Photo-TANKS

Group 1

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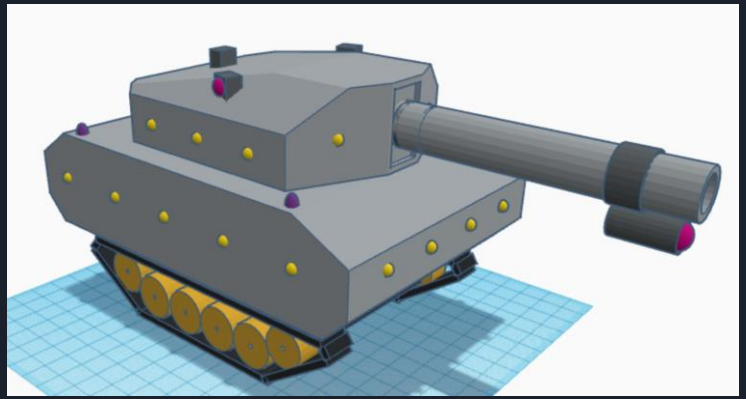
Project Description

- Demonstrated on a remote control tanks with 1st person perspective
- Friendly and enemy targeting indication
- Target acquisition system
  - Target recognition and detection



Motivation

Friendly Fire: Operation Desert Storm

- 9 M1 Abrams destroyed — 7 caused by friendly fire
- 28 Bradley IFV damaged/destroyed — 20 caused by friendly fire
- Led to development of the Battlefield Combat Identification System
  - Project abandoned in 2003

Current target acquisition process is slow and can leave soldiers at risk

We had two questions:

1. What if the US goes to war against a country that also utilizes our military equipment and technology?

1. How would we be able to differentiate between friendly vehicles and aircraft, and hostile counterparts if the battlefield is composed of two sides utilizing the same equipment?

Goals & Objectives

- Rapid target identification
- 360° coverage, autonomous target acquisition
- Maximize ease of use
- Demonstrated on a tank platform, with the hope of integration for other platforms
- Designed so that any user could understand and operate the system

Requirements & Specifications

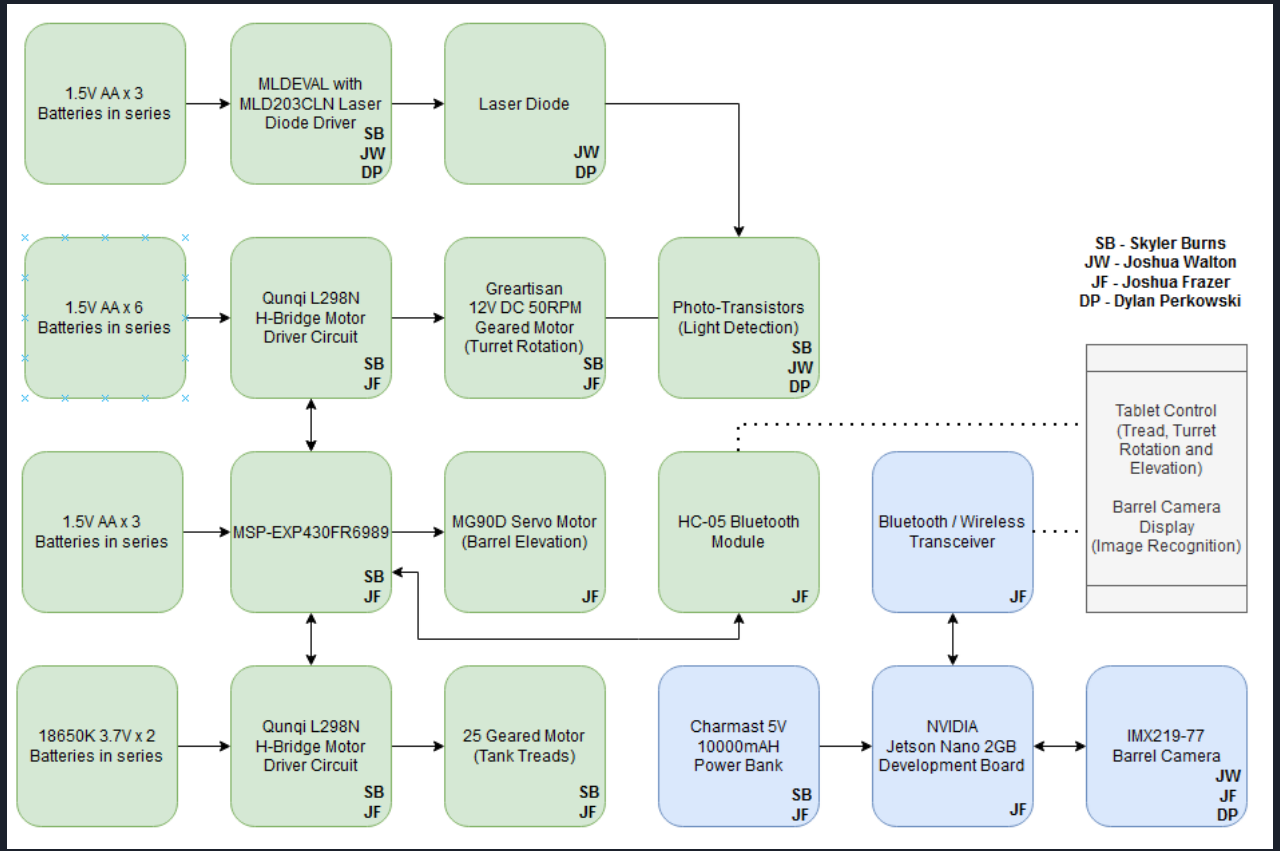
Tank Specifications		
Component(s)	**Parameter**	**Specification**
Laser Diode	Output Wavelength	635 nm
Phototransistor(s)	Relative Spectral Sensitivity	> 90%
Laser Beam	Dispersion	Minimal dispersion up to 10 m
Plano-Convex Lens	Far Focal Plane	> 1 m
Operator Camera	Image Delay	< 1 s
Direction Control	Controllable Function	Can use controller to control the tank and move it via the treads
Rotating Turret	Controllable Function	Can use controller to rotate turret 360° independent of direction of travel
Rotating Turret	Rotation Speed	≥ 30° per second
Barrel Elevation Mechanism	Contrallable Angle	Can use controller to adjust elevation/depression of the tank barrel in a 30° range
User Input	Input Delay	< 1 s
Connection	Range	> 2 m
Treads	Performance	Photo-TANKS treads will be able to climb & cover different terrains

Tank Specifications		
Component(s)	**Parameter**	**Specification**
Joysticks	Useability	Controller joysticks on the screen will be large and easy to use
Laser Diode (Low Power)	Target Identification	Operator uses low power laser beam (< 50% power) to trigger target identification
Laser Diode (High Power)	Weapon Firing	Operator uses high power laser beam (> 50% power) to 'fire' the tank's cannon
Jetson Nano 2GB AI Kit	Image Processing & Decisions	AI performs image processing and decision making to provide crew with information determined by the acqusition system
Power	Power Usage	Maximum amount of power usage is 25 W
Battery	Batery Life	Photo-TANKS shall have a continuosly running battery life of about 4 hours
Tank Body	Weight	The tank shall not weigh > 30 lbs
Laser Diode	Safety Standard	Photo-TANKS must follow the safety standards for a class 3R laser

Constraints

Economic	Partially self-funded, performance vs. cost. And, partially funded for the more *expensive* parts.
Time	~3 months to complete; Waiting for parts
Health & Safety	Class 3R laser diode; Mechanical components; Weight of overall system.
Manufacturing	Availability of usable parts while being within our price range might restrict our project.

Advanced Block Diagram



Part Consideration: Batteries

- Alkaline Batteries
  - Lasts long, cheap
  - Would need multiple to reach desired voltages
  - Good power solution for various components (ie: tread motors or the microcontroller)

Battery	Type	Voltage Produced (V)	Capacity (mAh)	Cost ($)	Lifetime (Unused)	Lifetime (Used)
Alkaline, Duracell	Primary Cell	1.5 (AA), 12 (specialized)	2500	6-8 (AA), ~5 (specialized, 2)	10 years (AA), 5 years	2-5 years
Alkaline, Energizer	Primary Cell	1.5 (AA), 12 (specialized)	2500	6-8 (AA), ~4 (specialized, 2)	10 years (AA), 5 years	2-5 years
Charmast Power Bank	Secondary Cell	5	10000	21.99	6 months	6-30 years
Lithium Ion, ICR-18650K	Secondary Cell	3.7	2600	~5 (for one)	6 months	6-30 years

- Charmast Power Pack
  - Lasts long, great amount of capacity, a good amount of voltage, and a ok price.
  - Charged the Jetson Nano

- ICR-18650K
  - Lasts long, small capacity and slightly worse voltage than the INIU.
  - Charged the barrel's servo-motor

Part Consideration: Tank - Treads

- Pre-built treads/chassis
- Acceptable load capacity
- Plenty of mounting points for hull

Tank Treads	Price ($)	Dimensions (LxWxH)	Load capacity (kg)	Nearly All-Terrain?
B08P49VLPS	79.99	13.38x9.44x4.8 inches	5	✓
B096DKCCBT	76.99	10.82x7.67x3.54 inches	5	✓
B08QZB5MFR	69.00	11.41x9.84x0.275 inches	4	✓

B096DKCCBT

Part Consideration: Tank Treads Motor

- 25 Geared Motor prebuilt into Tank Tread Assembly
- Cost effective solution considering it was included with Tank Assembly

Motor	Price ($)	Speed, No Torque (RPM)	Speed, Max Torque (RPM)	Motor Size (mm)	Motor Length
MG16B-060 -AB-00	$37.03	213	160	17	38
1271-12-21	25.63	125	80	27	36
25 Geared Motor	-	~150	~100	25	39.5

Part Consideration: Turret Rotation Motor

- Manufactured by Greartisan
- Inexpensive
- Slow RPM to allow better control for user
- Will meet rotation specification of 30°/s
- Can handle up to 15 Kg.cm of torque if undervolted to 10RPM

	Type	Rotation Speed (No-Load) (RPM)	Stall Torque (kg.cm)	Gear Material	Optimal Working Voltage	Rotation Direction & Speed Control	Cost ($)
24V DC Geared	DC Geared	50	4	Steel/Copper	24	✓	14.99
12V DC Geared	DC Geared	50	3.97	Steel/Copper	12	✓	14.99
DF15RSMG	Servo	62.5	19.3	Plastic/Steel	7.4	✓	18.05
B07K9KPDNV	DC Geared	50	3.97	None	12	x	14.99

Part Consideration: Barrel Elevation Servo Motors

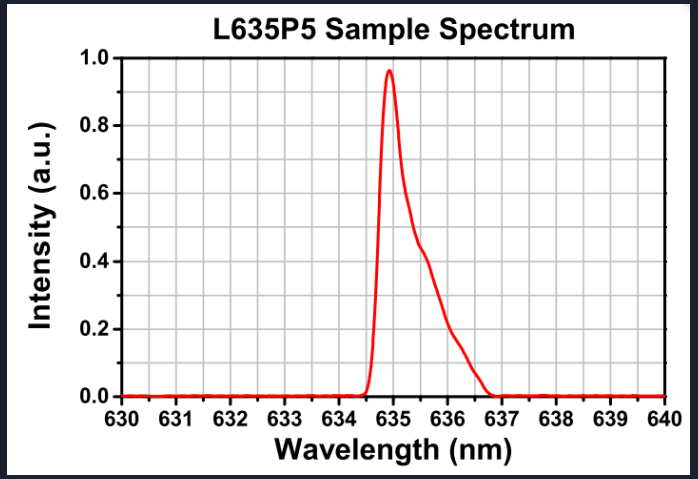
- Fits size requirement to fit inside turret head
- Expensive, great performance, very accurate movement steps
- Will meet barrel elevation adjustment requirement of 30°

	Stall Torque (kg·cm)	Operating Travel (°)	Optimal Working Voltage (V)	Pulse Cycle (ms)	Gear Material	Dimensions (mm)	Cost ($)
HXT900	1.6	± 45	4.8	20	Nylon	23 x 12 x 23	3.49
HD-1440A	0.6	± 90	4.8	2.2	Plastic	20.2 x 8.5 x 20.2	6.34
MG90D	2.1	± 45	4.8	1.0	Steel/Copper Mix	22.8 x 12.2 x 28.5	9.95

MG90D

Part Consideration: Laser Diode

- 5 mW laser diode (635 nm)
- Inexpensive



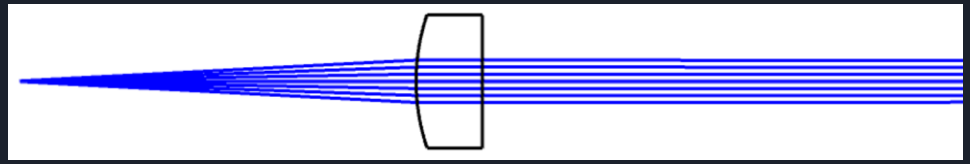
	Wavelength (nm)	Power (mW)	Typ./Max Current (mA)	Diameter (mm)	Beam Divergence (Max) (deg)	Cost ($)
L635P5	635	5	30/45	5.6	10	25.21
HL6320G	635	10	70/95	9	11	43.02
HL6322G	635	15	85/100	9	11	71.96
HL63163DG	633	100	170/230	5.6	13	307.32

Part Consideration: Lens

- Plano-convex lens
- 9 mm focal length

	Diameter (mm)	Focal Length (mm)	Radius of Curvature (mm)	Cost ($)
LA1024	2	4	2.1	63.55
LA1026	2	6	3.1	63.55
LA1036	3	6	3.1	63.55
LA1039	3	9	4.7	63.55

Lens: Zemax Simulation



LA1039 Simulated in Zemax (Imaged)

- Total axial length: 10.0105 m
- Spot size at stop: ~ 4 mm
- Axial length at focus: 0.511 m

LA1024 Simulated in Zemax

- Total axial length: 10.0050 m
- Spot size at stop: ~ 0.5 mm
- Axial length at focus: 0.227 m

Part Consideration: Optical Sensors

- Optical sensor must be able to collect our laser diodes wavelength: 635nm
- Will meet requirement of spectral sensitivity > 90 %
- Higher Spectral Sensitivity allows for more accurate identification of various laser intensities

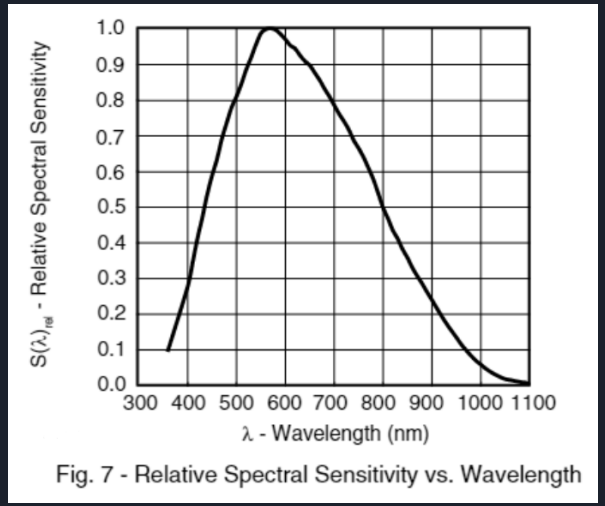
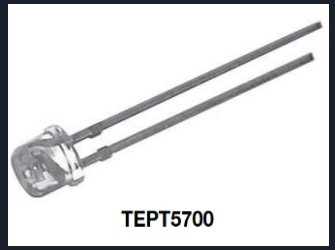


Fig. 7 - Relative Spectral Sensitivity vs. Wavelength

	Type	Wavelength Sensitivity Max (nm)	Diameter (mm)	Dark Current (nA)	Responsivity (A/W)	Cost ($) (for 1)
TEPT5700	Photo-Transistor	800	5	100	0.95	0.77
EAALST05RDMA0	Photo-Transistor	700	5	100	-	0.17
FDS010	Photo-Diode	1100	1	0.3	0.44	48.15
FD11A	Photo-Diode	1000	1.1	0.002	0.6	14.58


TEPT5700

Laser Diode Evaluation Board

- MLDEVAL
  - Thorlabs Laser Diode Driver Evaluation Board
  - Multiple Chip Support
  - Compatible with MLD203CLN Constant Current Driver
  - 5V Powered
  - Supports all Thorlab Laser Diode Pin Codes
  - On board Current Control via Potentiometer

Constant Current Laser Diode Driver

- MLD203CLN
  - Thorlabs Low Noise Constant Current Laser Driver
  - Provides a constant current to the laser diode at a given voltage
  - Generally paired with a filtered voltage source and a potentiometer to control output
  - Has built in soft-start and brownout protection to prevent the laser diode from current spikes, hence burning out the laser diode.

Part Consideration: Bluetooth Modules

- Intel 8265NGW (Jetson Nano)
  - Jetson Nano Community recommended Transceiver
  - Bluetooth 4.2 and Wifi Capabilities
  - M.2 connection: PCIe, USB and UART
  - Antenna Connections for extended range
  - Extended guides on setup and functionality with Jetson Nano
  - 22mm x 30mm x 2.4mm, 12mm x 16mm x 1.8mm
  - 2.6 Grams
- HiLetGo HC-05 (MSP-EXP430FR6989)
  - Inexpensive Module ($8.59)
  - Proven compatibility with MSP430
  - Multiple setup guides using MSP430
  - 37.3mm x 15.5mm
  - Small current draw (10mA)
  - 3.5 Grams

Part Consideration: Micro Controller Units

	Jetson Nano Developer Kit	Raspberry Pi 4	Google Coral Dev Board	Intel Up Squared AI Vision X Developer Kit
Company	NVIDIA	Sony	Google	Intel
Cost	$60	$45	$130	$419
Released	March 2019	June 2019	October 2020	2018
Processor	ARM Cortex-A57 64-bit @ 1.42 GHz	BCM2711 chip with ARM Cortex-A72 64-bit @ 1.5 GHz	Cortex A-53 64-bit @ 1.5 GHz	Atom X7-E3950 @ 1.6 GHz
Memory	LPDDR4 SDRAM	LPDDR4 SDRAM	LPDDR4 SDRAM	LPDDR4 SDRAM
GB Options	2GB, 4GB	1GB, 2GB, 4GB, 8GB	1GB, 4GB	4GB, 8GB
Wifi/Bluetooth	Capabilities	Included	Capabilities	Capabilities or Included
Ports	Micro SD, HDMI, 2 ethernets, 5 USBs	3 USBs, audio jack, 2 HDMIs, ethernet	4 USBs, 3 audio jacks, HDMI, ethernet, micro SD	HDMI, 6 USBs, 2 ethernets
GPU	128-core Maxwell	Broadcom VideoCore VI	Vivante GC7000 lite	Intel® HD Graphics 505

- Jetson Nano Developer Kit
  - Carried the best GPU for the operations we were wanting to implement
- Raspberry Pi 4
  - Although, it carried a good variety of RAM options and slightly better CPU clock speeds, it fell short due to the GPU power.
- Google Coral Dev Board
  - Since the only options were the 1GB and 4GB, we would have been forced to go with the 4GB which would cost us more for something unnecessary.
- Intel Up Squared AI Vision X Developer Kit
  - Too powerful for what we needed. The cost was also too great.

Part Consideration: Micro Controller Units
MSP430 Overall

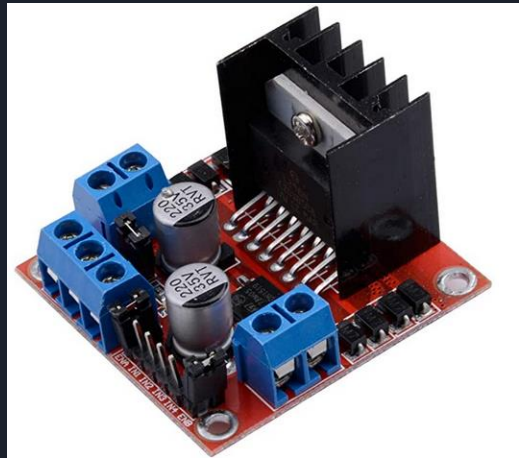
- MSP-EXP430FR6989
  - Cheap cost
  - Previous experience with board
  - MSP platform is an industry standard in academic environments
  - Tons of sample projects and tutorials available from community and manufacturer

Part Consideration: Micro Controller Units
MSP430 Technical Aspects

- MSP-EXP430FR6989
  - 18 GPIO pins for multi-peripheral support (83 total GPIO)
  - 5 PWM pins provides support for multiple motors without needing aftermarket boards
  - Built in 16 channel 12-bit ADC
  - Low power operation modes for longer run times

Qunqi L298N H-Bridge Motor Driver Controller

- L289N Motor Driver Controller
  - Cheap Cost
  - Control DC Voltage for two motors
  - Small Form Factor
  - Allows up to 12V to each motor
  - Control signal allows for switching polarity
  - Compatible with any MCU with digital pins



Part Consideration: Barrel Camera

	Arducam NoIR IMX219-AF Programmable/Auto Focus IR Sensitive Camera Module for Nvidia Jetson Nano	Raspberry Pi Camera Module 2	IMX219-77 8MP Camera with 77° FOV - Compatible with NVIDIA Jetson Nano/ Xavier NX
Megapixels	8	8	8
Photosensitive Chip	Sony IMX219	Sony IMX219	Sony IMX219
Resolution	3280 × 2464 pixels	3280 × 2464 pixels	3280 × 2464 pixels
Horizontal FOV	65 degrees	62.2 degrees	---
Vertical FOV	51 degrees	48.8 degrees	---
Diagonal FOV	77.6 degrees	---	77 degrees
Frame Rate	30fps@8MP, 60fps@1080p, 180fps@720p	1080p30, 720p60 and 640 × 480p60/90	30fps
Price	~$40	$25	~$20

- High resolution (3280 x 2464)
- Acceptable FOV
- Acceptable Frame Rate
- Inexpensive
- Plug and Play with Jetson

Software Design: Processes

- Basic movement (Left track, right track, turret base, and turret barrel)
  - Activate left motor and right motor for tracks.
  - Activate movement for turret base and barrel
- Keep functionality for inputs (All Cameras, Phototransistors, Controller)
  - Receive feed from camera
  - Poll for phototransistor changes
- Outputs process like they should (Controller, Camera feed , Laser)
  - Process the live feed from camera to the controller to display to user via gstreamer
- Internal processes (Movement, PIN I/O's, Triggers, Transceivers, AI Video Processing)

Software Design: Jetson Nano 2GB Developer Kit Responsibility

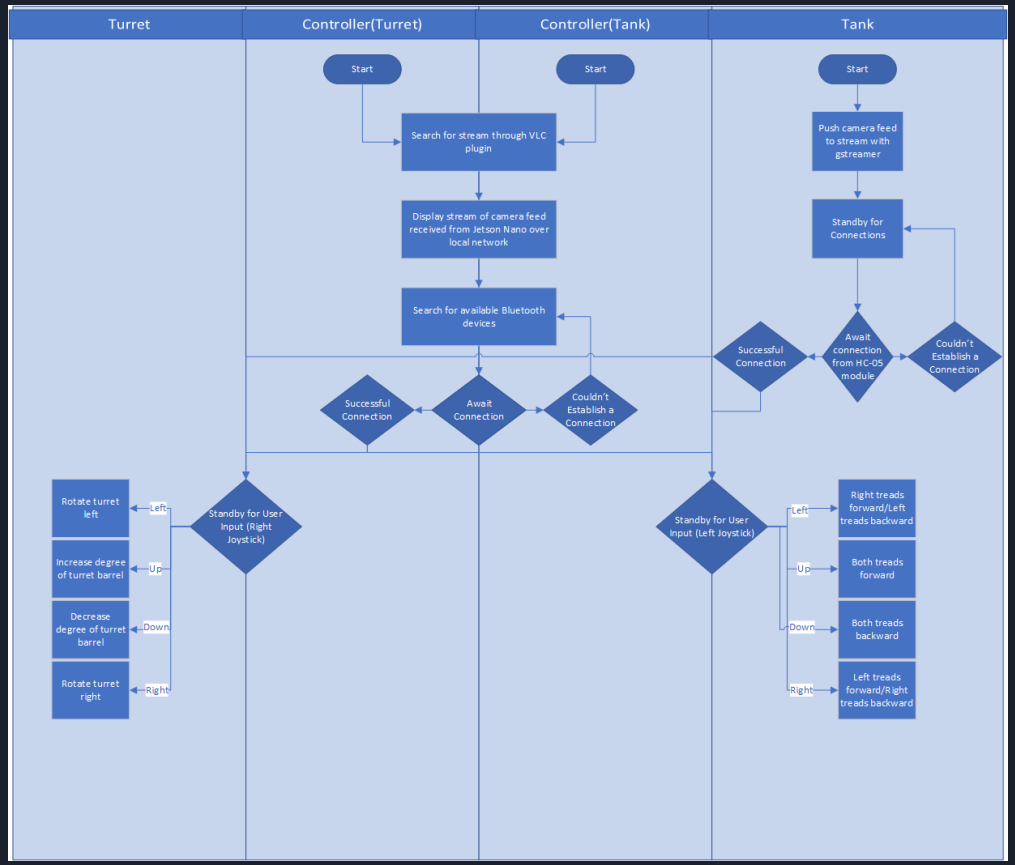
- Process all AI functionality
- Receives all the camera feed to process for the remote to see bounding boxes and identification of what is being seen
  - Sent over stream through local network
- Responsible to send finished processed video to stream with gstreamer

Software Design: Types of AI Video Processing

- **Object Detection**
  - **Uses bounding boxes due to identify each individual object whether or not they are in the same class.**

- **Image Recognition**
  - **Less specific object detection. Just classifies without bounding boxes.**

Software Design: Software Flowchart



Software Design: What is being processed?

- Viewing certain objects with bounding boxes
  - Household objects
    - Ex: Keyboard, TV, Monitor
  - Vehicle
    - Ex: Trucks, Car, Airplane
  - Table
    - Ex: Desk
  - Chair
    - Ex: Office Chair
  - Person
    - Ex: People

Software Design: Convolutional Networks Considerations

Model	Application	Framework	NVIDIA Jetson Nano	Raspberry Pi 3	Raspberry Pi 3 + Intel Neural Compute Stick 2	Google Edge TPU Dev Board
ResNet-50 (224×224)	Classification	TensorFlow	36 FPS	1.4 FPS	16 FPS	DNR
MobileNet-v2 (300×300)	Classification	TensorFlow	64 FPS	2.5 FPS	30 FPS	130 FPS
SSD ResNet-18 (960×544)	Object Detection	TensorFlow	5 FPS	DNR	DNR	DNR
SSD ResNet-18 (480×272)	Object Detection	TensorFlow	16 FPS	DNR	DNR	DNR
SSD ResNet-18 (300×300)	Object Detection	TensorFlow	18 FPS	DNR	DNR	DNR
SSD Mobilenet-V2 (960×544)	Object Detection	TensorFlow	8 FPS	DNR	1.8 FPS	DNR
SSD Mobilenet-V2 (480×272)	Object Detection	TensorFlow	27 FPS	DNR	7 FPS	DNR
SSD Mobilenet-V2 (300×300)	Object Detection	TensorFlow	39 FPS	1 FPS	11 FPS	48 FPS
Inception V4 (299×299)	Classification	PyTorch	11 FPS	DNR	DNR	9 FPS
Tiny YOLO V3 (416×416)	Object Detection	Darknet	25 FPS	0.5 FPS	DNR	DNR
OpenPose (256×256)	Pose Estimation	Caffe	14 FPS	DNR	5 FPS	DNR
VGG-19 (224×224)	Classification	MXNet	10 FPS	0.5 FPS	5 FPS	DNR
Super Resolution (481×321)	Image Processing	PyTorch	15 FPS	DNR	0.6 FPS	DNR
Unet (1x512x512)	Segmentation	Caffe	18 FPS	DNR	5 FPS	DNR

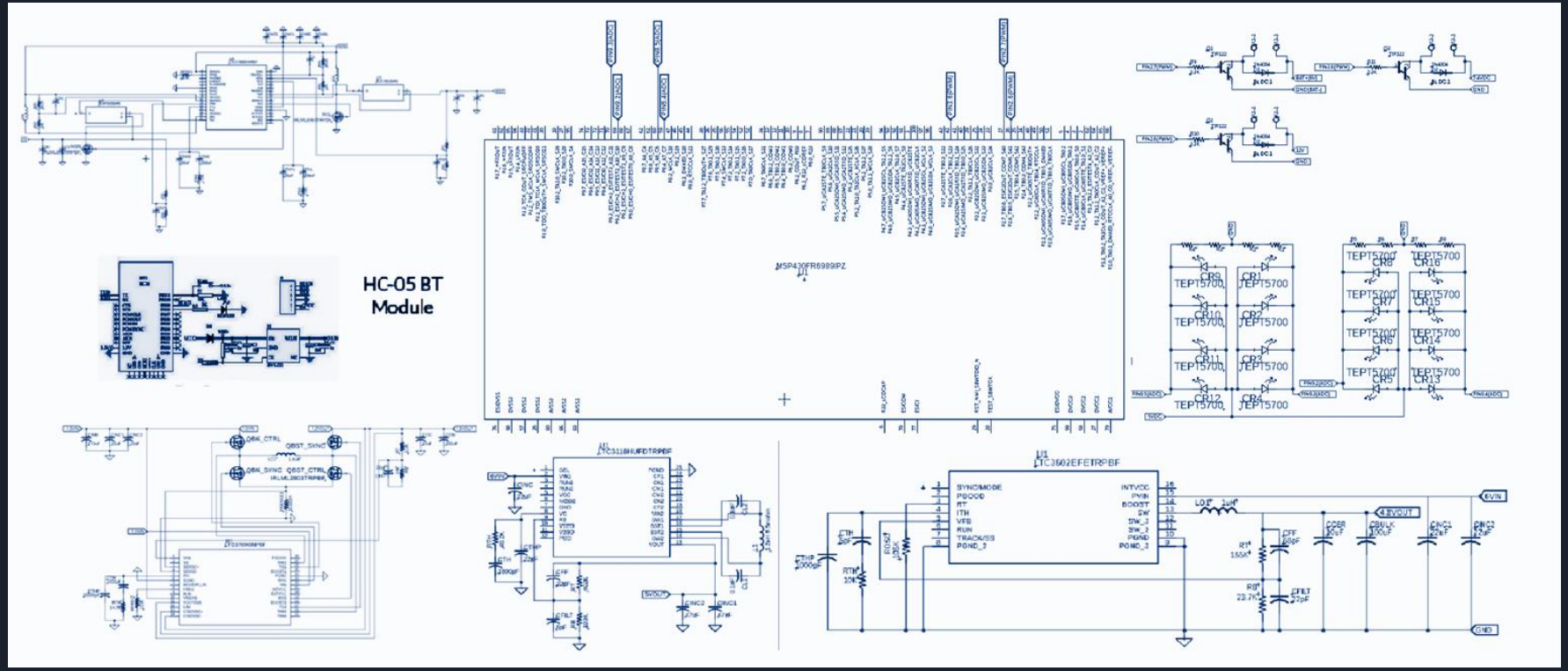
Software Design: Convolutional Networks Considerations

- MobileNet*
  - Separable convolution
  - Size and time to calculate is kept small
- ResNet
  - Great and accurate for larger projects
  - Slower than other CNNs
- TinyYOLO V3 (TinyYouOnlyLookOnce V3)
  - Uses an extractor, called Darknet
  - Works very quickly for smaller projects with the cost of accuracy
- Single Shot Detector
  - Similar to TinyYOLO but a bit more accurate
  - Can be matched with other CNNs to increase performance

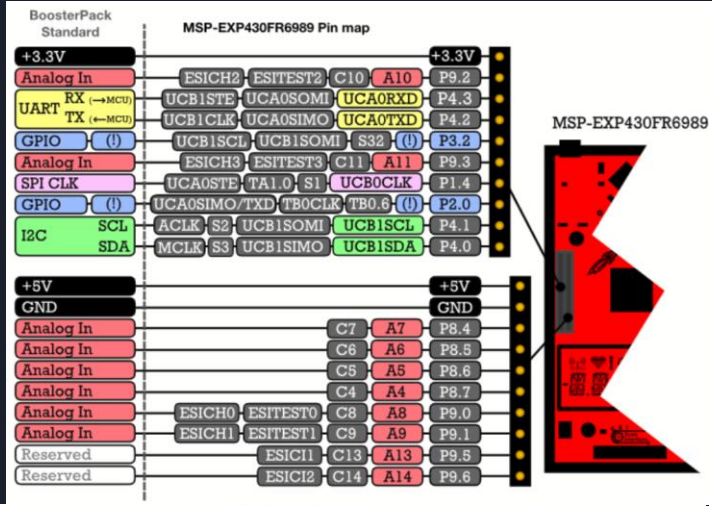
Software Design: MSP430 Responsibility

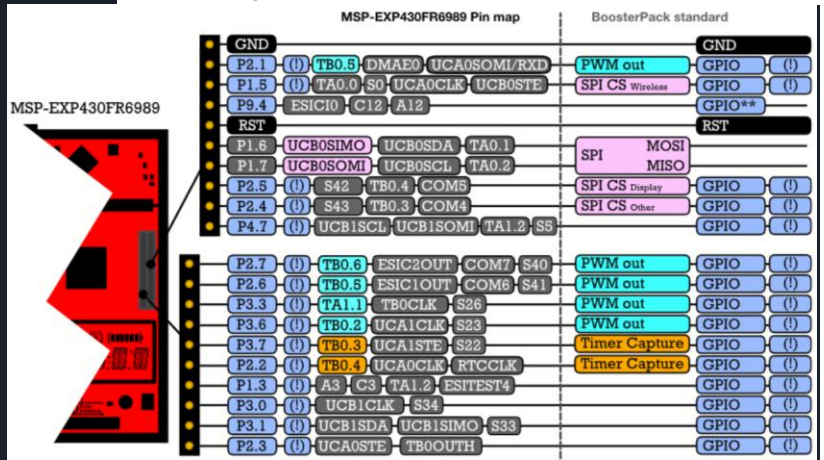
- Carries most features that doesn't entail any AI functionality
- Tank Movement
  - Tracks, turret, and barrel
- Phototransistors
  - ADC convertor receives laser input to determine high beams on phototransistors
- Certain triggers
  - When to send the bluetooth data to certain pins
  - When and how servos should operate
- Bluetooth Transceivers
  - Way to send data to the tank from the controller

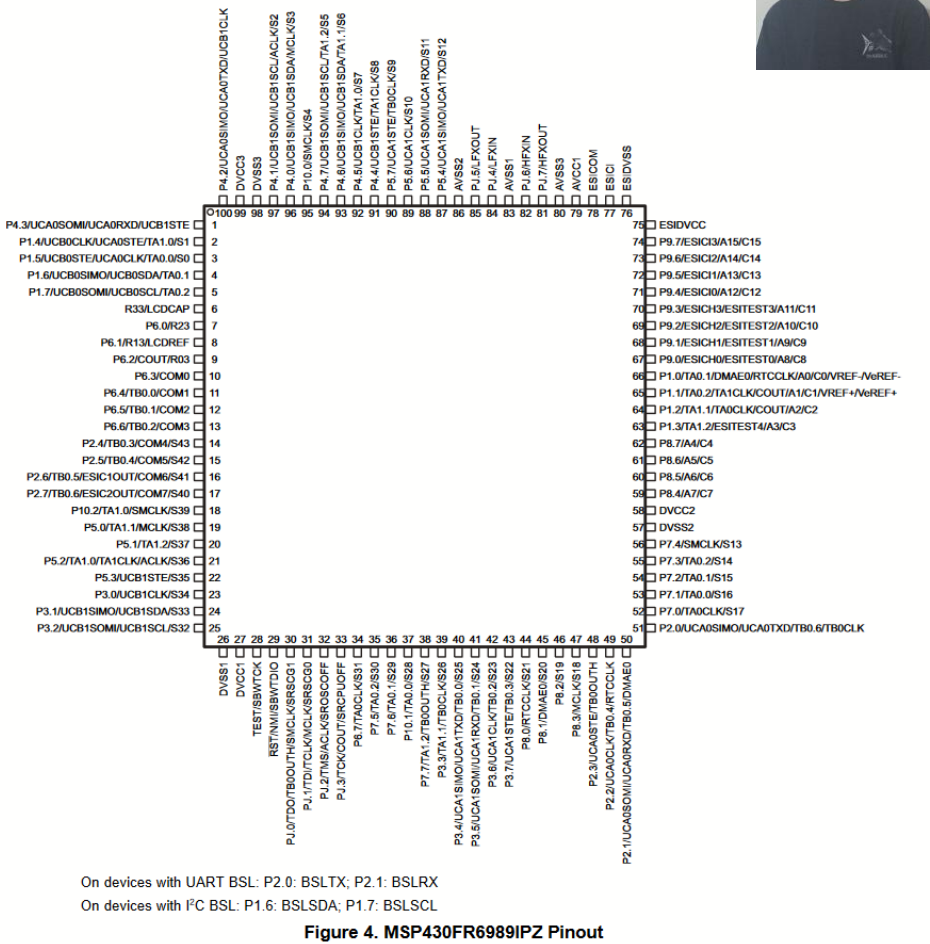
Overall Schematic



MSP-EXP430FR6989 Main CPU + Connector Pinouts







On devices with UART BSL: P2.0: BSLTX; P2.1: BSLRX
On devices with I²C BSL: P1.6: BSLSDA; P1.7: BSLSCL

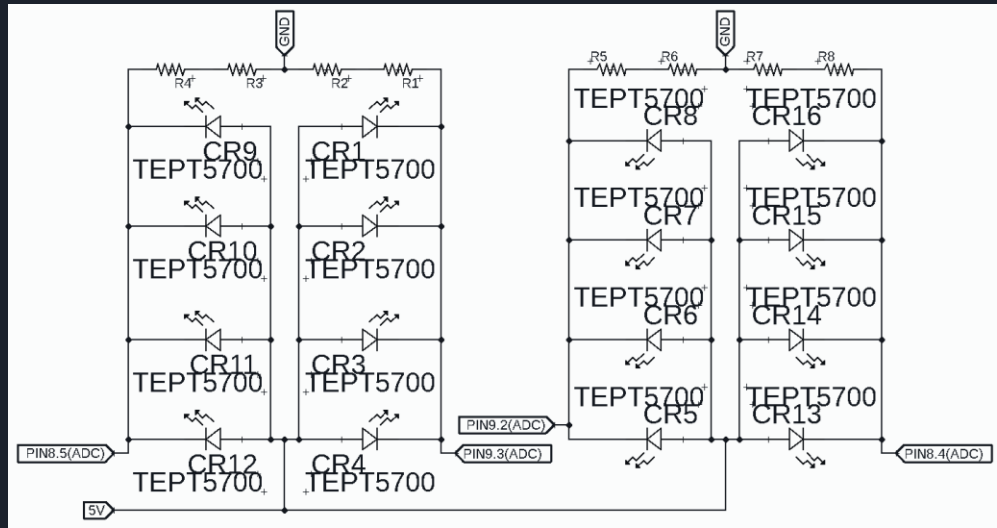
Figure 4. MSP430FR6989IPZ Pinout

Circuit Design

Circuit:

- 4 Phototransistor per side
- Pull-Down resistors
- ADC per side
- Each Phototransistor set has own pin

TEPT5700 Light Detection Circuits

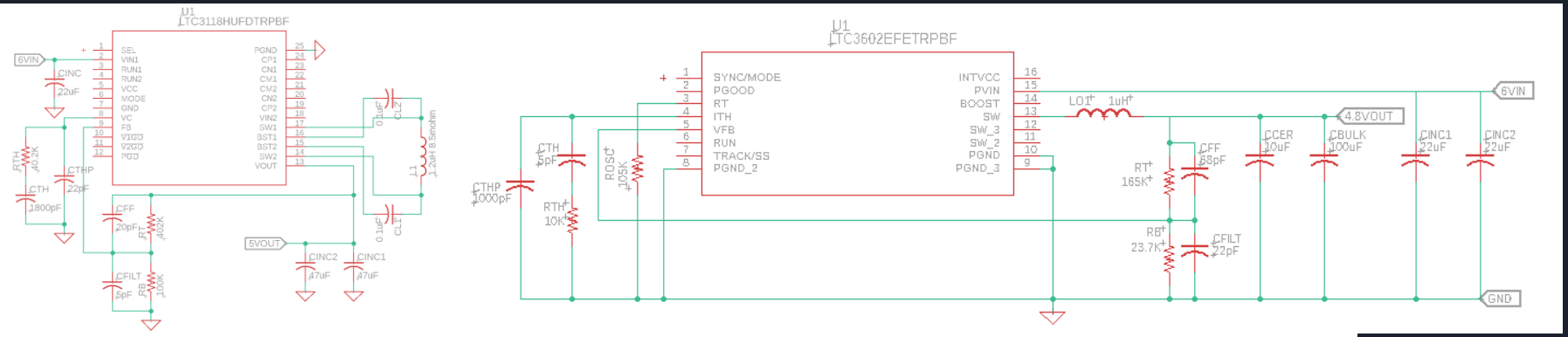


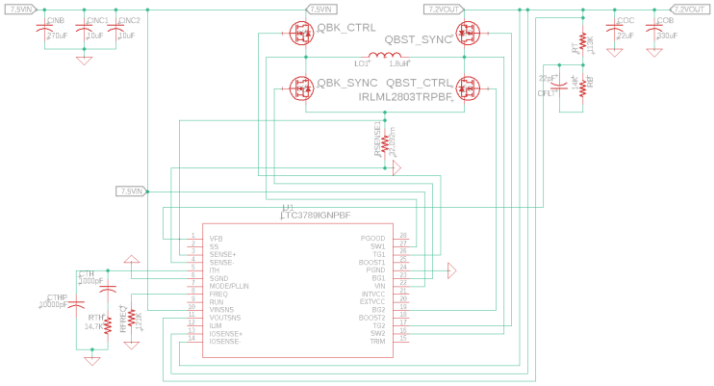
Motor Power Circuit Considerations

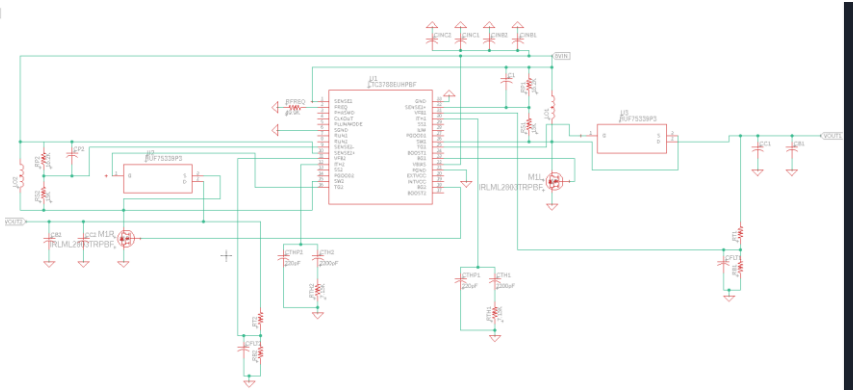
- MG90D Servo Motor
  - Operational Voltage: 4.8V - 6V, Recommended Operational Voltage: 4.8V
  - Considering 4 1.5V AA Batteries in series with Buck-Boost Converter for a consistent 4.8V at 2A max current
- Tank Tread 25 Geared Motor:
  - 7.2V recommended operation
- Greartisan 12V 50RPM Geared DC Motor
  - 12 Volt operation
  - Can be undervolted to slow down RPM
  - Reverse polarity Capable

Voltage Conversion Circuits

- Designed using LTpowerCAD II V2.7.2







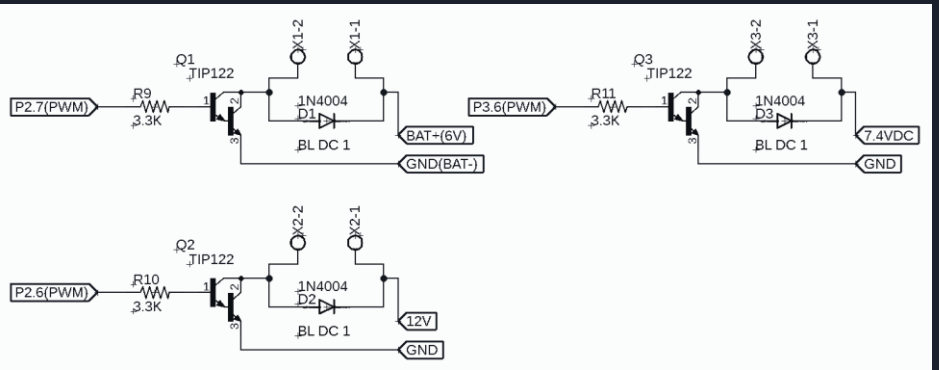
Microcontroller Power

- Jetson Nano 2GB:
  - Requires 5V through USB-C, 3A Recommended current
  - Charmast Battery Pack at 5V, 3A, Dual USB-A to USB-C Ports
- MSP-EXPFR6989:
  - Requires 5V through Micro-USB at 1A max current

Ratings	Charmast Power Bank	4 AA Batteries
Supplied Voltage	5V	6V
		4.8V
Supplied Current	3A	Dependent on cable
Interface	USB - C	Any
Capacity	10000 mAH / 18W	8K-10K mAH
Dimensions	3.56 in x 2.44 in x 0.87 in	
Weight	6.6 oz	108 Grams

Motor Circuit Design

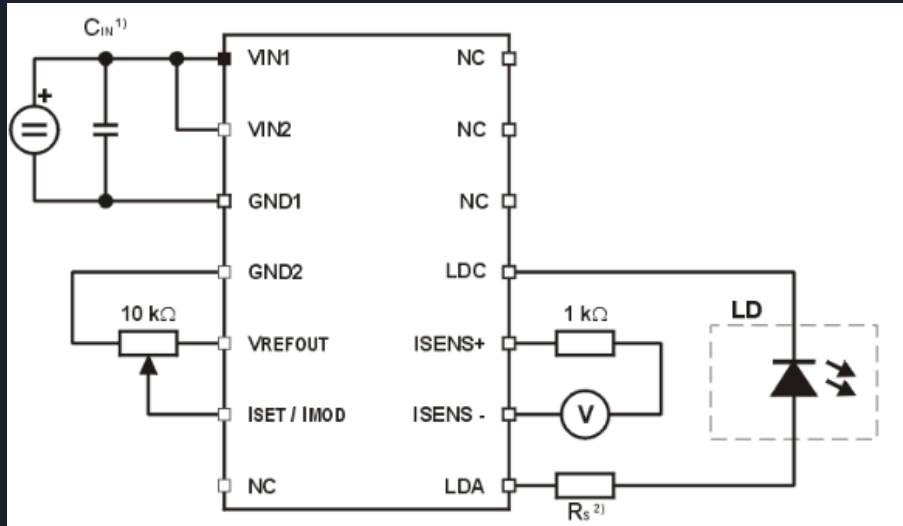
Motor Drivers



- Resistors Protects Main Board From Damage
- Transistor can provide 15A on motor startup and 5A continuously on normal operation
- Diode prevents back current from damaging motor

MLD203CLN Laser Diode Driver Circuitry

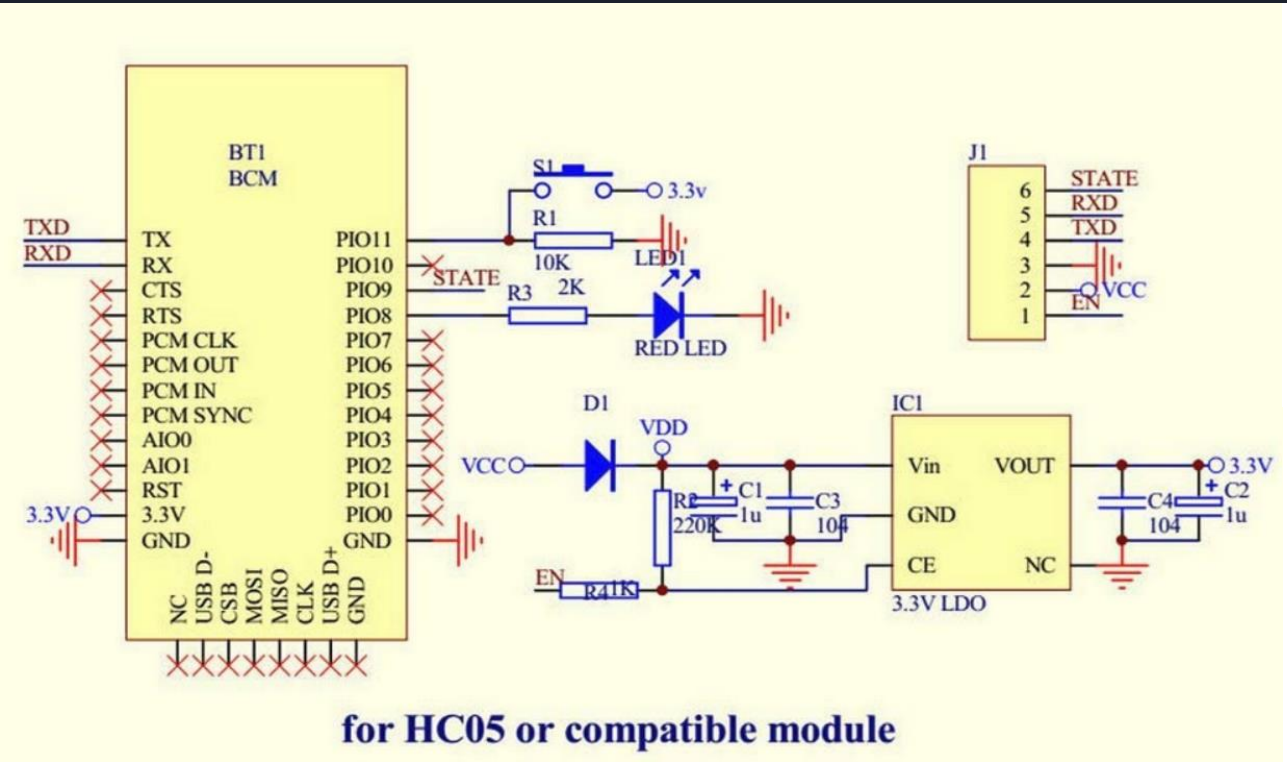
- **Standard Configuration:**
  - **Constant Power Solution**
  - **Rs optional resistor to limit laser diode current**
  - **Potentiometer to set Current**
  - **Cin optional capacitor for reduction of power supply ripple**



MLD203CLN Typical External Circuit

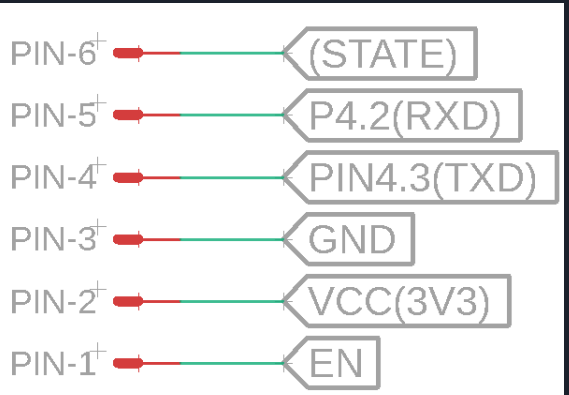
HC-05 Bluetooth Module

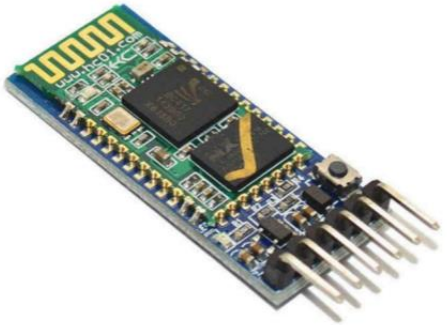
HC-05 Manufacturers Circuit Diagram



for HC05 or compatible module

HC-05 Pin to MSP PINOUT





Financials

Items	Quantity	Cost
Turret Motor	1	$14.99
Barrel Motor	1	$9.95
Motor Driver Controller	2	$13.98
Charmast Power Pack	1	$19.49
ICR-18650K	2	$10
Alkaline-Batteries	20*	$18
Barrel Cameras	1	$80
PCB	1	$100
Bluetooth transceiver	1	$7.51
Jetson Nano 2GB	1	$60
Total Cost		$333.92

- (*) These items were bought in sets
- For one tank, the total will be $762.76

Items	Quantity	Cost
Tank Treads	2*	$150
Laser Diode	1	$25.21
Constant Current Driver for Laser Diode	1	$38.95
Evaluation Board for Laser Diode	1	$136.43
Lens	1	$63.55
Phototransistors	30*	$14.70
Total Cost		$428.84

Questions?