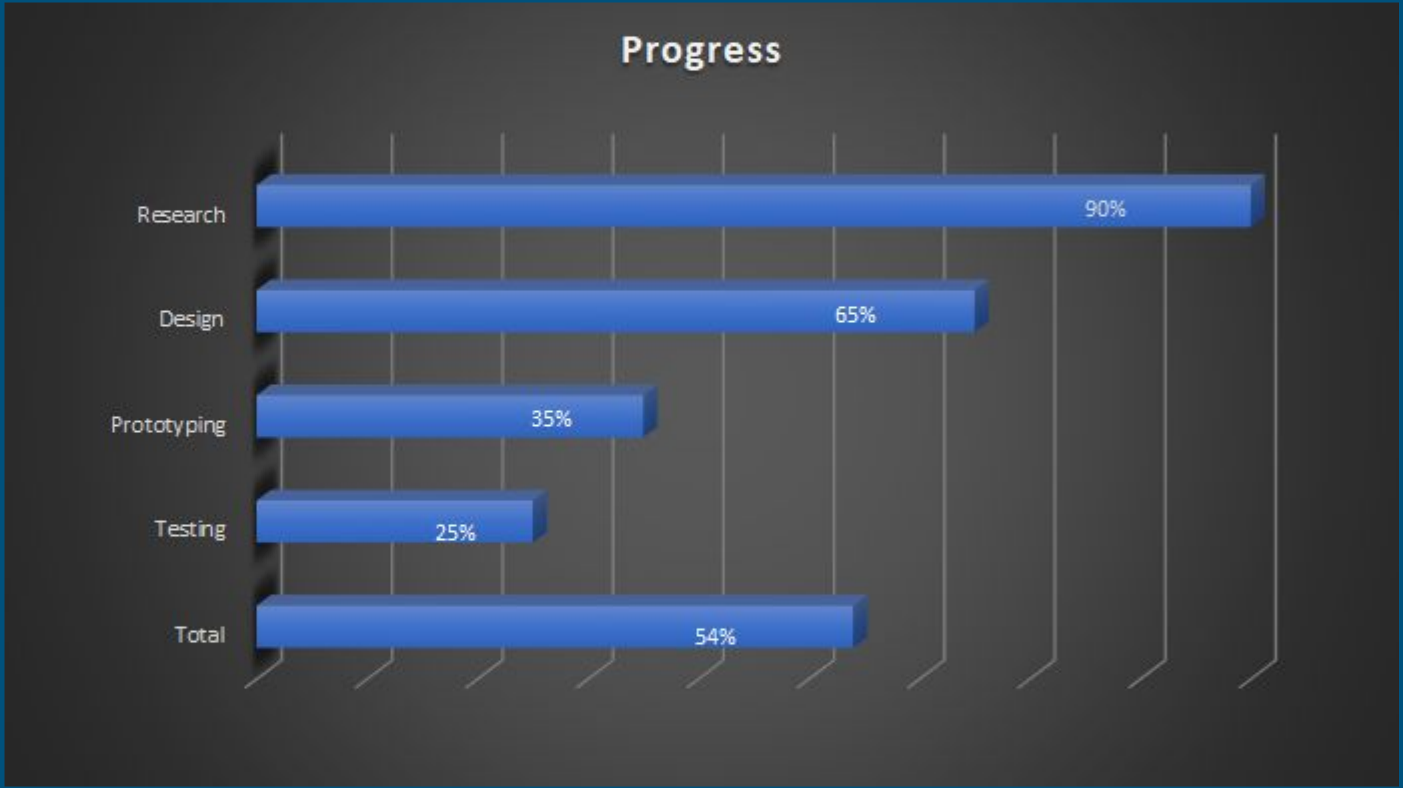
Subsystem	Item	Quantity	Vendor	Estimated Cost
Motor	23L204S-L8 Stepper Motor	1	Anaheim Automation	$175
	L298N H bridge Motor Driver	1	STMicroelectronics	$4.86
	1N4933 Diode	4	Diodes Incorporated	$0.31x4 = $1.24
	ATMega328P-PU Microcontroller	1	Atmel	$2.01
	Motor Battery Powerizer LiFePO4 (24V 10Ah)	1	Powerizer	$299.0
	Push Button Miscellaneous electrical components (resistors, chips, capacitors, wires, etc)	1 -	Amazon	$8.50 $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
	Beagle Bone Black	1	Spark Fun	$54.95
Additional Costs	PCB(s) (Estimate)	4	OSH Park	$15x4 =$40.00
	Shipping, Taxes, and other miscellaneous fees.	-	-	$20
Total Estimated Cost				**$761.54**

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.	S		P	
Ellis C.		P		P


Progress
Research
Design
Prototyping
Testing
Total
90%
65%
35%
25%
54%

Difficulties

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

Questions?