STINGER AV

Fast Acquisition Real-Time Tracking Machine

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DESIGN CONCEPT

The Stinger Autonomous Vehicle is a proof of concept designed for high-risk operations. Stinger is to be utilized by trained county/state law enforcement, federal agencies, and military operations.

The Stinger AV autonomously seeks out targets of interest in order to mark, locate, deter, immobilize or destroy.

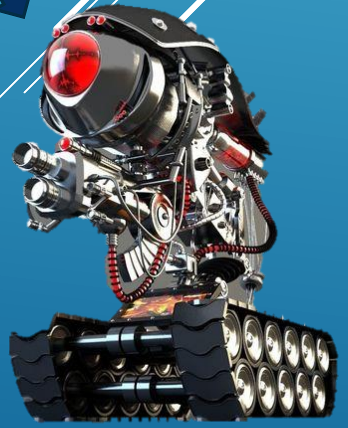
The Stinger AV is safely operated from a remote location through long range wireless networks.

MOTIVATION

- Crowd Control
  - Intimidation Factor
  - Audible and Visual Warnings
- Threat Detection
  - Up-to-date Image Processing Techniques
  - Advanced Optical Sensors
- Fast Response
  - Powerful processing power
  - Lightweight and Agile

DESIGN EVOLUTION

- Began with a robust military inspired design
  - Pros: Intimidation factor
    Strong chassis
    Can be deployed in harsh environments
  - Cons: Too Bulky
    Not maneuverable enough
- Moved to a two wheeled design
  - Pros: Agile
  - Cons: Requires a balancing system
    Easily disrupted
- Switched to a tank based design
  - Pros: Increased intimidation factor
    Maneuverability of a two-wheeled system
  - Cons: Heavier than the previous iteration

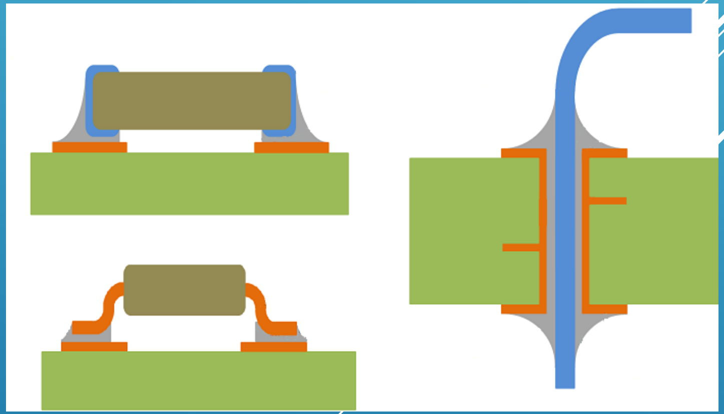


GOALS & OBJECTIVES

- ☑ The probe vehicle will have the ability to autonomously navigate an environment that is unfamiliar to the operator
- ☑ The probe vehicle will be able to autonomously seek out different colors balloons with the use of image processing
- ☑ Robust to noise and occlusion
  - Continued development of better/more robust color detection
- ☑ Multi-terrain operability
- ☑ The operator will have a ground control station which provides a live feed from the perspective of the probe vehicle
  - Live feed imagery was removed to reduce latency.
- ☑ The operator will have the capability of commandeering control of the probe vehicle at any point in time in order to navigate to and from the site or in case an object of interest is apparent to the operator but not the probe vehicle
- ☑ The probe vehicle will communicate with ground control via Wi-Fi (or other RF technology) on a dedicated wireless network

PCB DESIGN REQUIREMENTS

- Must be small enough to fit inside a typical RC car
  - Board outline must be no larger than the largest component
- Transmission line impedance must be carefully controlled
  - Differential Paired Traces
- Component selection must keep manufacturability in mind
  - Surface Mount vs Through Hole



COMPONENT DESIGN DECISIONS

POWER SUPPLY OPTIONS

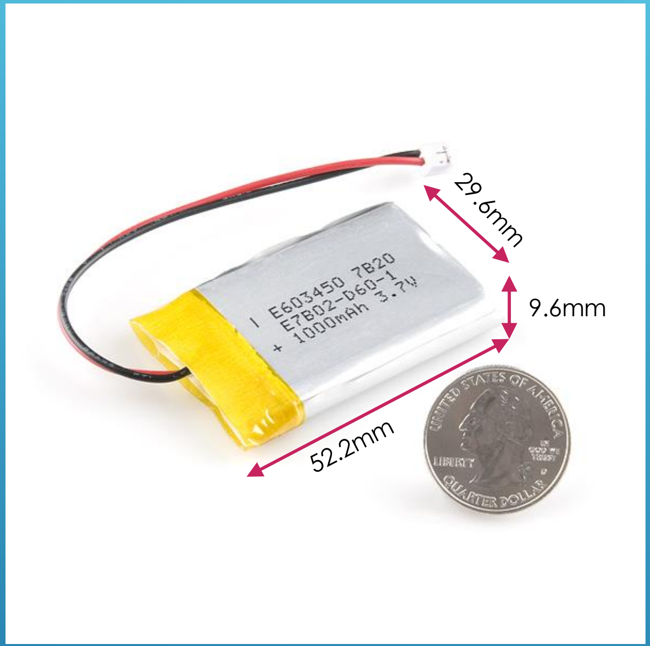
- Alkaline Batteries
  - Provides roughly 1.1V nominal, rated at 1.5V
  - Easily obtainable
  - Non-rechargeable
  - Various capacities (AA,AAA,C,D)
  - Relatively safe
  - Heavy
  - Low energy density
    - Takes up valuable space
- Lithium Ion Polymer Batteries (LiPO)
  - Provides 3.7V nominal/ rated for 4.2V
  - Easily obtainable
  - Volatile
    - Usually contains Onboard Protection System (OPS_ for additional safety measures
  - Higher density than rechargeable Nickel-Metal-Hydride (Ni-MH) and Nickel-Cadmium (NiCad) cells and Lead-Acid batteries
  - Lightweight

BATTERY COMPARISON CHART

Battery Type	Volume (cubic inches)	Weight (g)	Capacity (mAh)	Voltage (V) Max/ Nominal	Recharge Capable	Number of Cycles	Cost (dollars)
Alkaline (AAA)	0.24	12.00	1150	1.5/1.2	No	One time use	1-4.00 (4pk)
Alkaline (AA)	0.51	24.00	2122	1.5/1.2	No	One time use	1-4.50 (4pk)
NiMH (AA)	0.51	26.00	1000	1.5/1.2	Yes	1000	7-14 (4pk)
Lithium Polymer	0.61	20.00 (Raw)	1000	4.2/3.7	Yes	300-400	5-10 (ea)
Lithium Ion	0.61	22.68	1000	4.2/3.7	Yes	300-400	5-10 (ea)

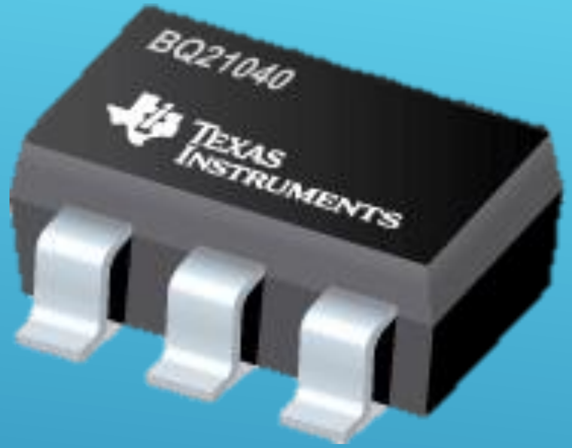
POWER SUPPLY

- Power Source
  - 2 ea. Replaceable/rechargeable Lipo Batteries
    - Lightweight, high power density
    - 3.7V Nominal/ ~4.2V Fully Charged
    - >30 minutes operating time
- Challenges
  - Volatile, requires monitoring system
  - Charging in series can cause potential fire hazard
    - Switching unit had to be designed to charge batteries In parallel, and discharge in series.



BATTERY MANAGEMENT CONTROLLER OPTIONS

- Texas Instruments BQ21040
  - Operates off wide range of input voltage
    - OV protection supports low-cost unregulated adapters
    - Programmable fast charge current through external resistor
      - Charge speed up to 800mA
    - 1% charge voltage accuracy
    - 10% charge current accuracy



- MicrochipMCP73831/2
  - Four voltage regulations options
    - 4.2V, 4.35V,4.4V,4.5V
  - Tristate charge status output
  - Programmable charge current
    - 15mA to 500mA

- NXP MC34673
  - Four voltage regulations options
    - 4.2V, 4.35V,4.4V,4.5V
  - Programmable charge current
    - 130mA to 1100mA
  - Automatic Recharge
  - Max input voltage of 18V

BATTERY MANAGEMENT SYSTEM

Manufacturer	Part Number	# of cells	Cost	Unit
Mirochip	MCP73831/2	Single	$0.59	ea.
Texas Instruments	BQ21040	Single	$0.14	ea.
NXP	MC34673	Single	$0.44	ea.

BMC FINAL DECISION:

The BQ21040 by Texas Instruments was chosen for our final design.

The IC’s met most all of our needs; however, The BQ21040 was priced well below its competitors and lead times for shipping made solidified the teams decision

VOLTAGE REGULATOR

- Purpose
  - Supply constant/reliable voltage to:
    - Raspberry Pi
      - Input voltage: 4.75V – 5.25V
      - **Recommended 2.5A power supply**
    - Microcontroller (ATMEGA328P)
      - Operating Voltage: 1.8 – 5.5V
      - Current draw 01.uA – 0.2mA
    - Motor Driver (L293D)
      - Operating Voltage: 4.5 – 36V
      - Output current: 600mA – 1.2A (peak)

Our design team decided on using a voltage regulator capable of producing a continuous 5V output capable of providing at least 2A for peak load demand.

**Developmental testing conducted by the team of the Raspberry Pi under computationally heavy loads showed less than 1A current draw.

VOLTAGE REGULATOR TYPES

- Linear Voltage Regulator
  - Pro's:
    - Simple Design
    - Low Cost
  - Cons:
    - Inefficient
    - Wasteful energy in form of heat
    - May require large heat sink (increased form factor)
- Switching Voltage Regulator (Buck Converter)
  - Pro's:
    - Efficient
    - Low power usage (low heat)
    - Great for battery powered devices
  - Con's:
    - More complex
    - Higher cost

VOLTAGE REGULATOR COMPARISON

- Linear Voltage Regulator (PN: ba50dd0t)
  - Provides 5V/2A
- Switching Voltage Regulator (PN: MICC2177-5.0)
  - Provides 5V/2.5A

Our design team settled on the switching voltage regulator (MICC2177-5.0)

Rationale: The Stinger AV is battery operated and is intended to handle harsh environments of extreme heat. A switching regulator is ideal for battery powered devices and small enclosures with limited cooling/airflow. The increased cost was deemed necessary by the team in order to satisfy design specification.

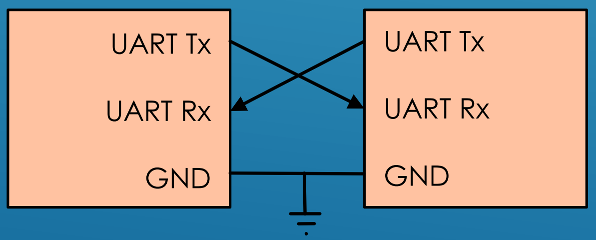
MICROCONTROLLERS

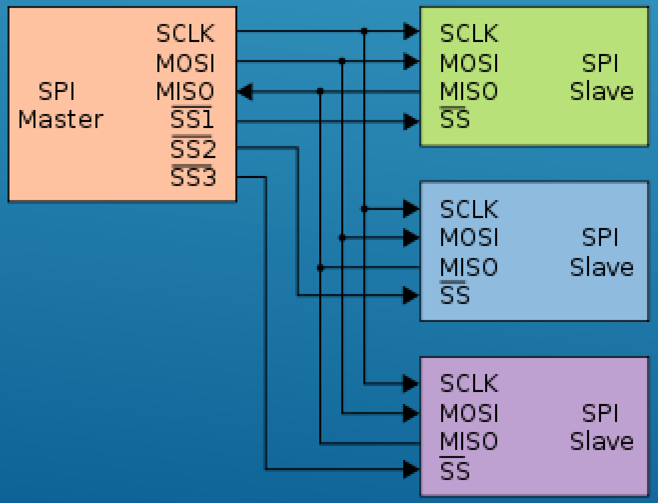
MCU	Operating Voltages	# of PWM Channels	ADC	# of I/O	Power Consumption – Active	Power Consumption – Power-down Mode	CPU Speed
ATMEGA8-16AU	2.7V - 5.5V	3	8@10-bit	23	1MHz, 3V, 25°C 900µA	3V, 25°C 0.5µA	16 MIPS
ATMEGA168-20PU	1.8V – 5.5V	6	6@10-bit	23	1MHz, 1.8V, 25°C 250µA	1.8V, 25°C 0.1µA	20 MIPS
ATMEGA328P-PU	1.8V – 5.5V	6	6@10-bit	23	1MHz, 1.8V, 25°C 200µA	1.8V, 25°C 0.1µA	20 MIPS
ATTINY85-20PU	2.7V – 5.5V	2	4@10-bit	6	1MHz, 2.7V, 25°C 450µA	2.7V, 25°C 0.15µA	20 MIPS
ATTINY85V-10PU	1.8V – 5.5V	2	4@10-bit	6	1MHz, 1.8V, 25°C 300µA	1.8V, 25°C 0.1µA	10 MIPS
ATTINY13A-10PU	1.8V – 5.5V	2	4@10-bit	6	1MHz, 1.8V, 25°C 190µA	1.8V, 25°C 9nA	10 MIPS
PIC16F688	2.0V – 5.5V	0	8@10-bit	12	1MHz, 2.0V, 25°C 55µA	2.0V, 25°C 50nA	5 MIPS
PIC16F636	2.0V – 5.5V	0	0	12	1MHz, 2.0V, 25°C 100µA	2.0V, 25°C 1nA	5 MIPS
PIC12F683	2.0V – 5.5V	1	4@10-bit	6	1MHz, 2.0V, 25°C 55µA	2.0V, 25°C 50nA	5 MIPS
MSP430FG4618	1.8V – 3.6V	0	12@12-bit	80	1MHz, 2.2V, 25°C 400µA	2.2V, 25°C 0.22µA	8 MIPS
MSP430G2553	1.8V – 3.6V	0	8@10-bit	16	1MHz, 2.2V, 25°C 230µA	2.2V, 25°C 0.1µA	16MIPS
MSP430G2452	1.8V – 3.6V	0	8@10-bit	16	1MHz, 2.2V, 25°C 220µA	2.2V, 25°C 0.1µA	16 MIPS

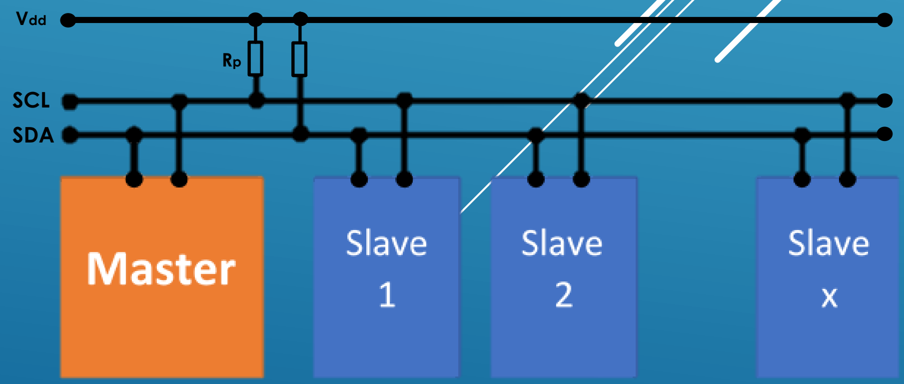
COMMUNICATION

- Microprocessor must communicate with microcontroller
- Latency must be as low as possible
- Must be scalable to accommodate additional peripherals

Standard	TX Type	# Signal Wires	Data Rate & Distance	Scalability	Application Example
UART	Asynchronous	2	20kbps @ 15m	Low (point-to-point)	Diagnostic display
SPI	Synchronous	4+	25Mbps @ 0.1m	Medium (chip selects)	High speed chip to chip link
I²C	Synchronous	2	1Mbps @ 0.5m	High (Identifier)	System sensor network







HARDWARE BLOCK DIAGRAM

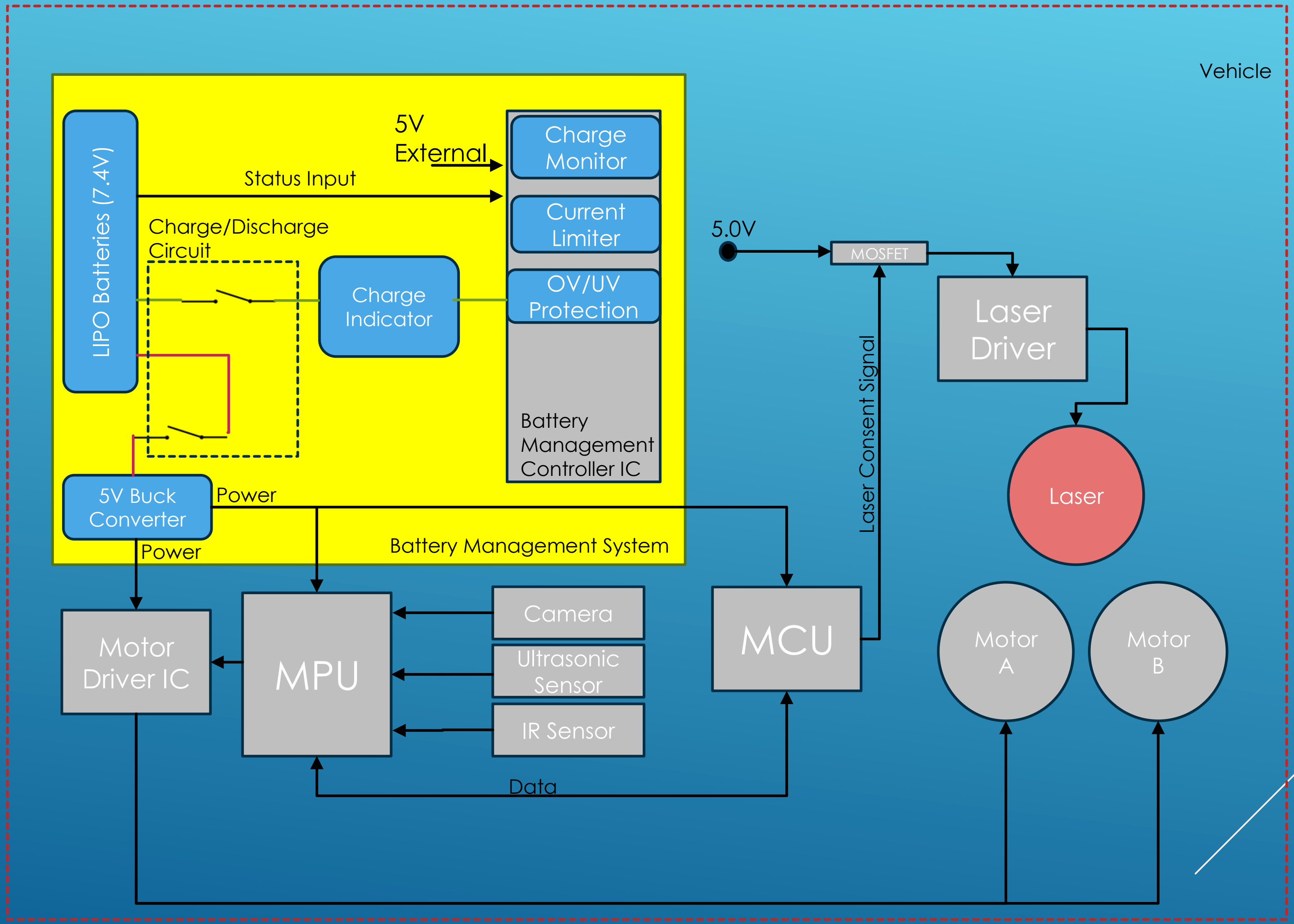


IMAGE PROCESSING/CV

COMPUTING MODULES SELECTION

- Used to execute the image processing algorithms
- Must be powerful enough to execute highly computational codes in a timely manner
- Options:
  1. Raspberry Pi 3 computer board
  2. Raspberry Pi Pro computer board
  3. RoBoard RB-100 SBC
  4. RoBoard RB-110 SBC
- Factors considered when selecting the Computing Modules:
  1. Dynamic Memory Space
  2. GPIO count
  3. Maximum output current
  4. Cost

COMPUTING MODULE COMPARISON

Computer	Memory Type and Space	GPIO count	I_MAX (mA)	Cost
Raspberry Pi 3 Computer Board	1 GB of LPDDR2 RAM	45	50	$39.95
Banana PI Pro Computer Board	1 GB of DDR3 RAM	40	50	$47.99
RoBoard RB-100 Single Board Computer	256 MB of DDR2 RAM	200	N/A	$250.00
RoBoard RB-110 Single Board Computer	256 MB of DDR2 RAM	200	N/A	269.99

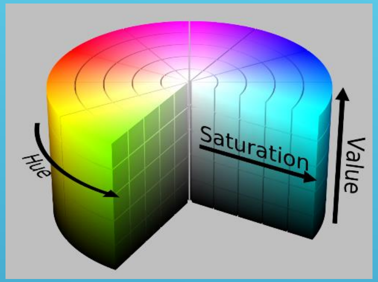
SOFTWARE

- The Software is written in Python Programming language
- We made use of Opencv and Numpy libraries
- We used Picamera module to acquire the imagery data
- Picamera module was selected because of the quality of images and the availability of Pimacera library
- Design Objective of the software:

1. Find the color of interest
2. Validate the color-based-detection

COLOR DETECTION_ COLOR DOMAINS

- The images are saved as RGB numpy arrays
- RGB is a very good domain for displaying the imagery data
- For the purpose of Color Detection → HSV domain is used
- HSV → (Hue Saturation Value)
- Hue range → [0 360]
- Saturation range → [0 255]
- Value range → [0 255]
- Limitations to the range of Hue determines the color of interest
- Limitations to the range of Saturation determines the purity of the color. (Saturation == 255 => Pure color)



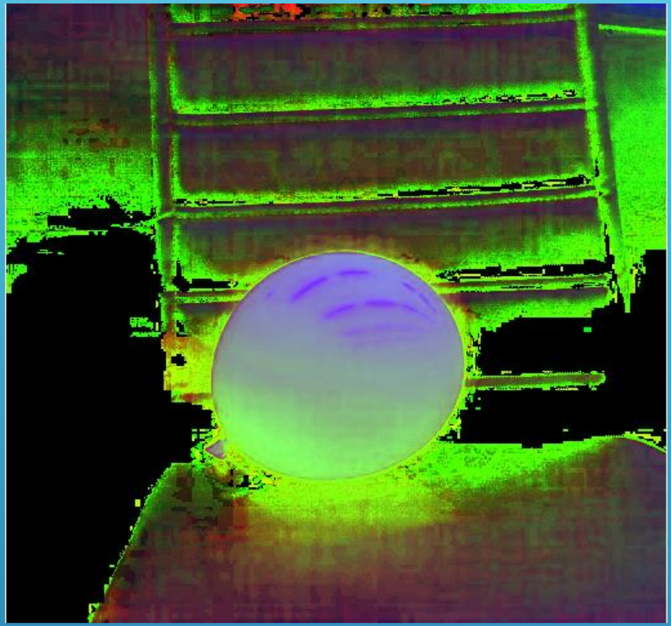
DESIGN PROCESS

1. Color Model Transformation
2. Thresholding the color and developing a binary mask
3. Applying morphological processes to the mask
4. Finding the minimum enclosing circle
5. Validating the process mask

COLOR MODEL TRANSFORMATION

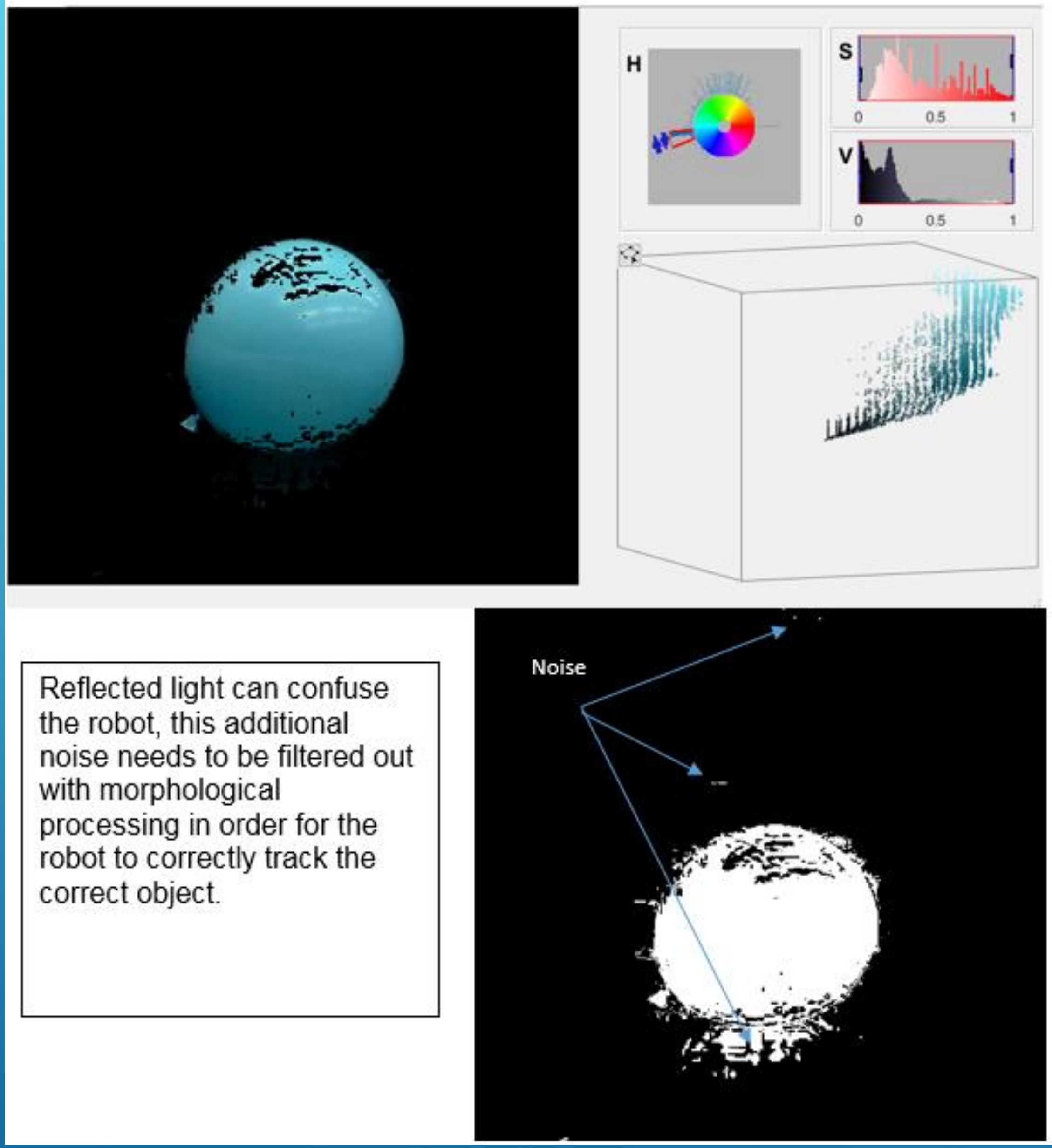
RGB → HSV

$$M = max\{r, g, b\}$$
$$m = min\{r, g, b\}$$
$$c = M - m$$
$$v = M$$
$$h = \begin{cases} (\frac{g-b}{c} mod 6) * 60 & r = M, c \neq 0 \\ (\frac{b-r}{c} + 2) * 60 & g = M, c \neq 0 \\ (\frac{r-g}{c} + 4) * 60 & b = m, c \neq 0 \\ 0 & c = 0 \end{cases}$$
$$s = \frac{c}{v}$$



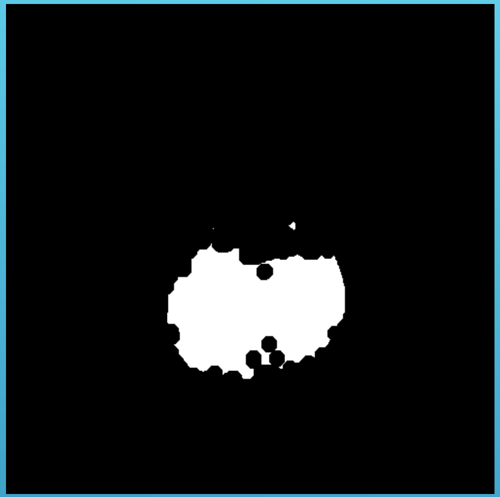
COLOR THRESHOLDING

- We define a range for Hue that corresponds to the color of interest (Blue in this case →)
- Then we define a mask that has ones for the Pixels that have the Hue value within the range of interest and zero otherwise
- For some colors, we also limit the range of Saturation
- The developed mask based on Saturation range is logically anded with the Hue mask
- Problems with the mask shown:
  1. Noise
  2. Accuracy

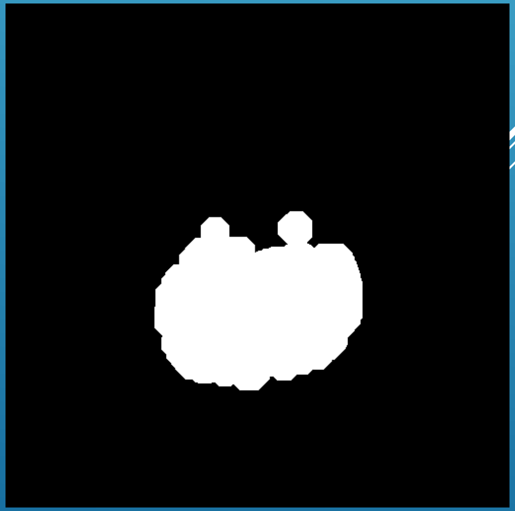


MORPHOLOGICAL PROCESS

- Erosion:
  - ❑ Used to deteriorate the mask in a circular fashion
  - ❑ Destroys noises in binary masks (White dots)
  - ❑ Maintains the structure of the mask

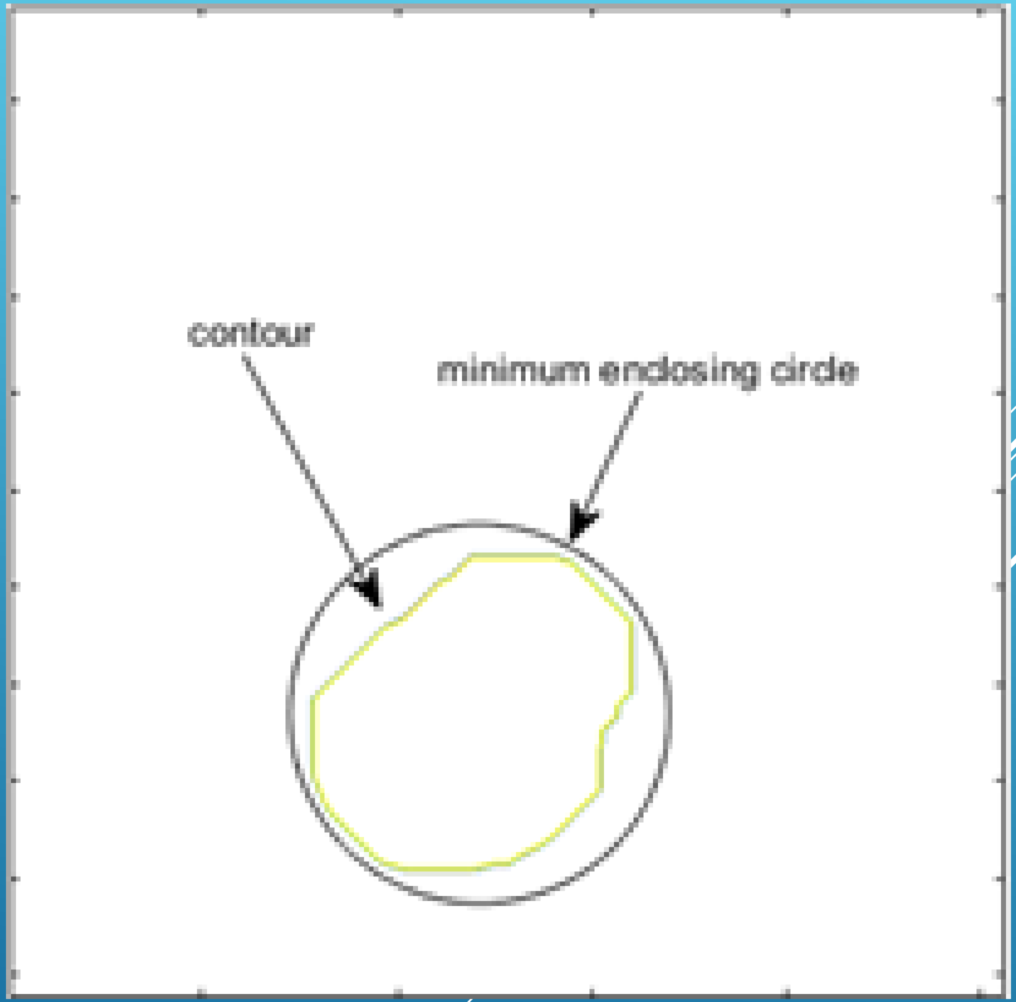


- Dilation
  - ❑ Used to expand the mask
  - ❑ Fills up holes in solid structures
  - ❑ Maintains the structure of the mask



MINIMUM ENCLOSING CIRCLE

- The Binary mask is used to develop a contour
- The contour is then used to find a minimum radius circle that encloses the contour
- The center of the circle is the location of the object in pixels

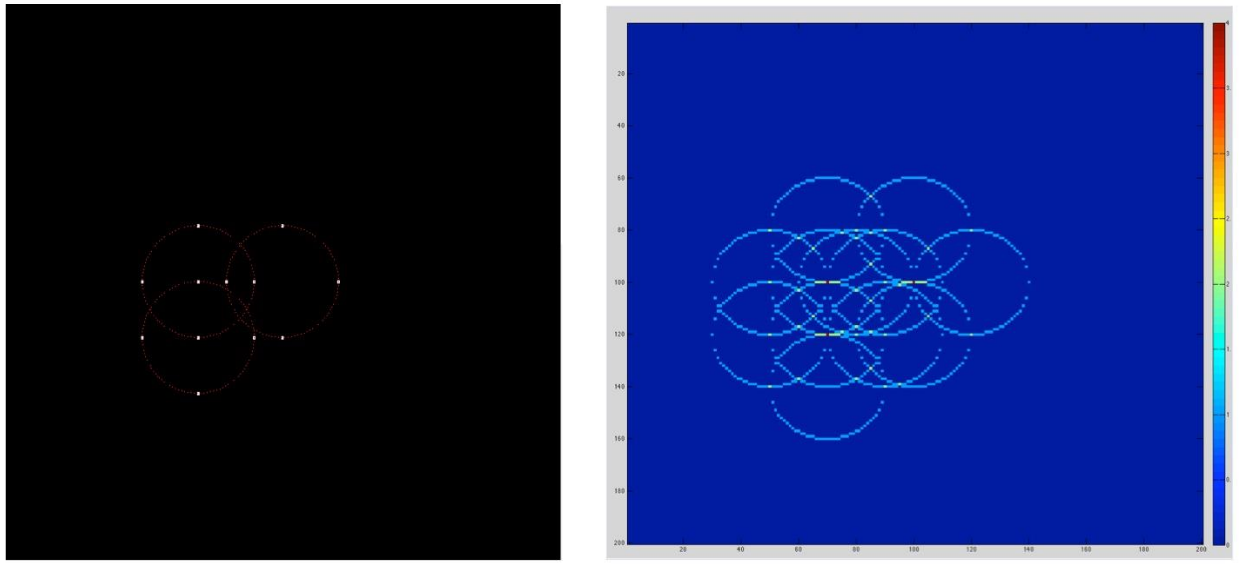


MASK VALIDATION

- Circular Hough Transform
  - ❑ Feature extraction technique to detect circular objects
  - ❑ The circles are detected based on a voting procedure
  - ❑ Works on the basis of edge detection
  - ❑ It would check the pixels of the edges to see if they match a circle

NOT A GOOD VALIDATION TECHNIQUE !!!

- Many false circles were detected
- No detection if the Balloon is too far
- At some instances, the balloon appear elliptic (not circular)

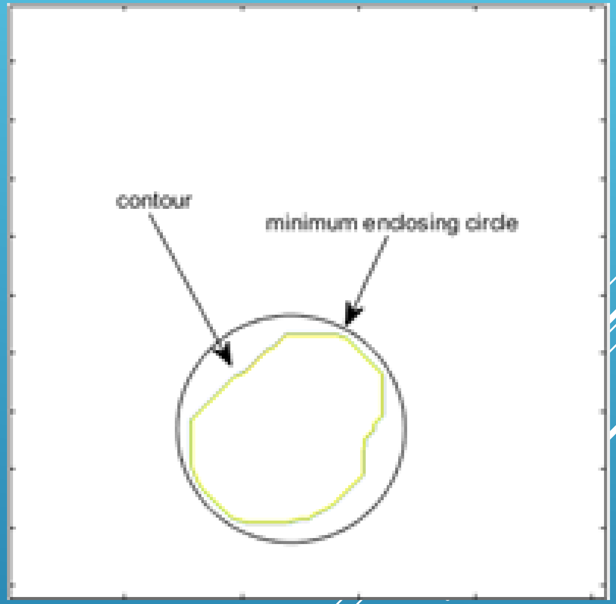


AREA-BASED VALIDATION

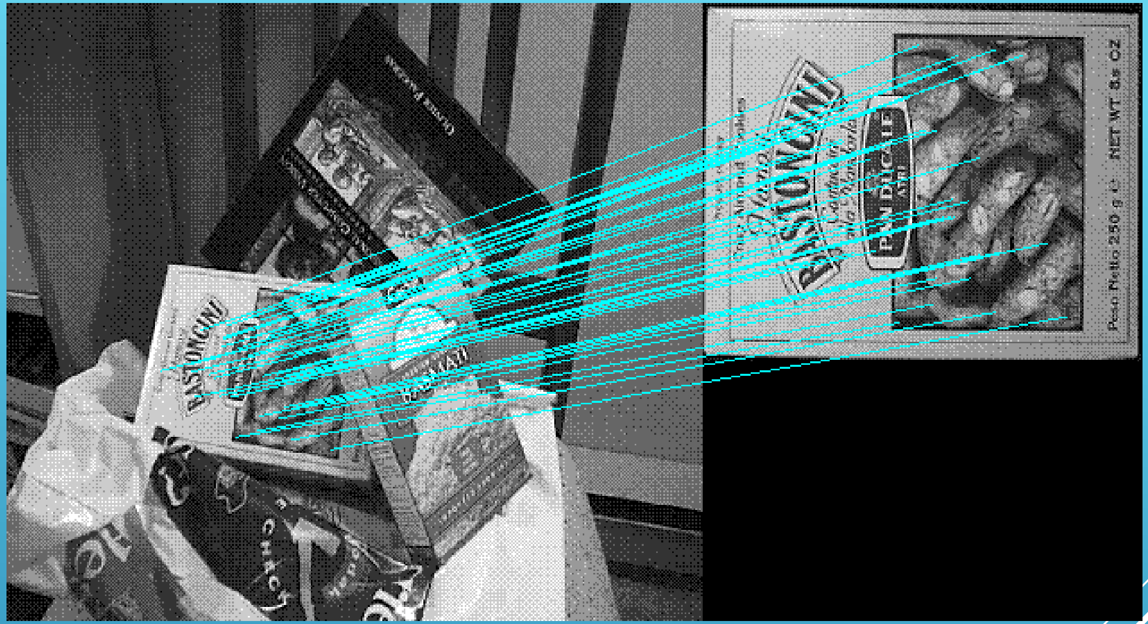
$A_d = A_{assumed} - A_{mask}$
$r = A_d / A_{assumed}$
Confidence = 1 – r
Confidence >=70 ➔ Circle detected

- The purpose of this calculation is to find the ratio of the area of the contour with respect to the enclosing circle
- How do we calculate the area of the contour??
  Count the number of 1s in the mask

VERY GOOD RESULTS!!!



SCALE INVARIANT FEATURE TRANSFORM



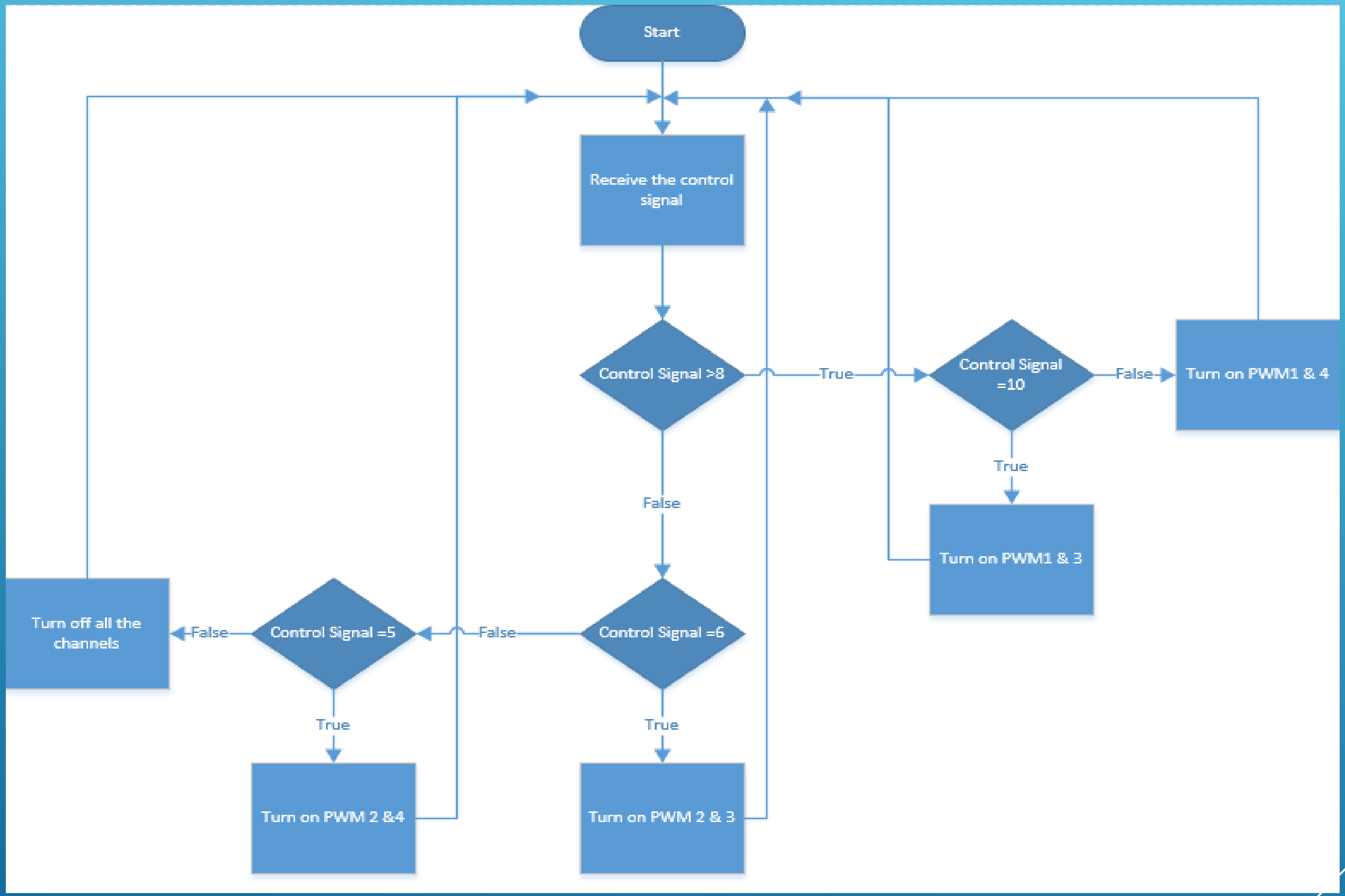
- SIFT algorithm
  - Local features
  - Distinct
  - Noise immunity
  - Patent protected by University of British Columbia
  - Implementation Procedure:
    1. Use a set of save imagery data of balloons to calculate distinct features (Training set)
    2. Apply the SIFT detector on the current frame to find interest points
    3. Calculate a feature vector to describe these interest points (testing set)
    4. Match these interest point with the training feature vector

CONTROL FLOW (SOFTWARE)

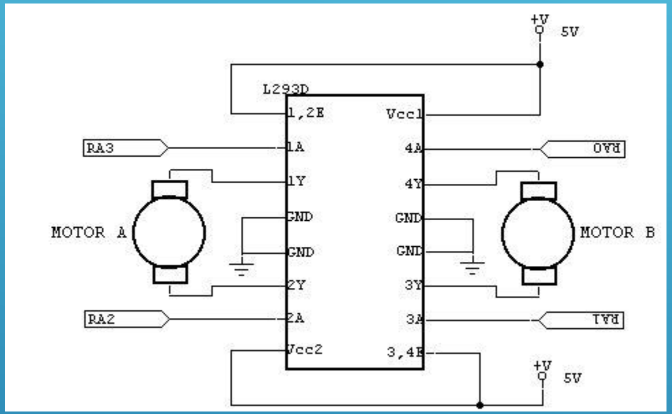
- There are 4 commands that will be executed by the robot
- Each command has a binary code that corresponds to the dedicated PWM channel on Atmega microcontroller
- Raspberry pi detects the balloons and sends a command to Atmega
- The command would activate the corresponding PWM channel

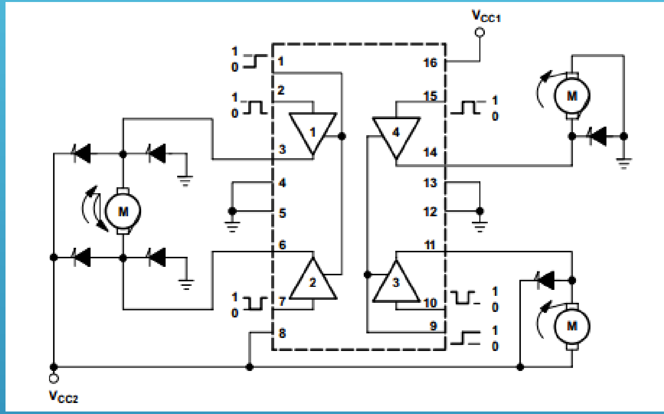
Direction	PWM1	PWM2	PWM3	PWM4	Binary Code
Forward	On	Off	On	Off	1010
Backward	Off	On	Off	On	0101
Left	On	Off	Off	On	1001
Right	Off	On	On	Off	0110

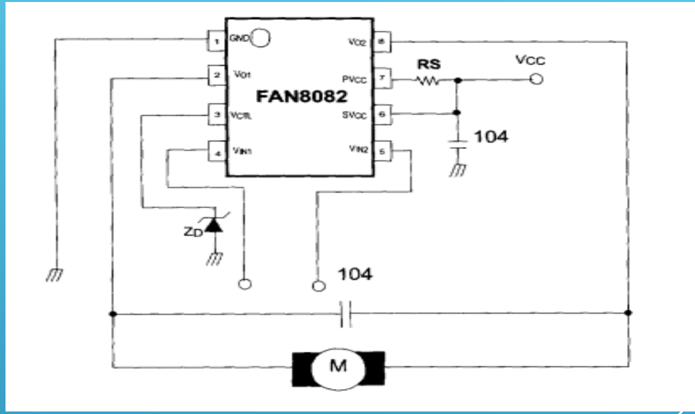
CONTROL FLOWCHART



MOTOR DRIVERS







L293D

- Supplied V =4.5-36V
- Separate Input-logic
- Iout = 1.2A
- Clamping Diodes
- $1/driver

L293

- Supplied V =4.5-36V
- Separate Input-logic
- Iout = 2A
- No Clamping Diodes
- $2.95/driver

FAN8082

- Supplied V = $18V_{max}$
- Iout = 1.6A
- Clamping Diodes
- $0.79/driver

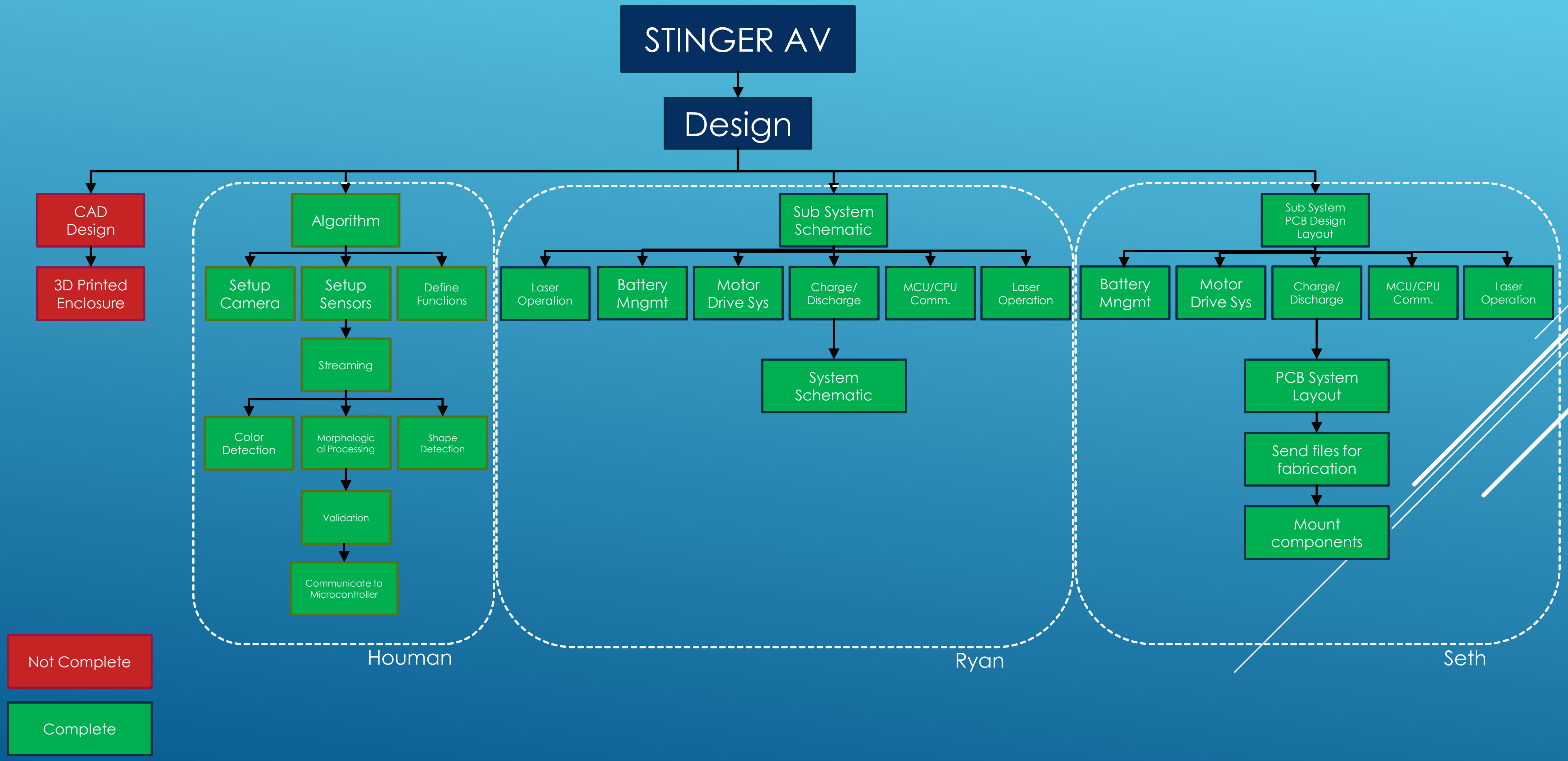
PROJECT BUDGET

- Most of the components have been ordered and received
- Possible future cost:
  - ❑ 3D Printed enclosure
  - ❑ Additional copies of the PCB
  - ❑ Additional screws and connectors for mounting the parts
- Estimated additional cost:
  - ❖ $100

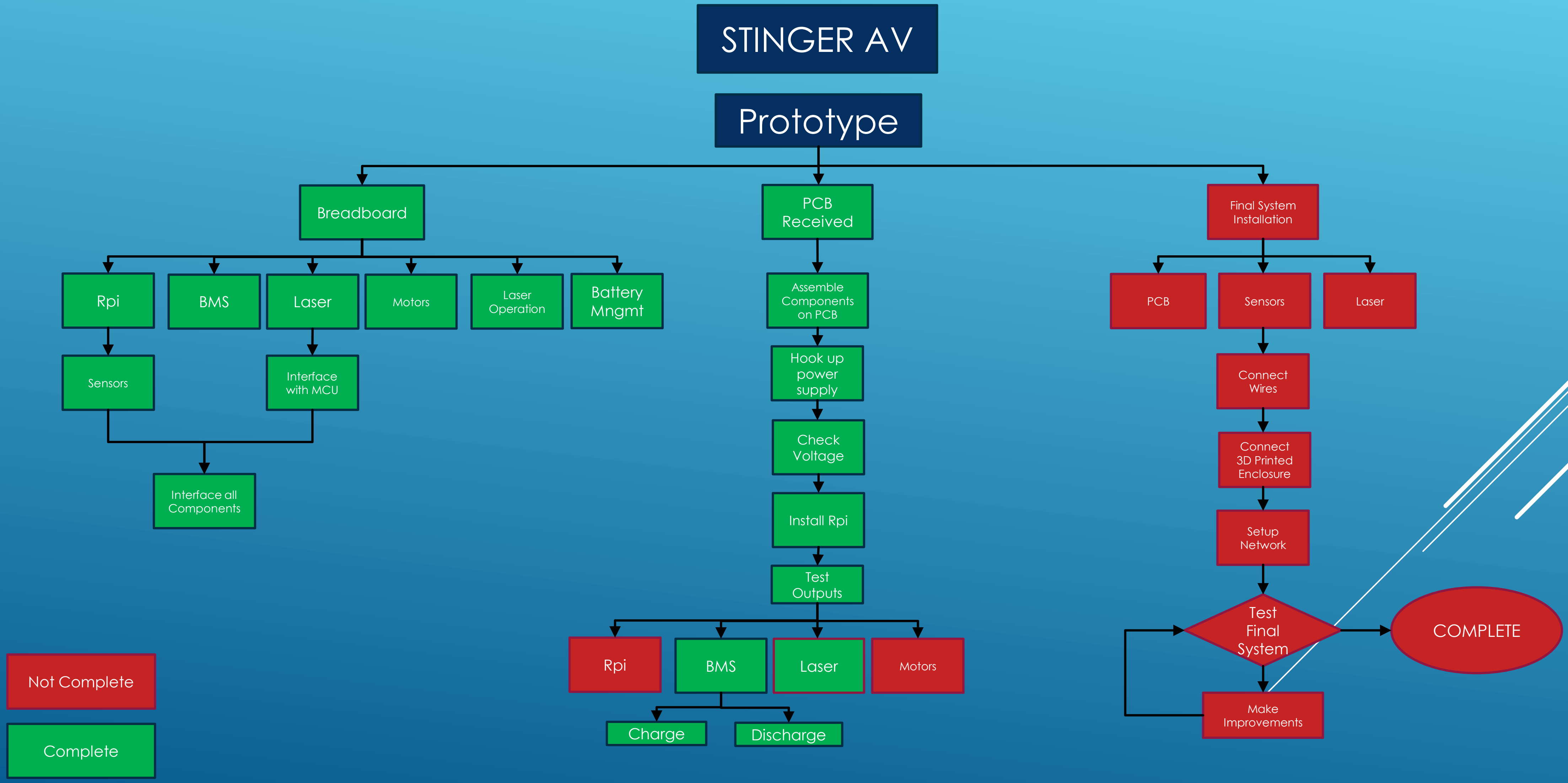
Project max Budget: $1000

Component	Quantity	Cost (ea)	Total Cost
Raspberry Pi 3 Computer Board	1	$39.95	$39.95
BQ21040 BMS Integrated Circuit	5	$1.34	$6.70
MCU: ATMEGA328P	2	$2.34	$4.68
Buck Converter (3.3 volt)	5	$0.58	$2.90
Buck Converter (5 volt)	2	$5.00	$10.00
Fixed 5V/2A Linear Voltage Regulator	2	$2.25	$4.50
3.7/4.2 2500mah Lithium Polymer Batteries	2	$7.99	$15.98
PCB layout charge	15	$6.00	$45.00
RC Sumo Jump Vehicle	1	$29.99	$29.99
Raspberry Pi accessory kit	1	$20.00	$20.00
Passives	n/a	n/a	$25.00
Wireless Keyboard/Mouse	1	$30.00	$30.00
HD Monitor	1	$80.00	$80.00
460mW/405nm laser	1	$70.00	%70.00
15mW/50mW laser	2	$20.00	$40.00
MOTOR DRIVER: L293D	10	$1	$10
Aluminum Alloy Tank Chassis	1	$87.99	87.99
Total Cost	--	--	$498.39

CURRENT PROGRESS_DESIGN



CURRENT PROGRESS_PROTOTYPE



CURRENT AND FUTURE PLANS

TASK	DUE DATE
Designing the Enclosure	06/16
3D printing	06/20
Assembling the parts	06/23
Testing	06/27