UCF

UNIVERSITY OF CENTRAL FLORIDA

Robot Basketball

Group 9 - Summer/Fall 2019

Brandon Gross EE

Suvrat Jain CpE

Cory Ricondo CpE

Mat Schneider CpE

Motivation

- Entertainment
- Robot Athleticism
- Technologies and skills

Goals and Objectives

ARCADE-STYLE ENTERTAINMENT SYSTEM

EYE-CATCHING, ENGAGING, AND FUN

LOW-COST AND SCALABLE

PORTABLE

ROBOT CAPABILITIES

Realistic Design Constraints

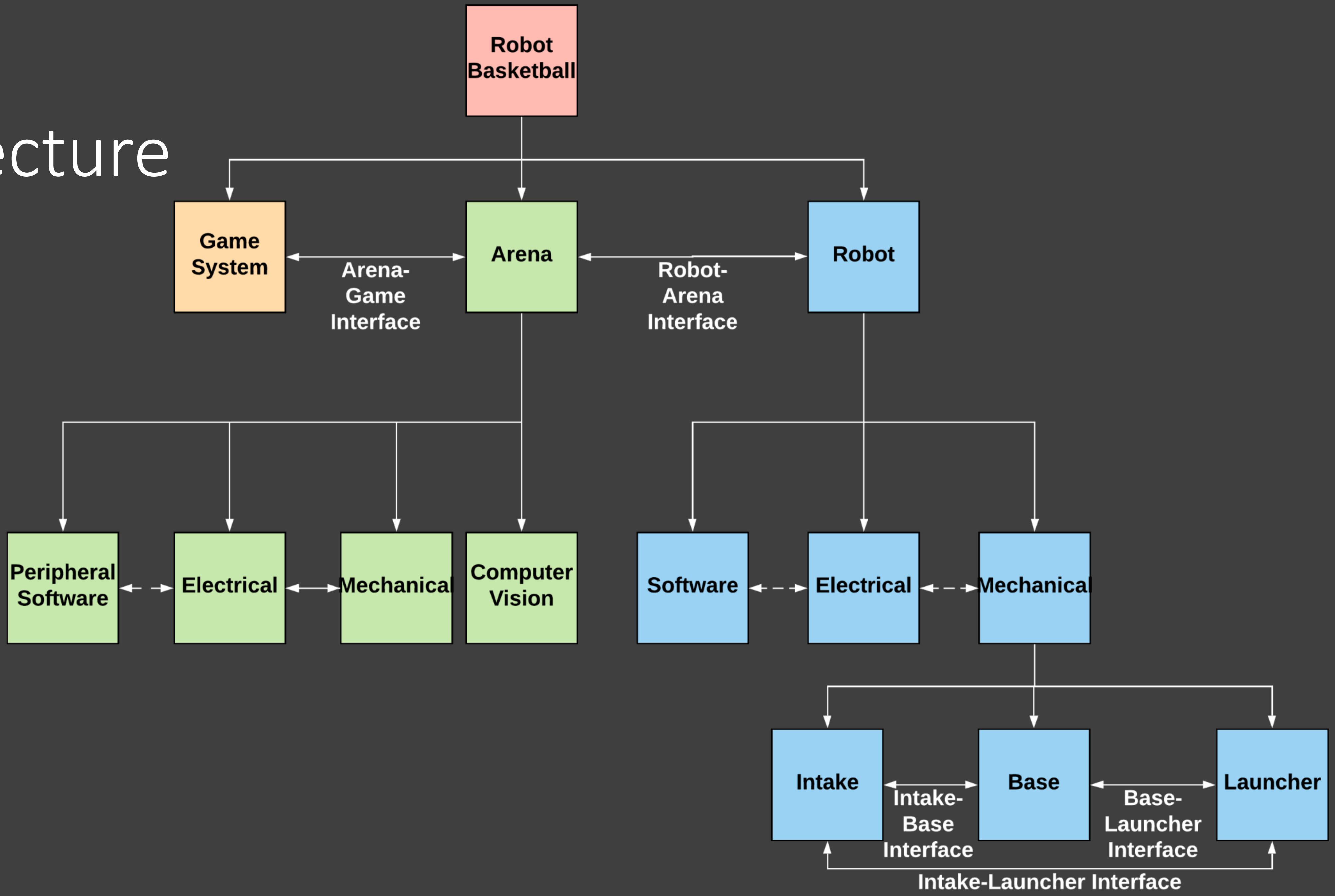
ECONOMIC

HEALTH AND SAFETY

MANUFACTURABILITY

SUSTAINABILITY

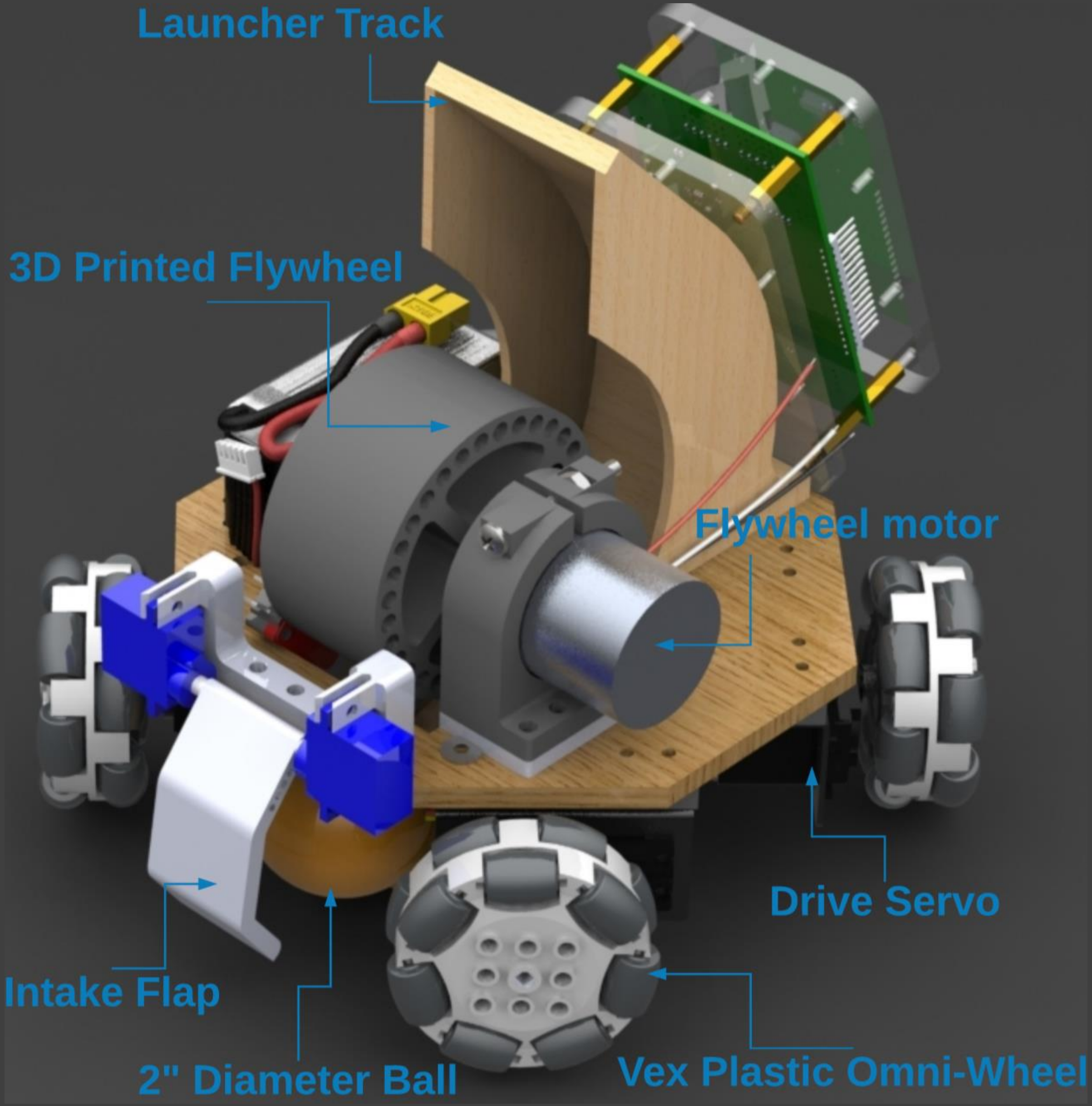
System Architecture

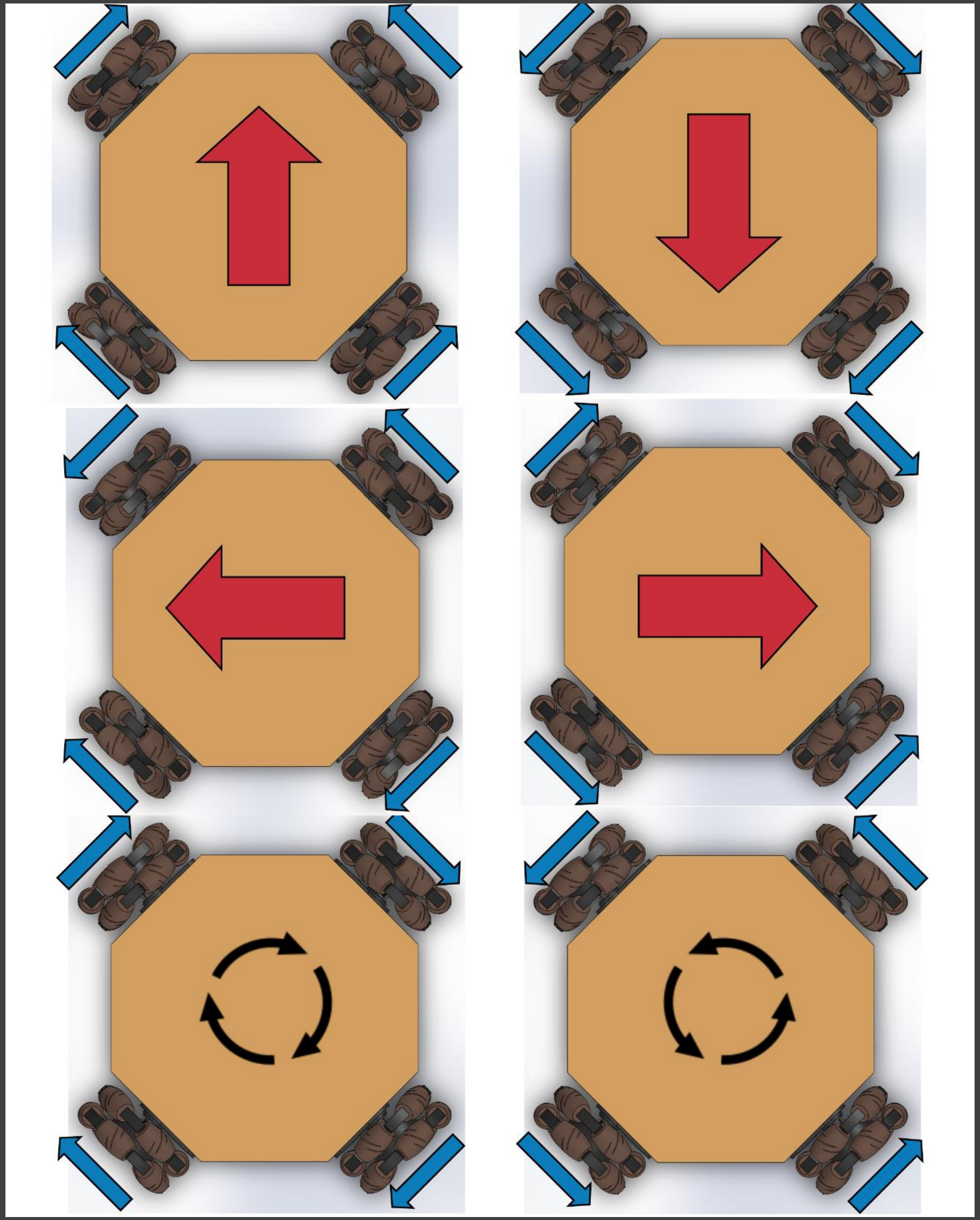


Requirement Specifications

Requirement #	System	Requirement	Value	Unit
1	Robot	The launcher shall launch a ball with a range of…	1-5	Feet
2	Robot	The robot shall drive in any direction at a minimum velocity of at least…	1.25	Feet/ second
3	Arena	The computer vision shall detect robot and ball position with an accuracy of at least…	.5	Inches
4	Arena	The computer vision shall detect robot orientation with an accuracy of at least…	3	Degrees
5	Game	The game shall control the robot with a gamepad at a rate of at least…	5	Hz
6	Game	The game shall prevent the robot from driving within a distance to the wall at most…	1	Inch

Robot

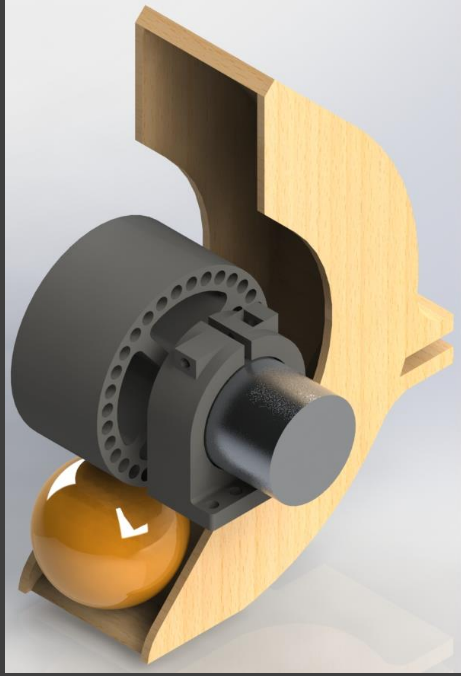

Launcher Track
3D Printed Flywheel
Flywheel motor
Drive Servo
Intake Flap
2" Diameter Ball
Vex Plastic Omni-Wheel

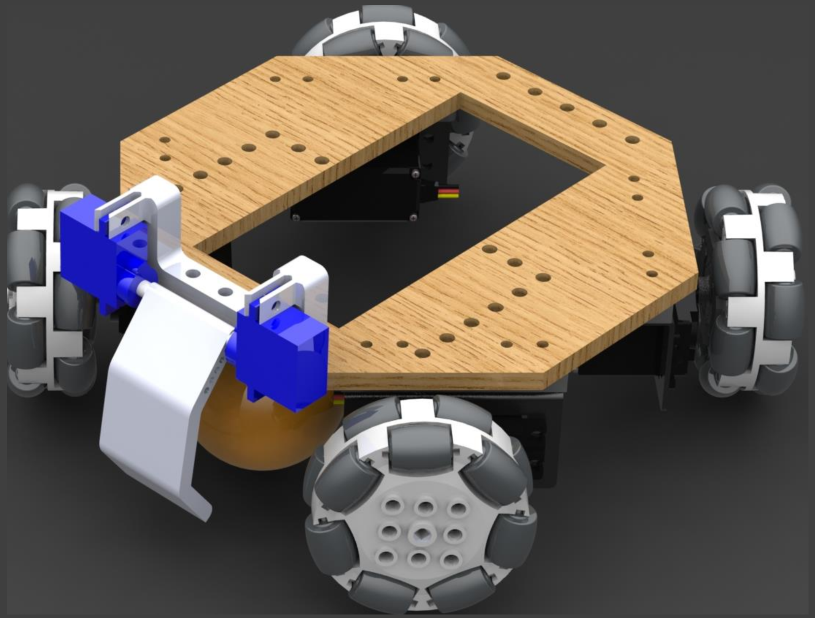


Mobile Base Design

- Holonomic vs Skid-Steer
  - Can maintain shot angle while traversing without turning
  - Slightly faster motion
  - Requires more torque

Robot Launcher/Intake Design





- Flipper mechanism to trap ball and feed it into intake
- Flywheel for launching simplicity
  - Issues
    - Initially chose a brushless DC motor with very high RPM (10,000+), however this was significantly too fast on lowest speeds and caused damage through vibrations
    - Significant energy loss in shot (500 RPM -> 3600 RPM)

Component Selection Overview - Robot

Category	Part Description	Part Name (Qty.)	Manufacturer	Operational Voltage [Using] (V)	Operational Current (mA)	Power (W) (Peak)	Cost ($)
Base	**Drive Motors**	Servos (4)	Parallax	5 - 8.4 [6.5]	200	~5	112
Launcher	**Flywheel**	DC Motor (1)	Johnson Electric	6 – 24 [11–12.5]	3000	36	6.00
Launcher	IR Sensor	Break Beam	Adafruit	5	20	0.1	1.95
Intake	Flippers	Servos (2)	Parallax	4 – 6.5 [6.5]	200	~3	26
Communication	**Bluetooth**	RN-42 (1)	Roving Networks	3.3	30	~0.1	15.73
Electrical	**Microcontroller**	ATmega328p (1)	Microchip Technologies	5	200	1	2.01
Electrical	**Motor Driver**	DRV8871 (1)	Texas Instruments	6.5 – 45 [11–12.5]	3600 (peak)	~43	2.13
Electrical	PWM Driver	PCA9685 (1)	NXP	5	400	2	2.33
Power	Battery	3S LiPo	Turingy	11-16	5000	63	27.00
Power	DC – DC converter	TPS56637RPAR	Texas Instrument	4.5 – 28 [6.5]	6000	39	1.10
Power	5V Regulator	R-78E5.0-1.0 (1)	Recom	7 – 28 [11 – 12]	1000	12	3.26
Power	3.3V Regulator	R-78E3.3-1.0 (1)	Recom	7 – 28 [11 – 12]	1000	12	3.26
Total						**~216**	**202.77**

Component Selection - Microcontroller

- Microcontroller needs to be able to support various chip drivers such as motor driver, PWM driver
- Microcontroller needs to have the ability to implement communication protocols for instance UART for Bluetooth data exchange
- Microcontroller needs to have thorough documentation and help online to speed development process

Processor	ATmega328P	ATmega2560	MSP430G2553
Operating/Input Voltage (V)	**5**	5	3.3
CPU Speed (MHz)	**16**	16	16
Analog IN/OUT	**6/0**	16/0	8/8
Digital IO/PWM	**14/6**	54/15	24
EEPROM [kB]	**1**	4	0.128
SRAM [kB]	**2**	8	0.512
Flash [kB]	**32**	256	16
UART	**1**	4	1
Cost ($)	**2.01**	12.35	2.41

Component Selection – Drive Motors

- Requires motors capable of driving the robot in high speed situations (0.3m/s)
- Requires closed-loop velocity control to accurately control holonomic motion
- Servo chosen because of the ease of control (Simplifies the drive code)

	Heneng DC Motor	Feedback 360 High Speed Continuous Rotation Servo	High Speed Continuous Rotation Servo
Cost($)	15	**28**	17
Manufacturer/ Distributor	Amazon	**Parallax**	Parallax
RPM	100	**140**	180
Torque (Kg-cm)	2	**2.5**	2.2
Voltage, Current (V), (A)	9,1.2	**6.5, 0.2**	7.4,0.6
Power(W)	10.8	**7.8**	4.44
Control	External Driver	**PWM**	PWM
Feedback	2 CPR Quadrature Encoder	**2 CPR Hall Effect**	None

Component Selection - Motor Driver

- The Motor Driver needs to drive a DC motor within the operating range of 6V – 24V
- The Motor Driver needs to be small enough to save PCB space
- The Motor Driver should support at least DC motor

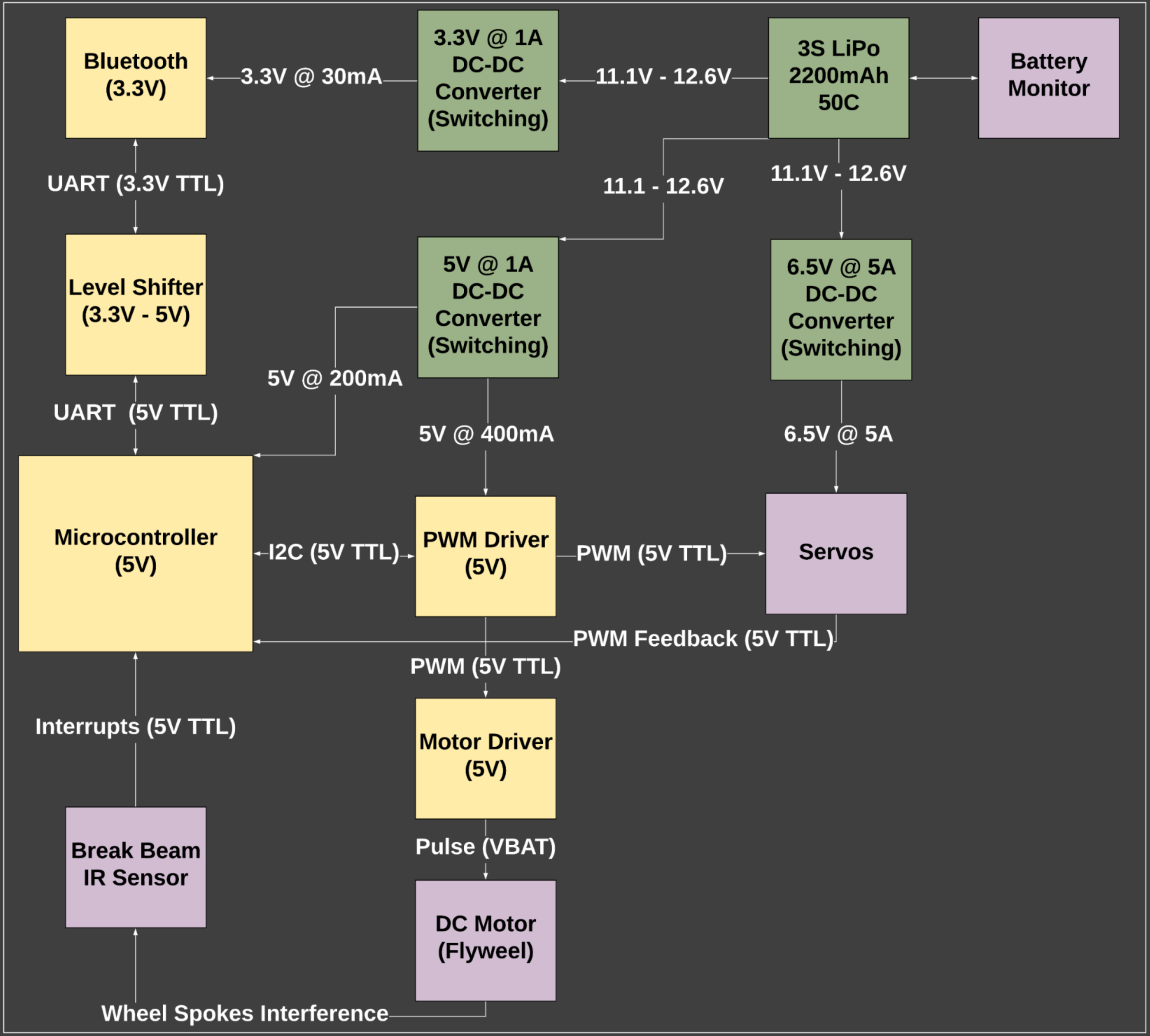
Driver IC	L293D	L298	DRV8871
Supply Voltage (V)	5 - 36	6.5 - 45	**6.5 - 45**
Max Output Current (A)	0.6	4	**3.6**
Number of Channels	2	2	**1**
Footprint (mm^2)	12.6 x 7.4	15.8 x 10.9	**4.90 × 6.00**
Cost($)	2.95	4.86	**2.13**

Component Selection - Communication

- The Communication device must be wireless
- The Communication device must be compatible with the Robot’s MCU and Arena’s computer
- The Communication device must be low power and have open source schematics available to lay on the PCB

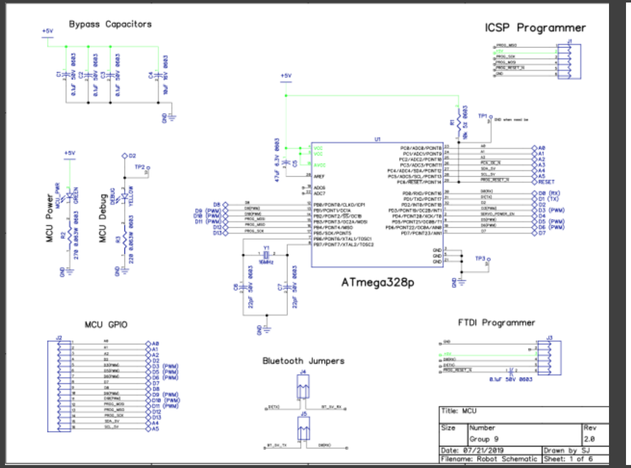
Bluetooth module	HC-05	BlueSMiRF
Operational Voltage (V)	3.3	**3.3**
Tx power (dBm)	<= 4	**<= 4**
Bluetooth Chip	TI CC2541	**RN-42**
Bluetooth Profiles Supported	SPP	**SPP & HCI**
AT Command Support	Yes	**Yes**
Linux Compatibility	Yes	**Yes**
Cost($)	~10	**~15**

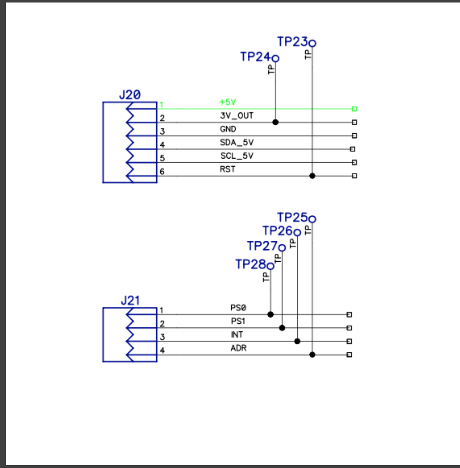
Robot PCB Overview

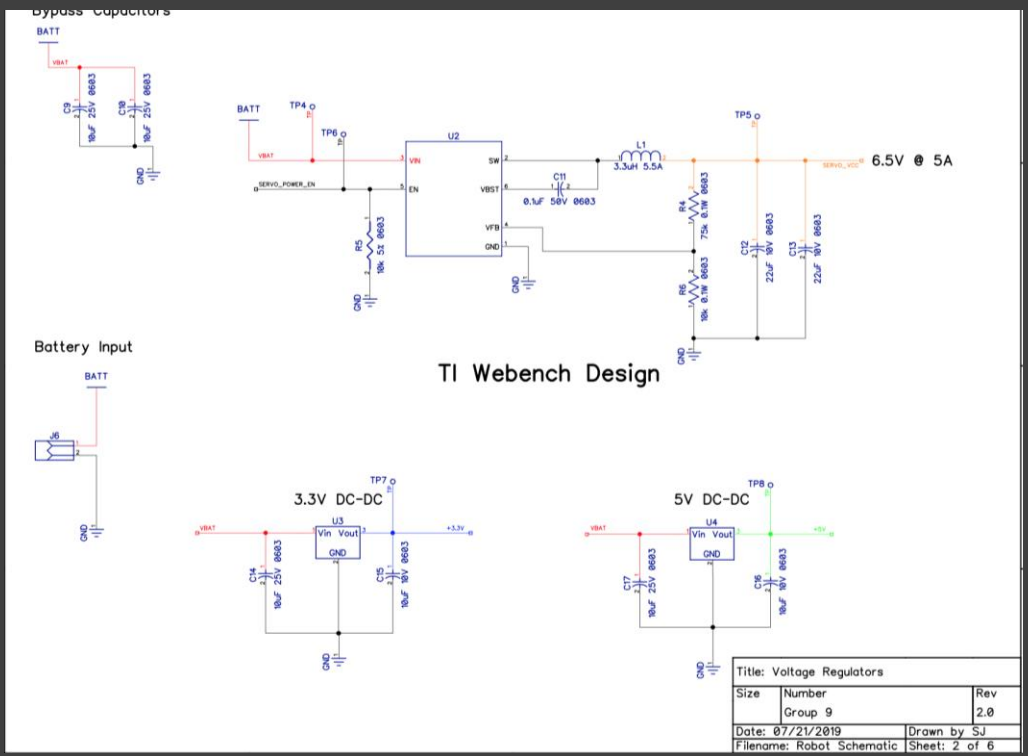


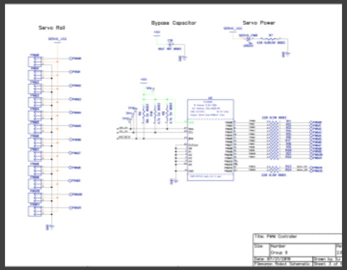
ICs | Peripherals | Power

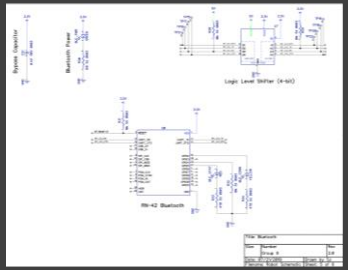
Overall Schematic

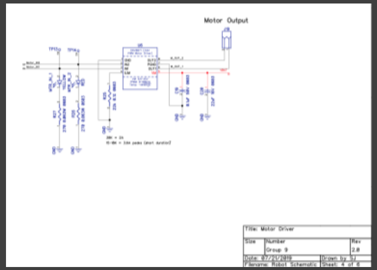




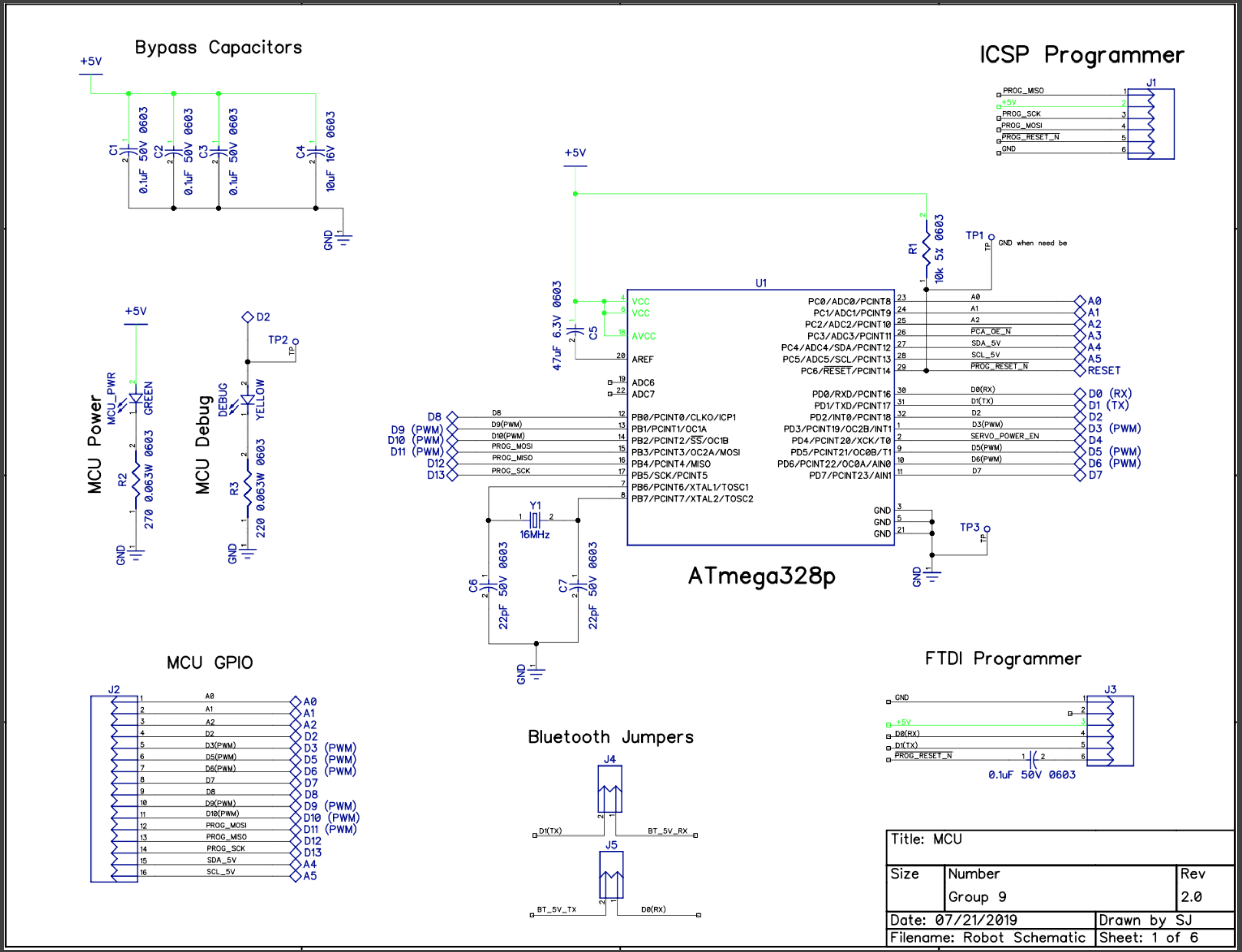




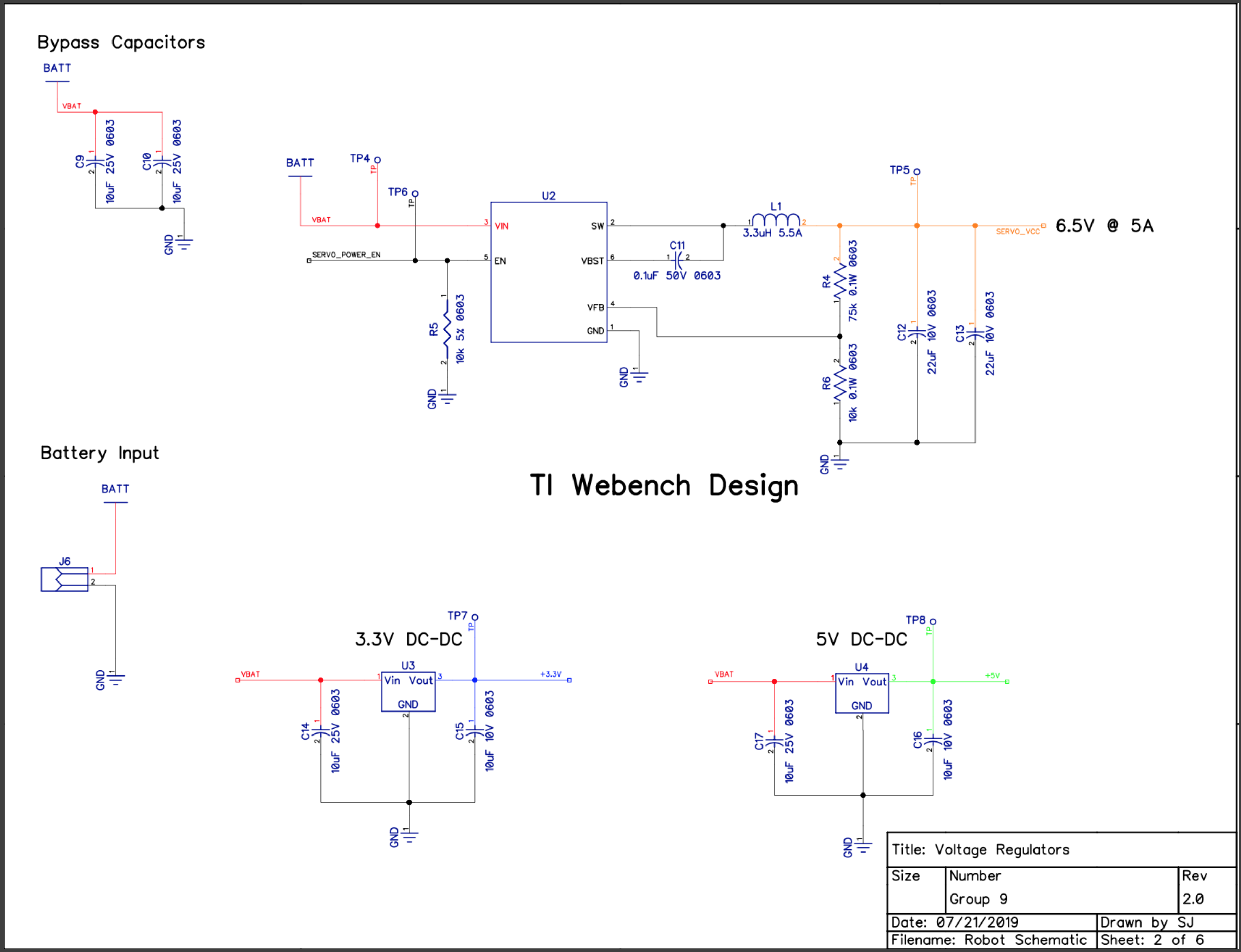




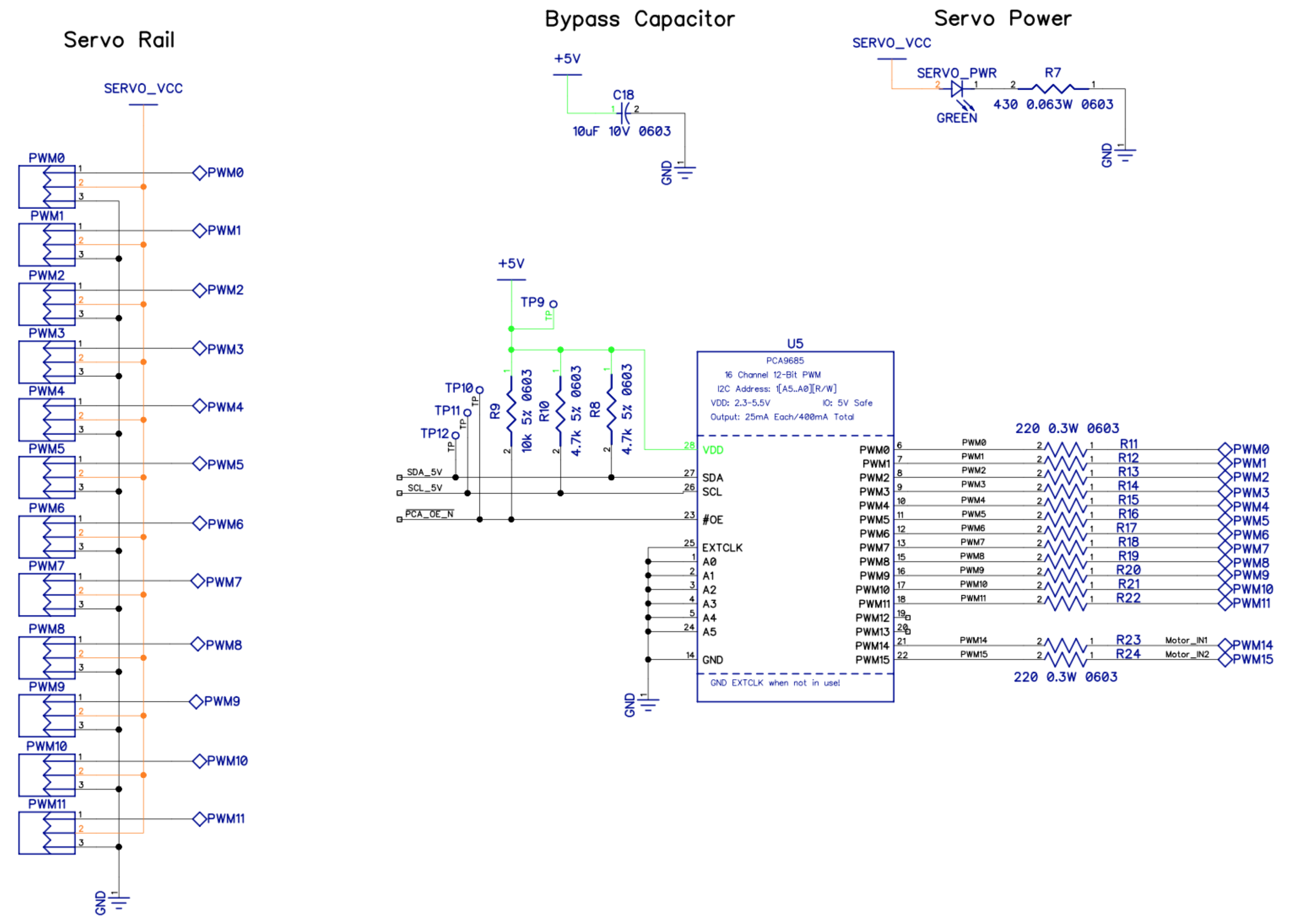
Robot Schematic: Microcontroller



Robot Schematic: Power Distribution

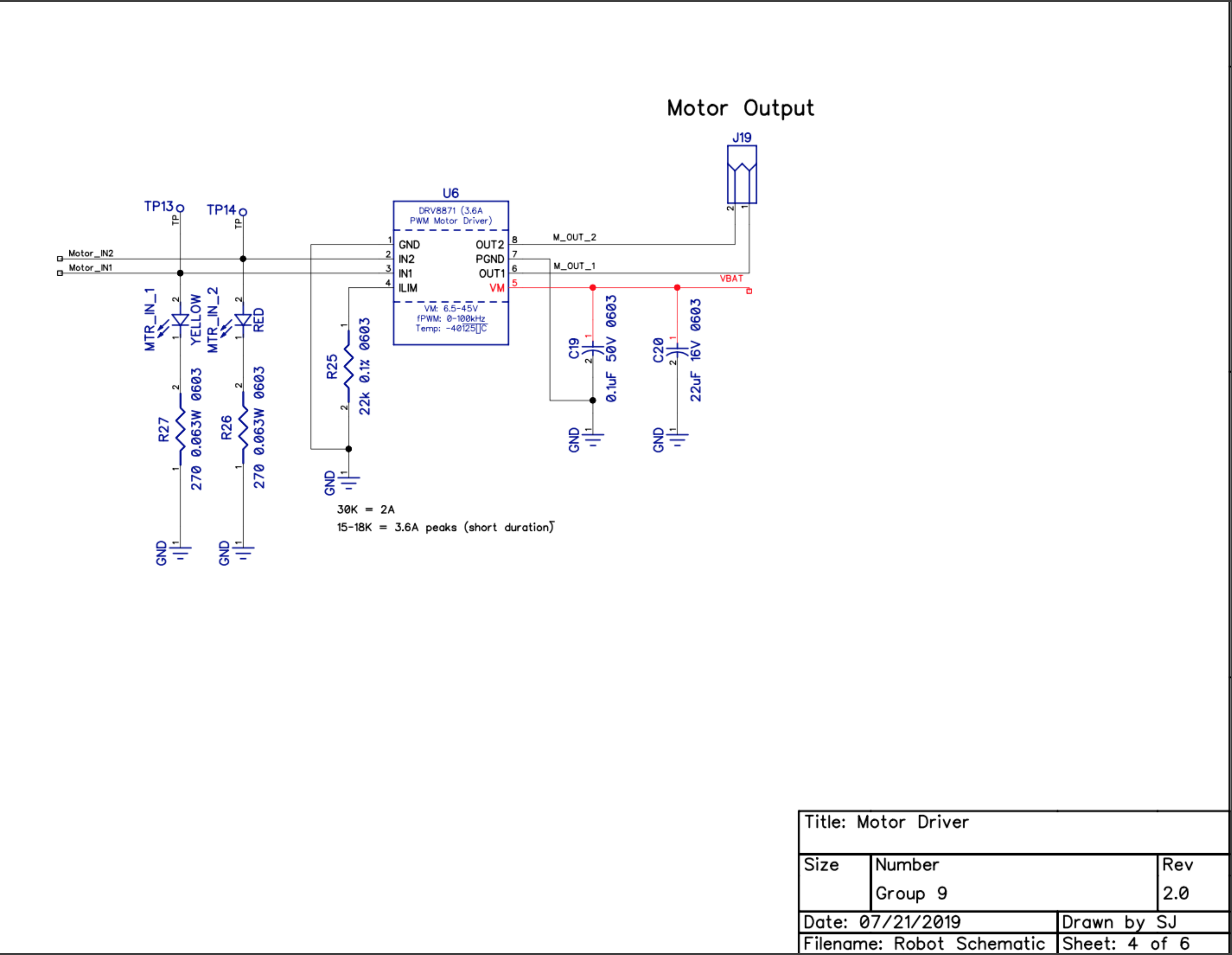


Robot Schematic: PWM Controller

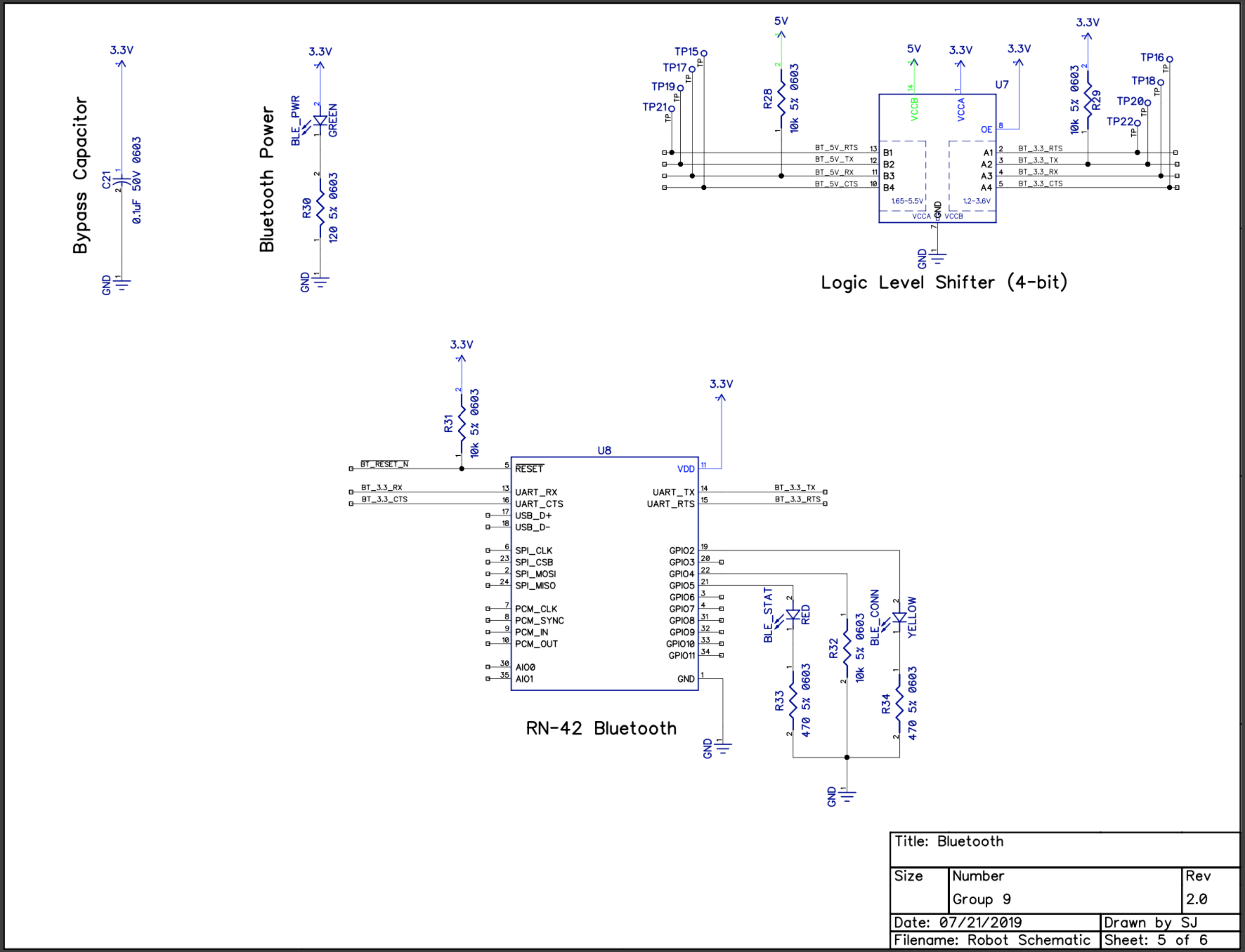


Title: PWM Controller		
Size	Number: Group 9	Rev: 2.0
Date: 07/21/2019		Drawn by SJ
Filename: Robot Schematic		Sheet: 3 of 6

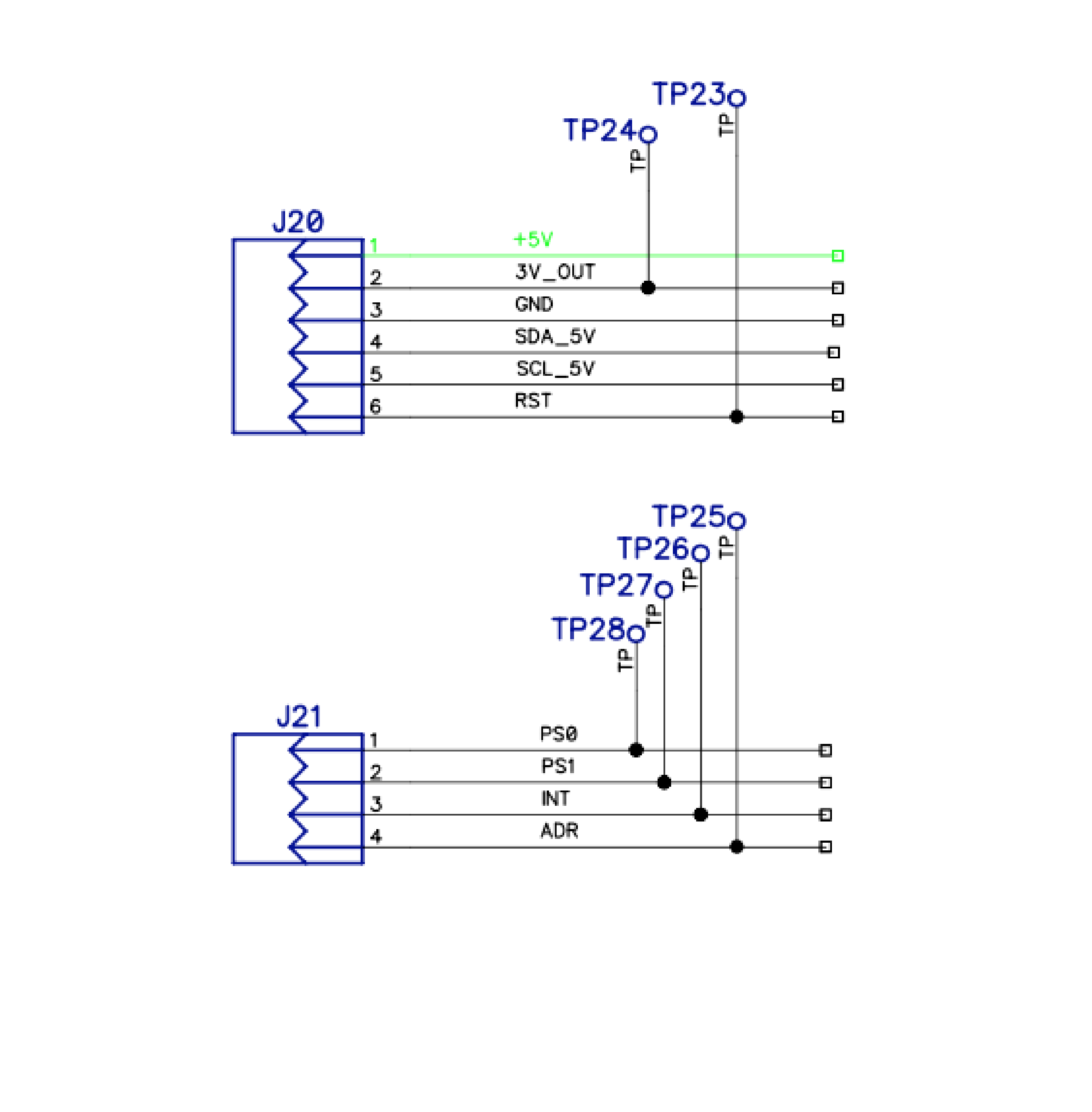
Robot Schematic: Flywheel Motor Controller



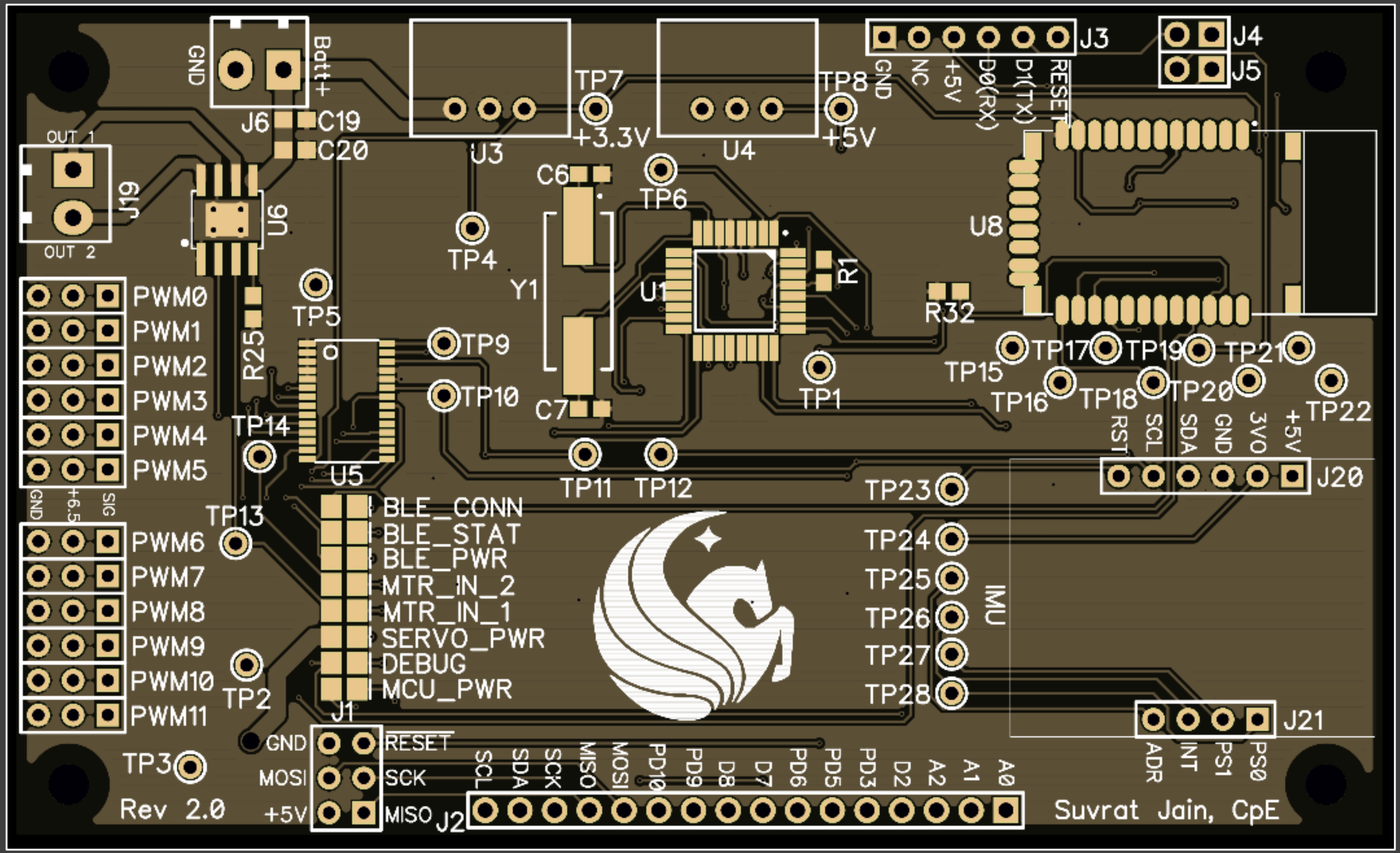
Robot Schematic: Bluetooth



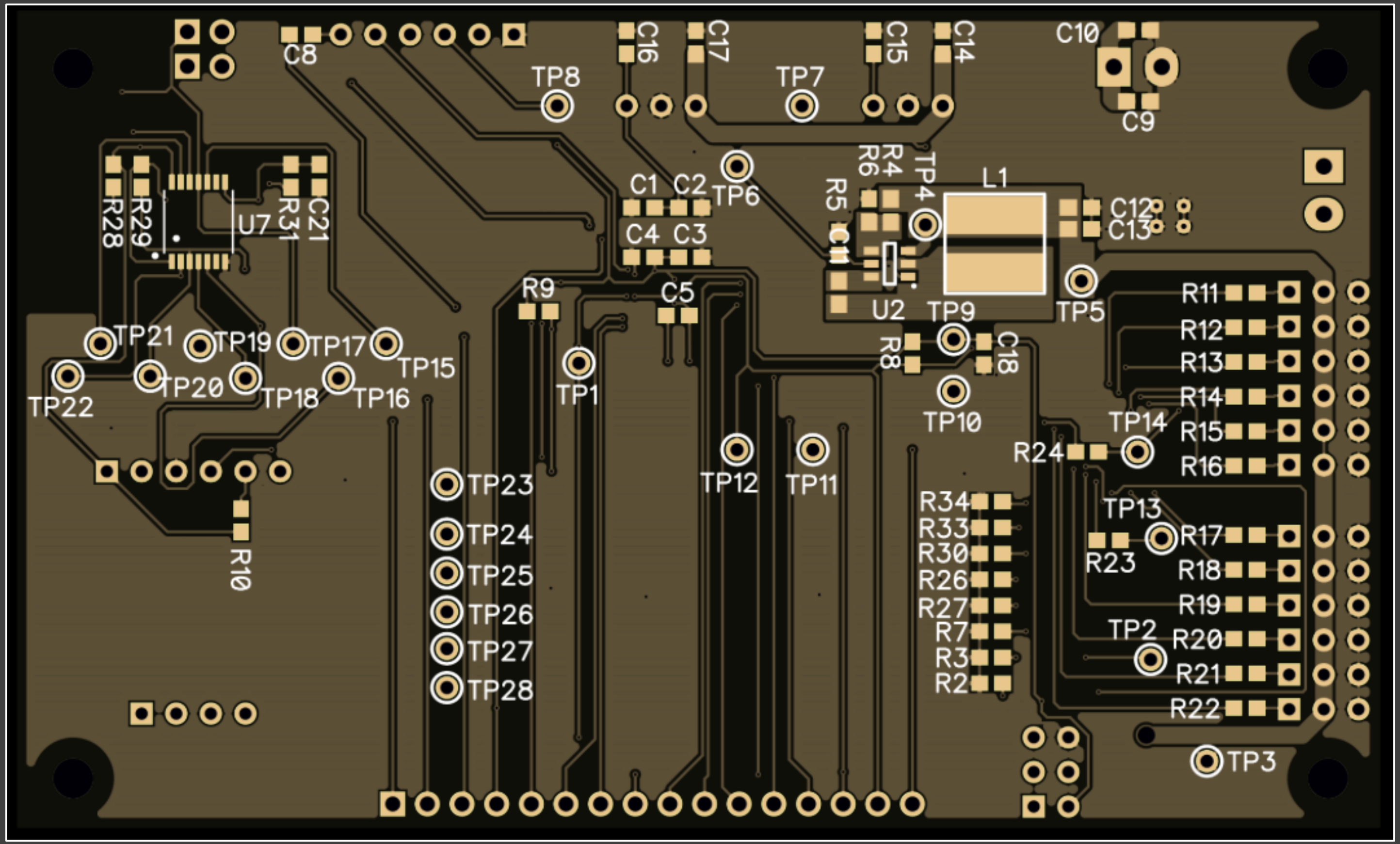
Robot Schematic: Expansion Interface



PCB Top Layout



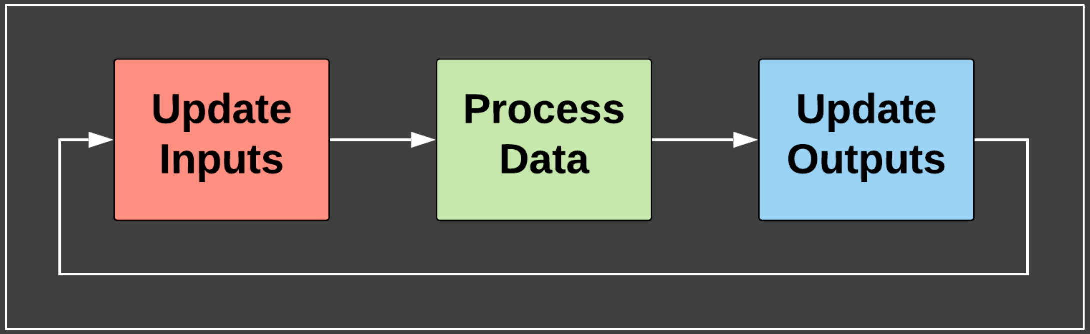
PCB Bottom Layout



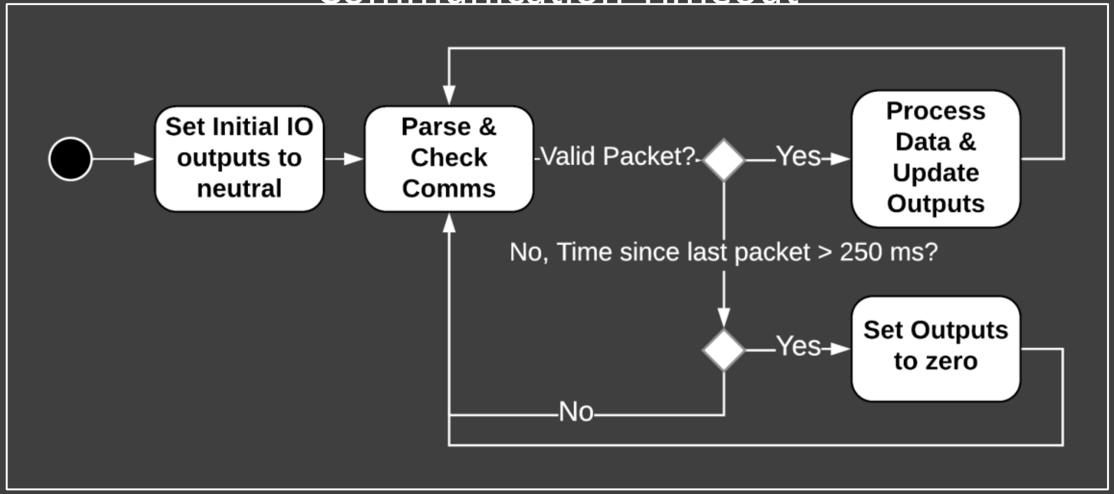
Robot Software Design

- Robot acts as an I/O device that takes in data from sensors and commands from the Arena, and then executes the commands through actuations
- Kinematics are done on the robot to abstract the control to the Game system
- Closed-loop control is implemented on drive & Launcher systems
- Outputs disabled when valid packets are not received after a short period of time
- Control loop time runs at ~50hz

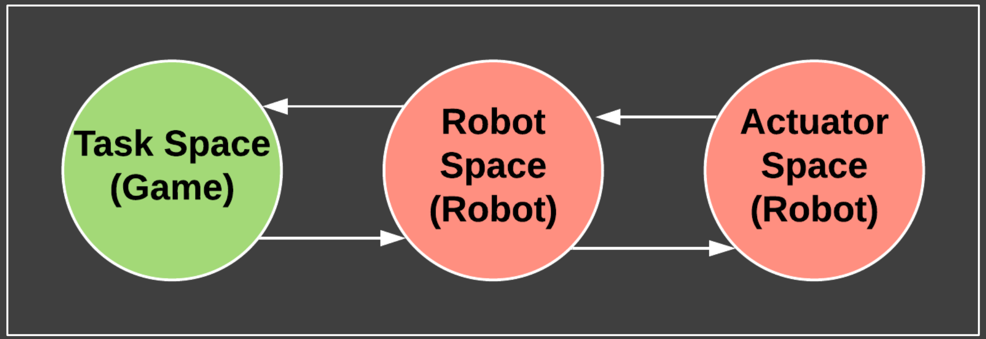
Data Flow



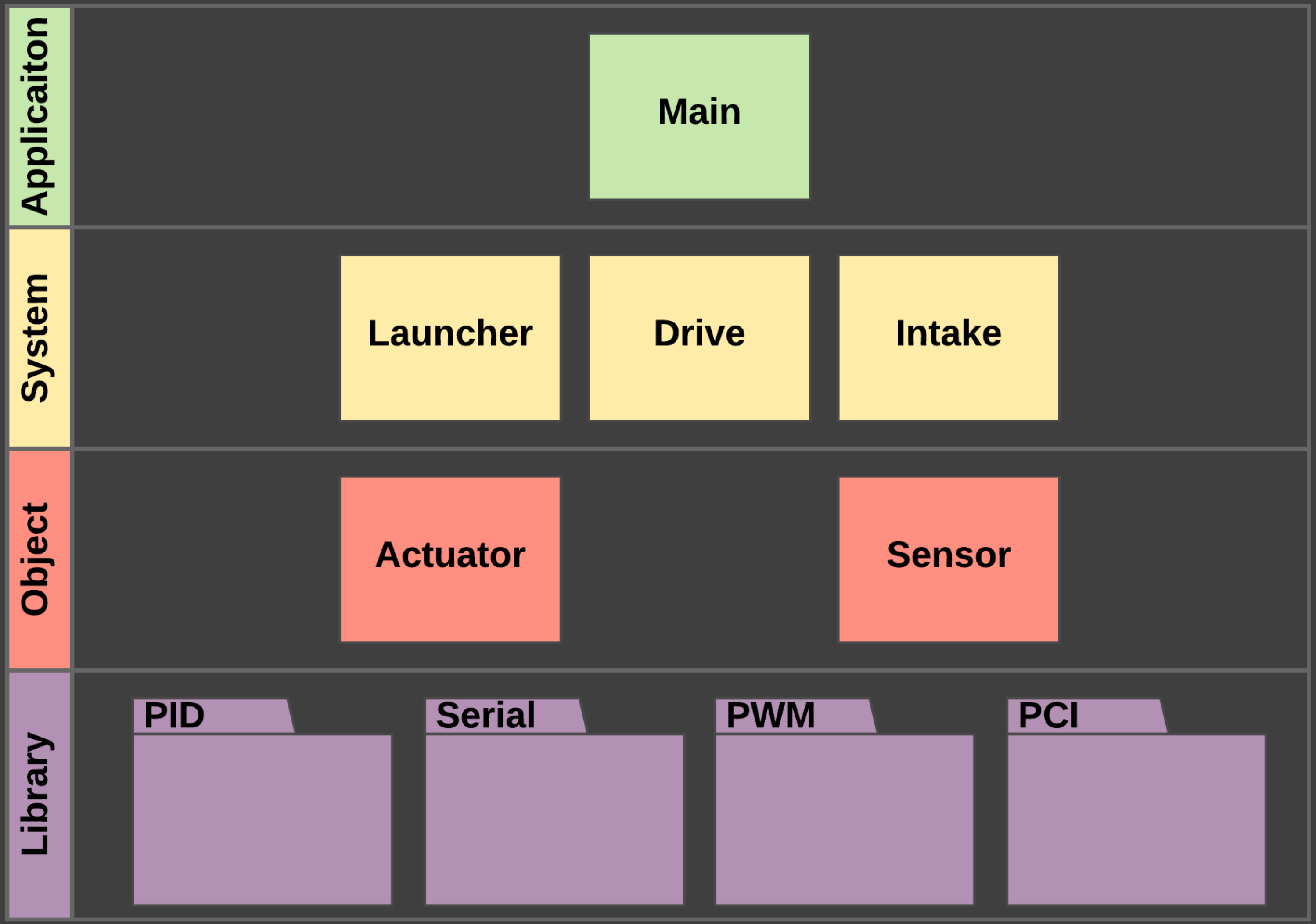
Communication Timeout



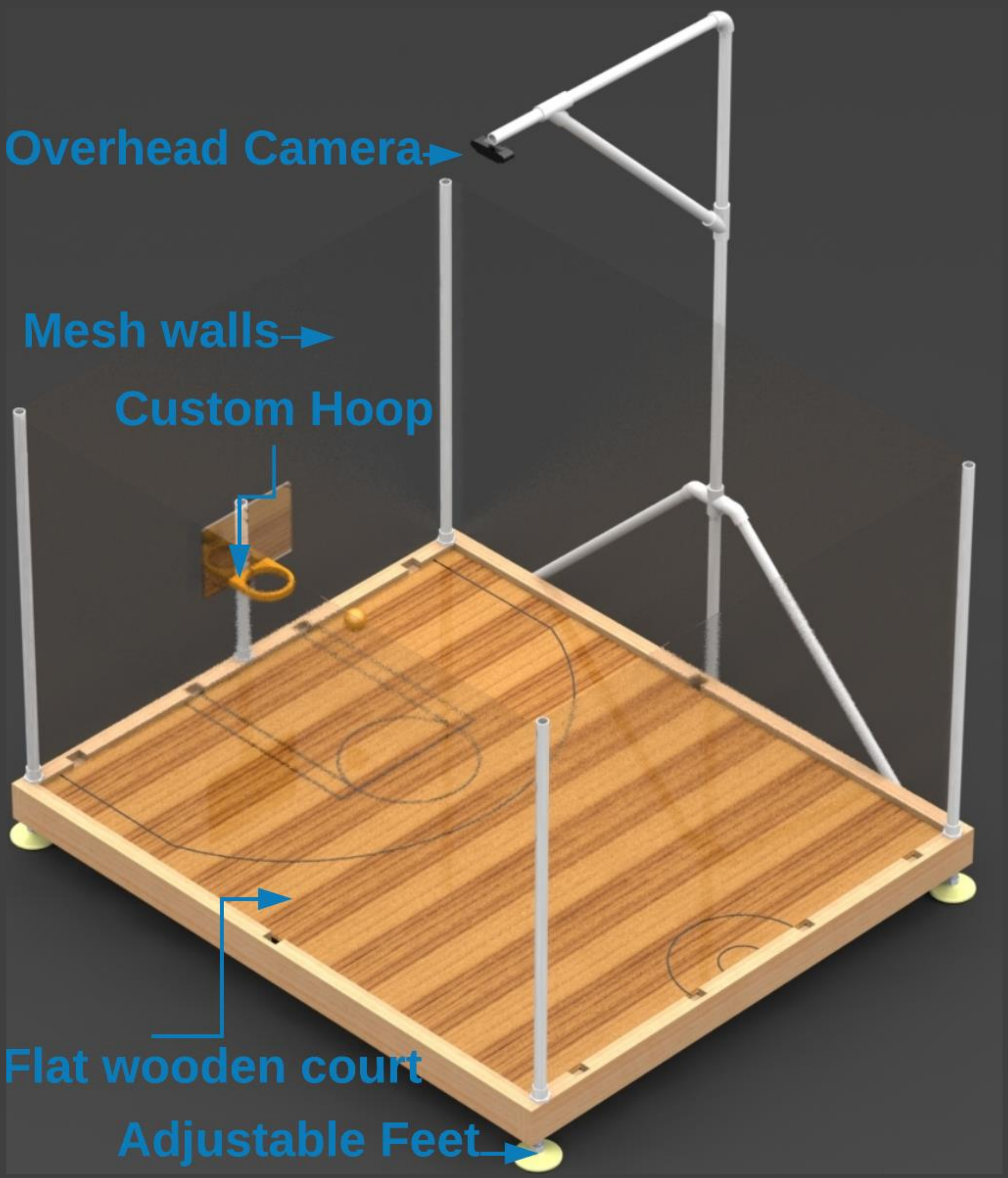
Space Transformations



Robot Software Model



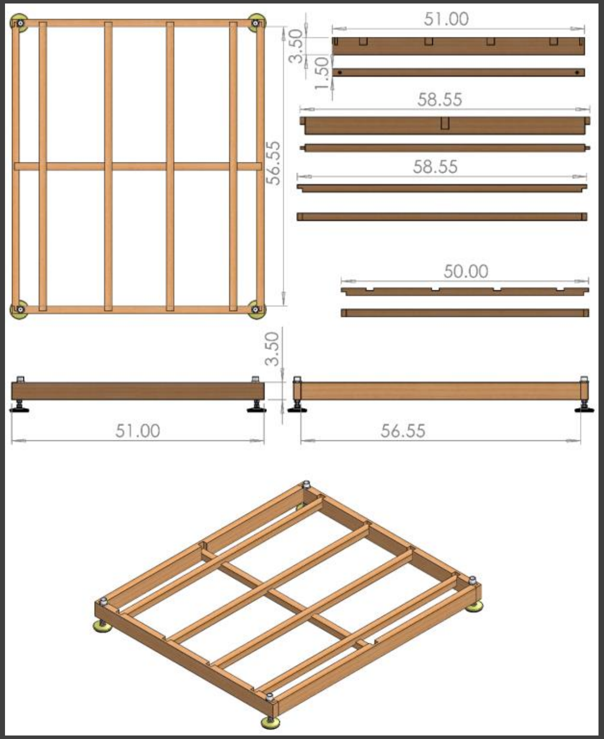
Arena

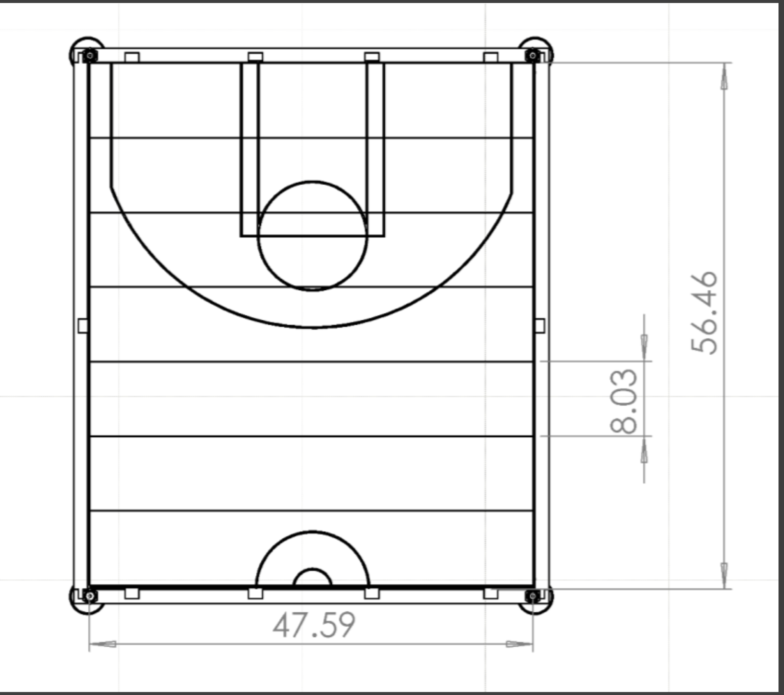


Overhead Camera
Mesh walls
Custom Hoop
Flat wooden court
Adjustable Feet

Arena - Frame & Court Design

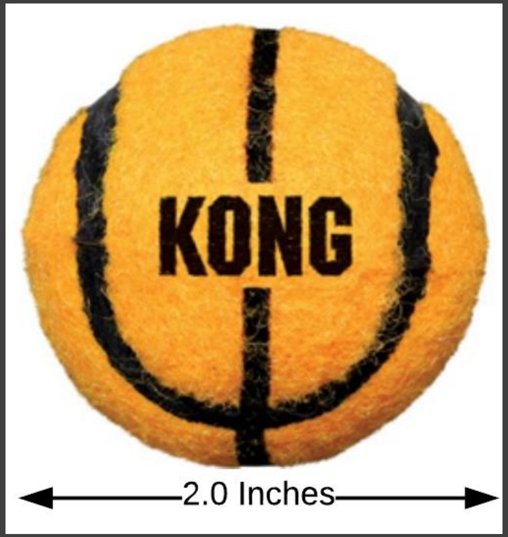
- Arena is 5’ length by 4’ Width by 3’ height (Minus camera mount)
- Broken into several locking pieces without tools or hardware
- Frame mounted on adjustable feet to level the floor
- Wall mesh included to prevent projectiles flying outside the Arena





Arena - Ball & Hoop Design

- Ball is a small-scale tennis ball with a basketball appearance
  - Chosen because of size, appearance, and higher weight than a ping-pong ball
- 3D-Printed hoop and mount attached to a PVC post and an ABS backboard
- IR Break Beam Sensor to capture when baskets are made



Component Selection – Embedded Computer

- High-powered computing is required to process the computer vision data and game engine on a single device
- It must also support a small number of I/O to aid in Arena intelligence

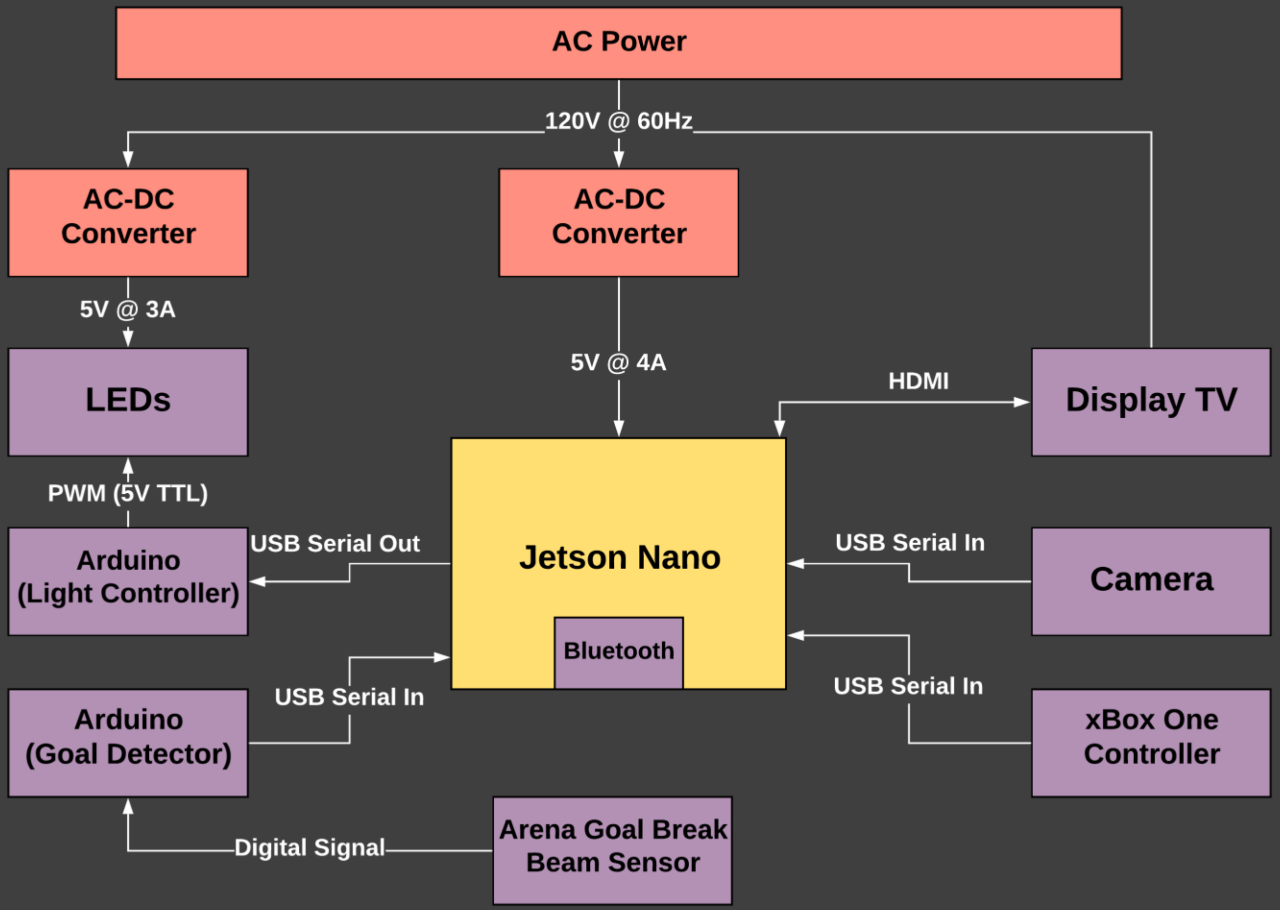
Feature	Raspberry Pi 3 Model B+	Jetson Nano
CPU	1.4 GHz 64-bit Quad-Core ARM Cortex A53	**1.4 GHz 64-bit Quad-Core ARM Cortex A57 MPCore**
GPU	Broadcom VideoCore IV	**128-Core Nvidia Maxwell**
RAM	1 GB LPDDR2 SDRAM	**4GB LPDDR4**
Operation Performance	21.4 GFLOPs	**472 GFLOPs**
Wireless	Dual-band 802.11ac wireless LAN, Bluetooth 4.2 onboard	**M.2 Key E Slot (None onboard)**
USB Ports	4x USB 2.0	**4x USB 3.0**
Video Ports	HDMI, DSI	**HDMI, Display Port**
Cost($)	35	**99**

Component Selection - Camera

	Pixy2	Logitech c920	Logitech C270
Cost ($)	$59.00	**$60.00**	$40.00
Resolution	1296x976	**1280 x 720** **1920 x 1080**	1280 x 720
Field of View	60° H x 40° V	**78° H x 43.3° V**	60° H x 40° V
Frame Rate	60 FPS	**60 FPS @ 720p** **30 FPS @ 1080p**	30 FPS
Mounting Height	6 Feet	**5 Feet**	6 Feet
Actual Test Quality	Extremely Poor	**Very Good**	Poor

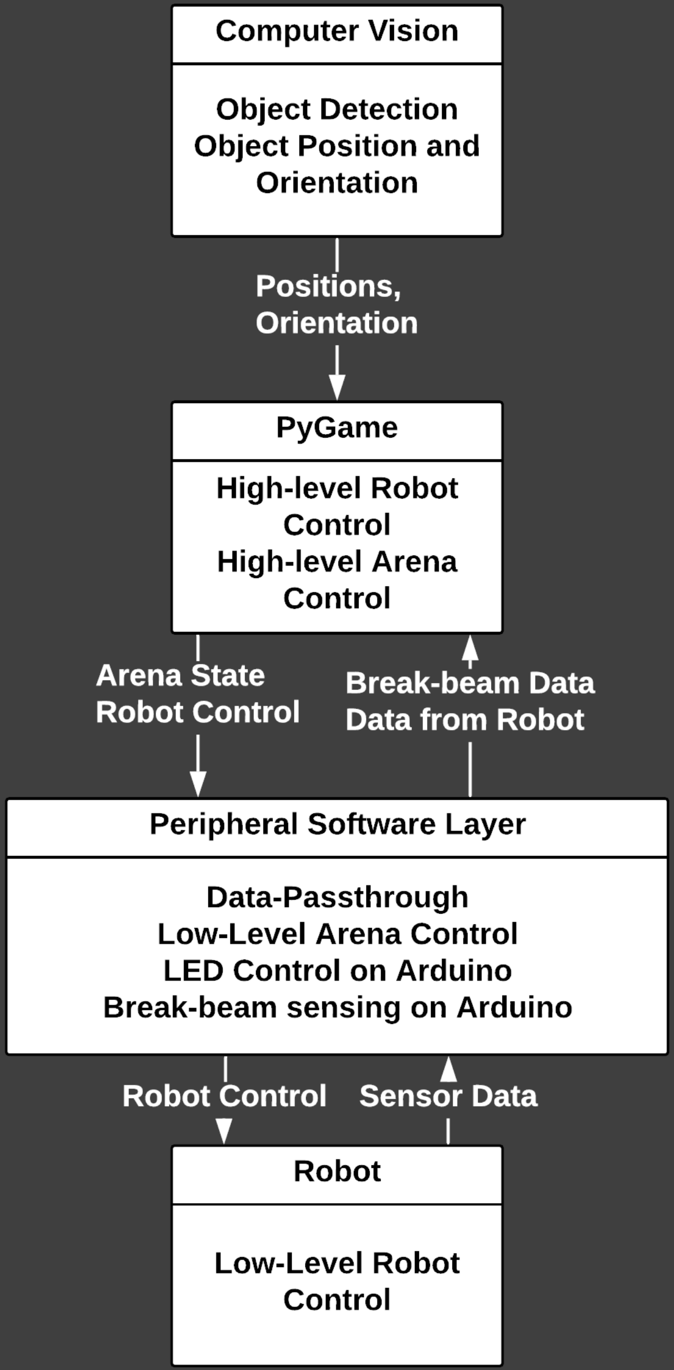
Arena - Electrical Design

- The Arena is AC Powered
- A 120V to 5V AC-DC converter is used to power the Nano
- Another 5V AC-DC converter is used to power the LEDs
- Nano does most of the processing for CV and Game System onboard
- The XBox Controller inputs are taken in serially via USB and sent to the Robot via Bluetooth
- The TV/Display is powered from an AC outlet as well



Arena Software Design

- Peripheral software sends and receive data from the game engine as well as control local I/O from the arena.
- LEDs are animated with Adafruit NeoPixel library
- LED animations are changed via state-change requests over serial port
- Break-beam data is sent as Boolean data over serial
- Bluetooth communication utilizes PyBluez library

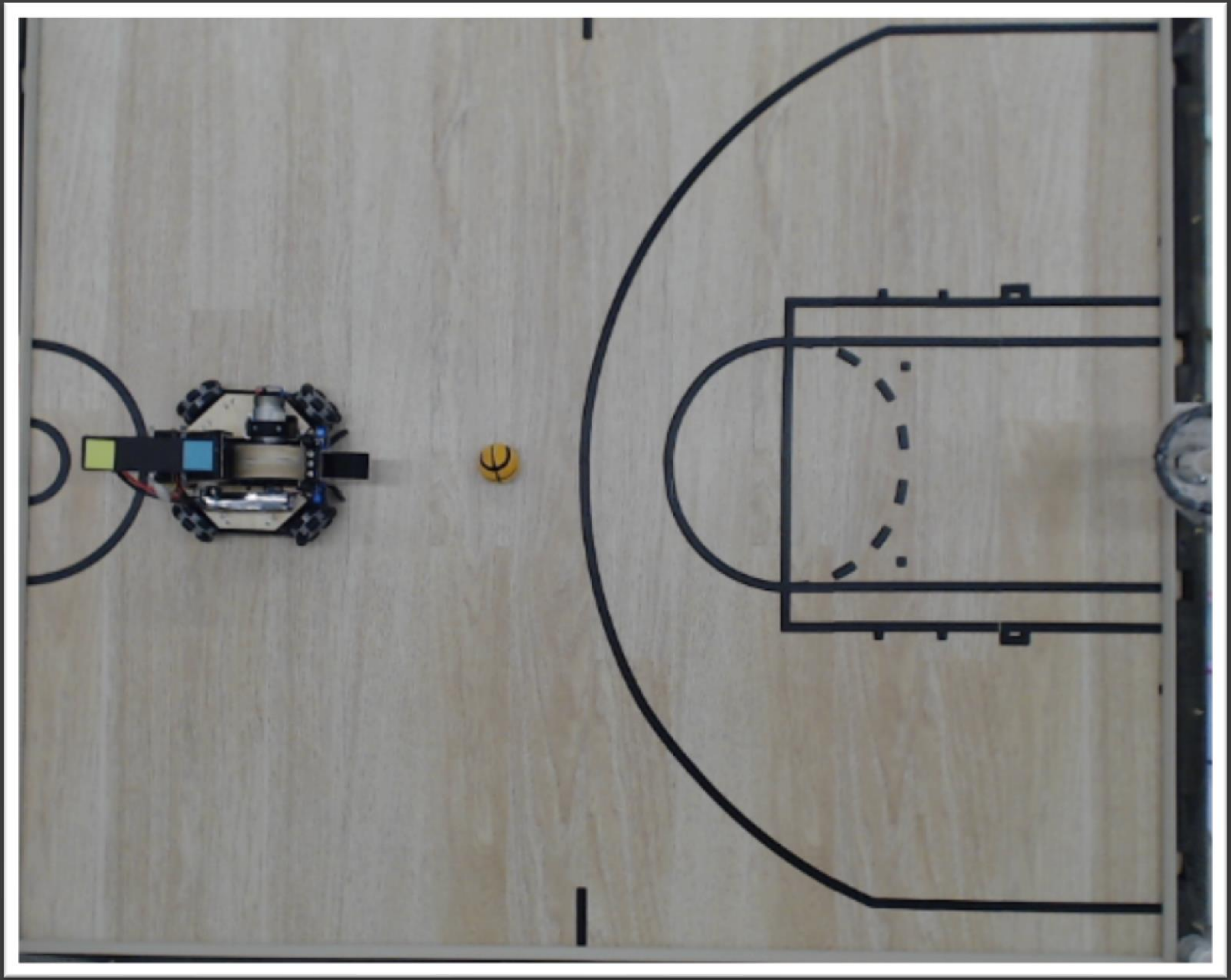


Arena Computer Vision System

- Position data is taken from markers mounted on the robot and the ball and then passed to the robot master control
- Data includes an orientation and location from the middle of the robot and location of the ball
- 2D image from single camera with a relatively high resolution of 720p, and 30 Frames per second
- Camera is mounted 5 feet high in order to see the entire field and objects on the field

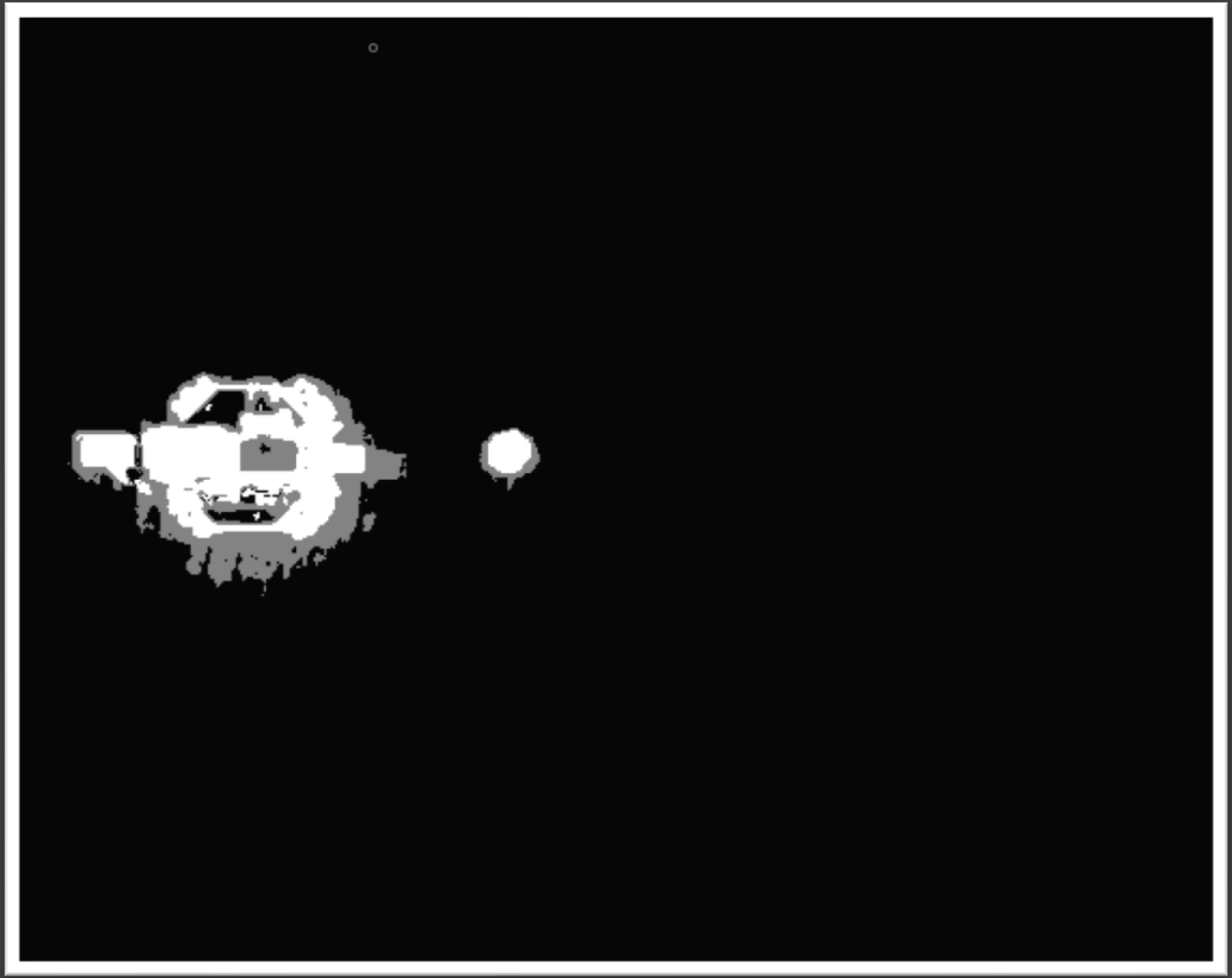
Step 1 – Collect the Frame

- Open Video Capture Device
- Set the FPS to 30 FPS
- Resize the frame
- Smooth with Gaussian Blur
- Add frame to the background subtraction object (Only for the first 30 frames to build the model)
- Building the model should be done with no objects on the court



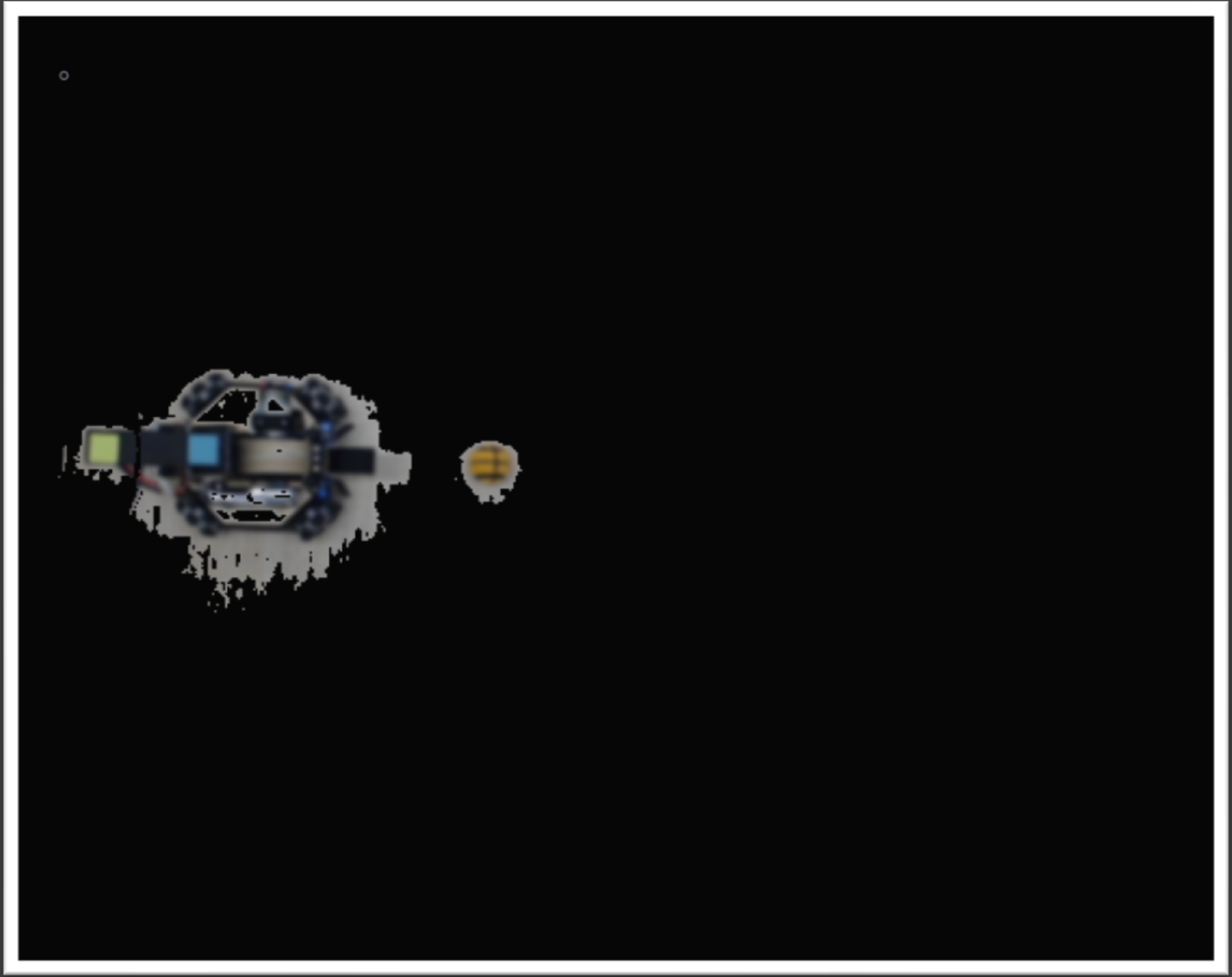
Step 2 – Foreground Mask

- Apply background subtraction to get a foreground mask



Step 3 – Background Mask 'AND' Frame

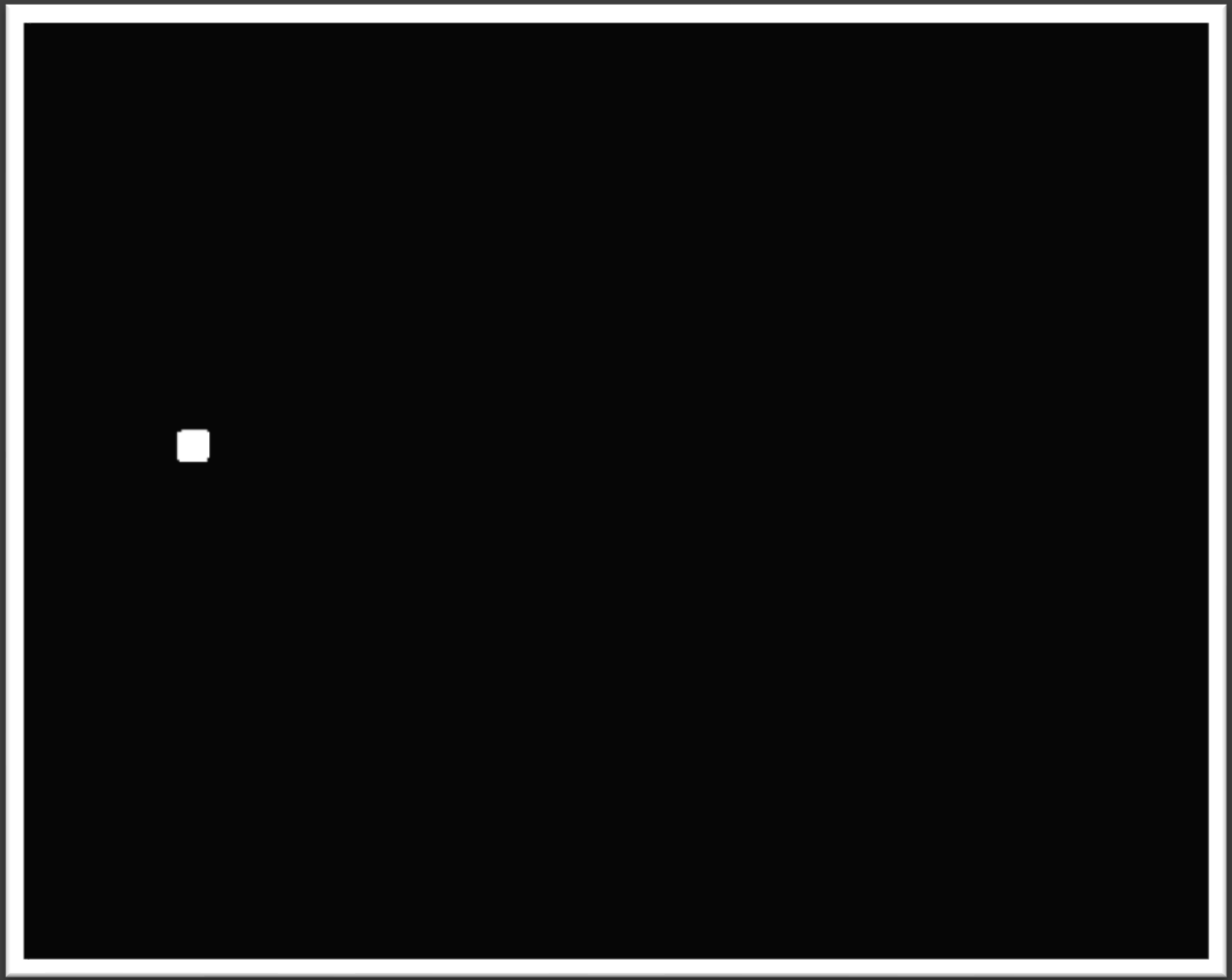
- Perform bitwise 'AND' on the blurred frame and foreground mask to get a color image from the results of background subtraction



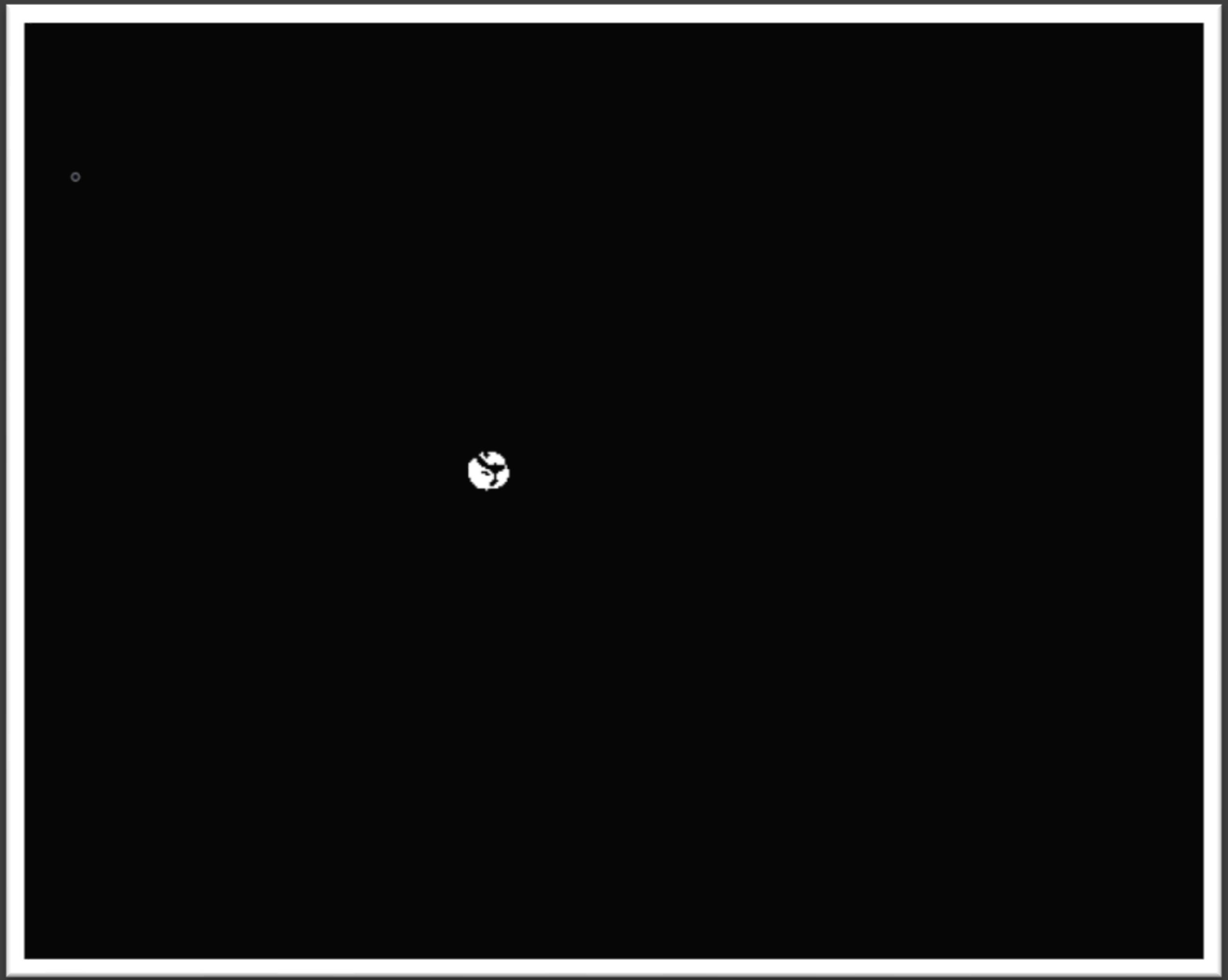
Step 4 – Color Filtering

- Lower and Upper bounds for each color are created using the HSV color scale
- An inRange() function is applied and a mask for each color is created

Colored Square

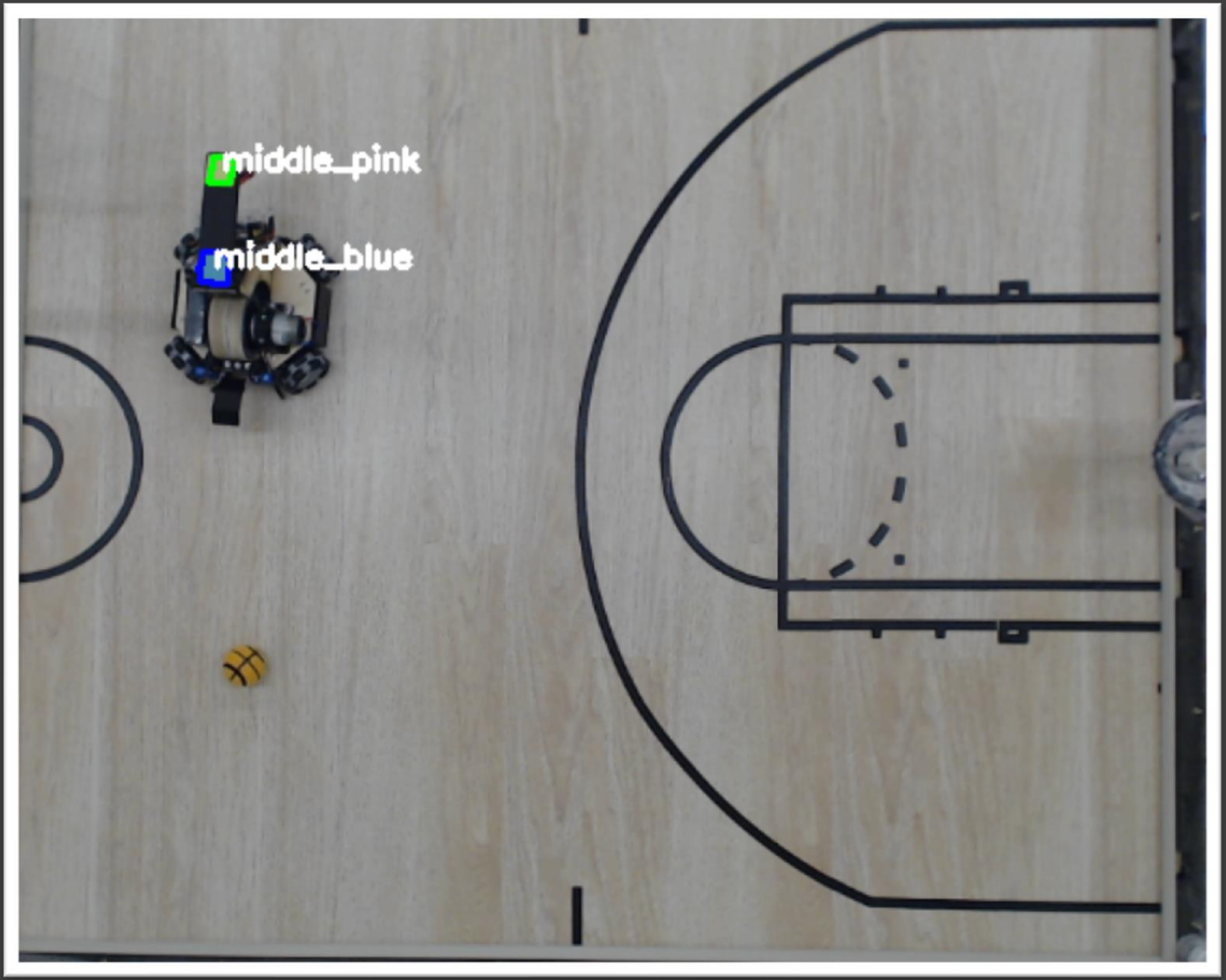


Orange Ball



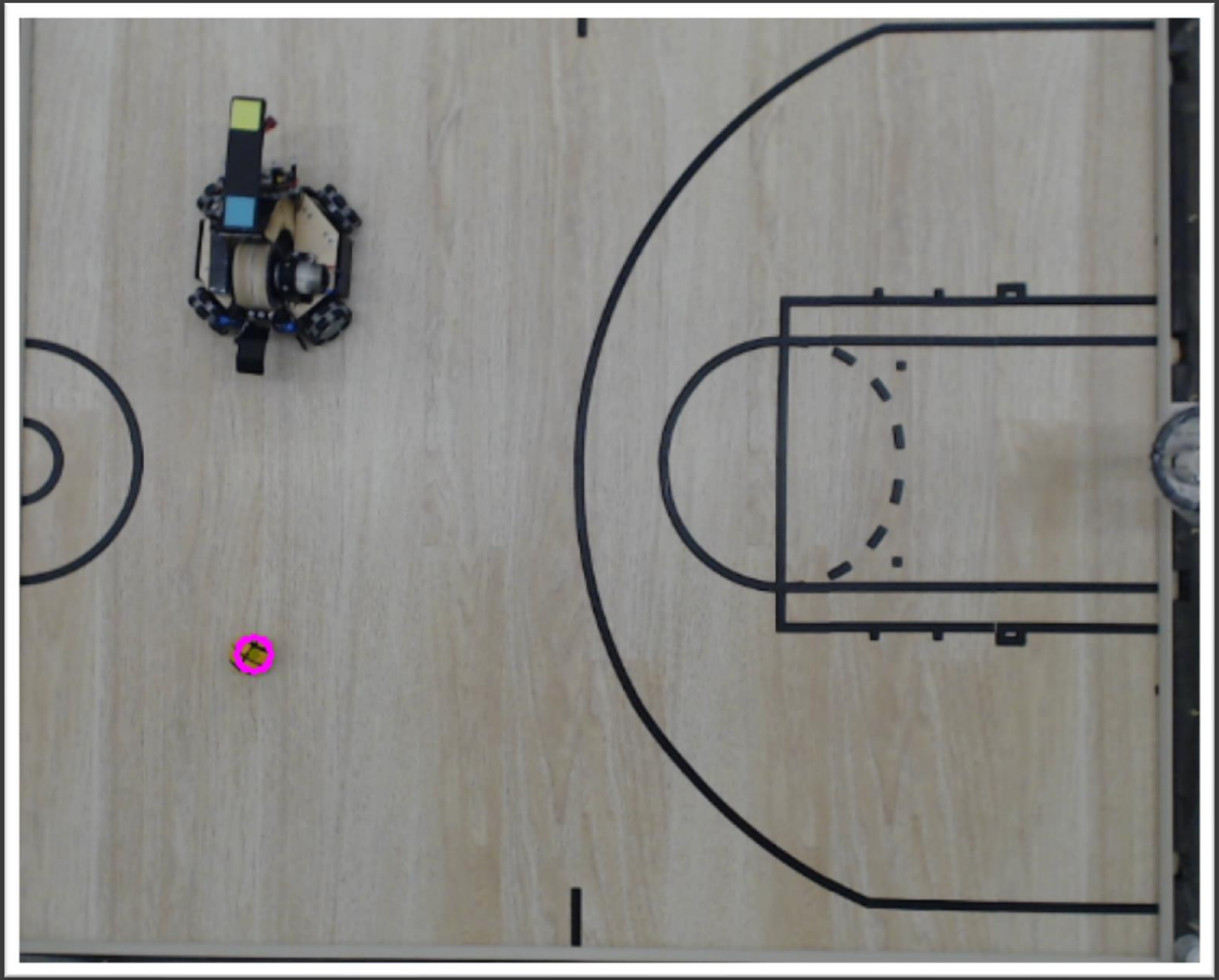
Step 5 – Contour Detection and Midpoint

- Find the contours of the squares
- Filter the list of contours by perimeter and number of sides
- Use moments to find the midpoint of each square



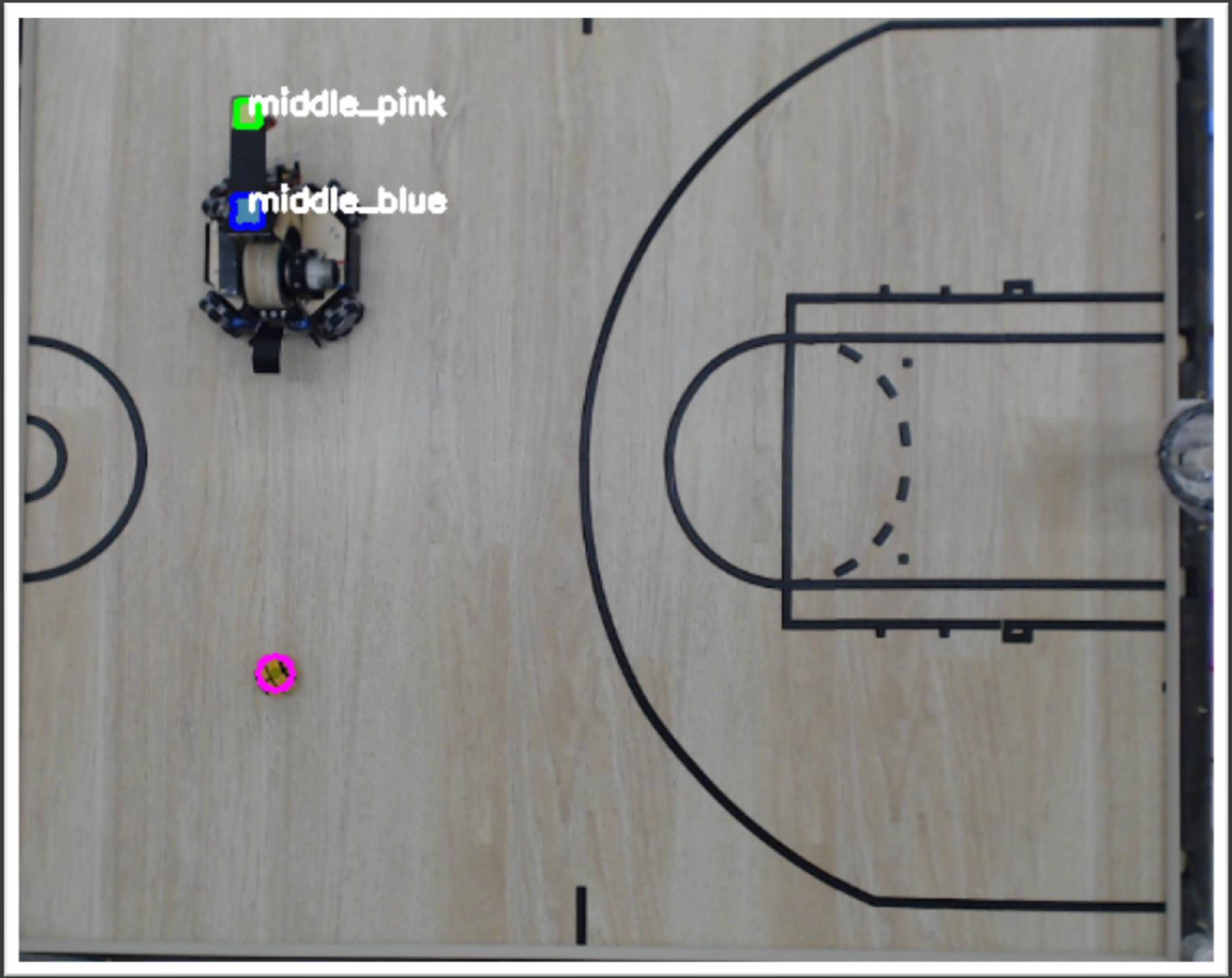
Step 6 – Canny Edge Detection & Hough Transform

- A Canny Edge filter is applied to the orange mask
- A Circle Hough Transform is applied, and the center is found



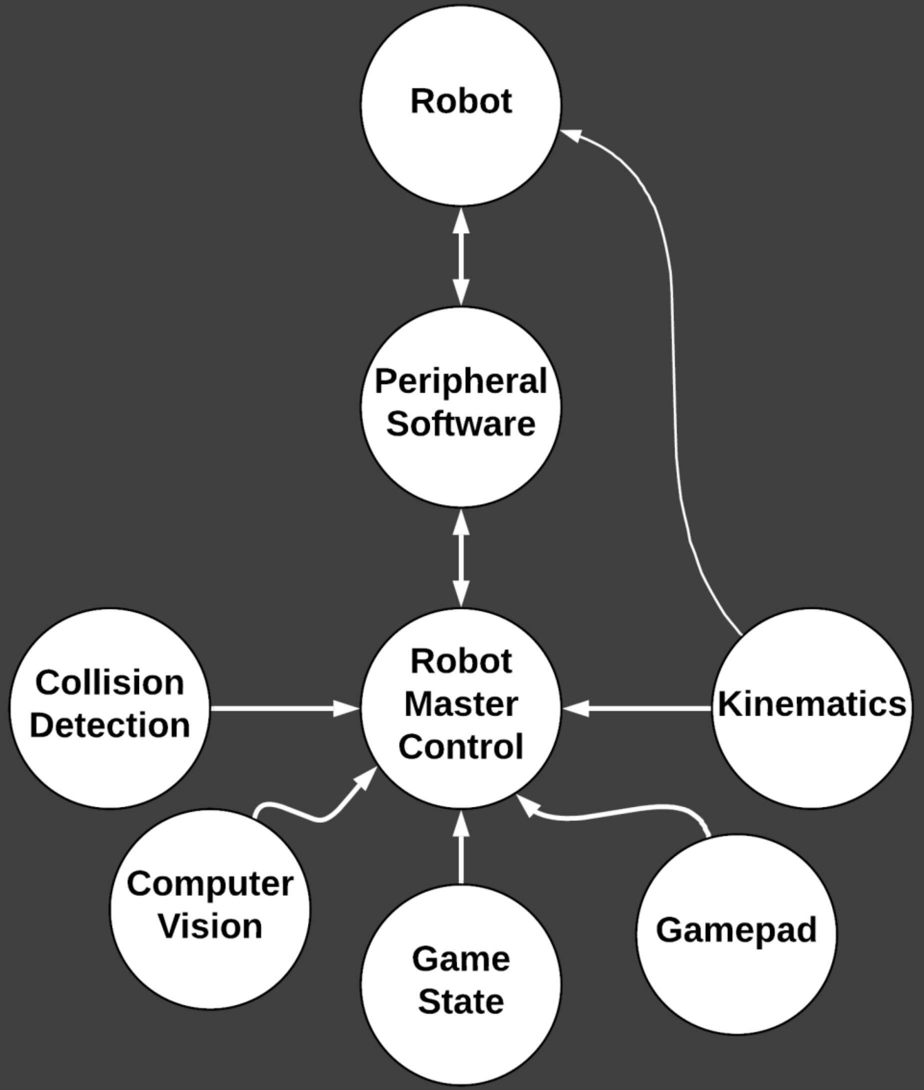
Final Output

- A unit vector is created using the x,y center values of each square
- The center of the robot is blue
- The unit vector, center point of the robot, and center point of the ball is sent to the game



Game Overview

- Game Engine
  - PyGame
- Collision Detection
  - Prevents robot from moving towards edges
- Video Playback
  - Data playback after shot is made
- Robot Control
  - Joystick input and positional data

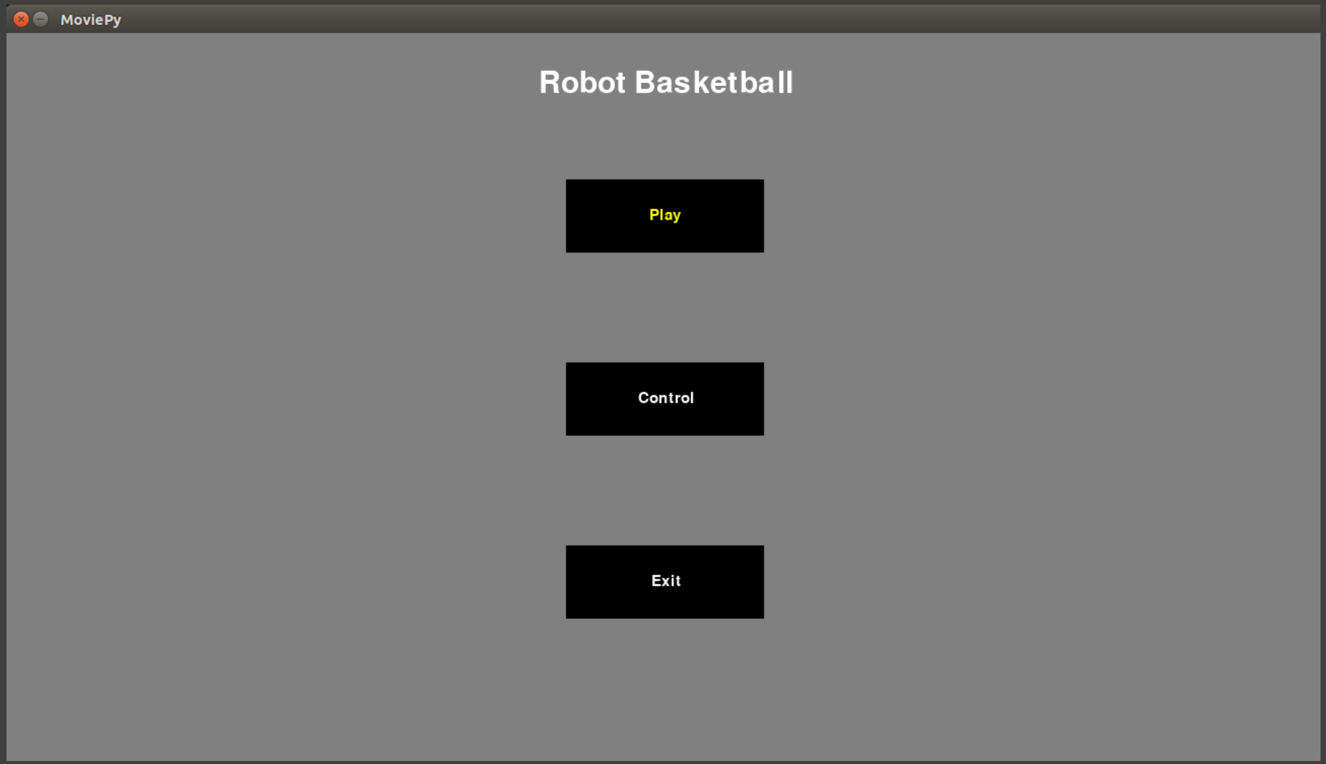


Component Selection – Game Engine

	Cost($)	Vendor	Language	Community Support	IPC	2D/3D	Editor Size
Godot	Free	Open Source	GDScript, C#,C++	Low	TCP/IP Socket, Shared Memory	Both	Very Small
Unreal	Free	Epic Games	C++	Medium	TCP/IP Socket, Shared Memory	Both	Large
Unity	Free	Unity Technologies	C#,C++	High	TCP/IP Socket, Shared Memory	Both	Very Large
PyGame	**Free**	**Open Source**	**Python**	**Medium-High**	**TCP/IP Socket, Shared Memory**	**2D**	**No editor**

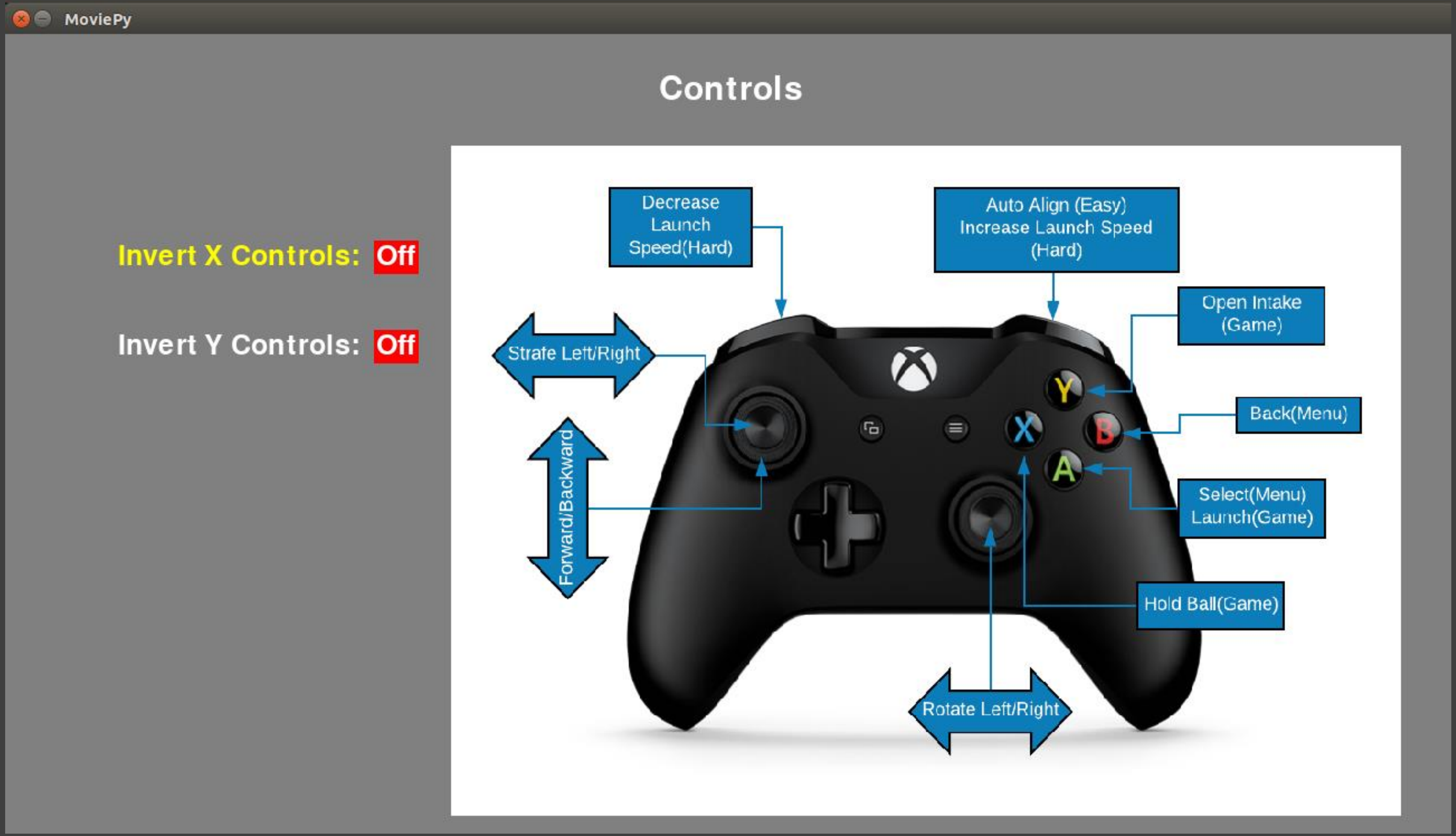
Main Menu

- Central Hub for game
- Leads to either the Control or the Difficulty Selection screen



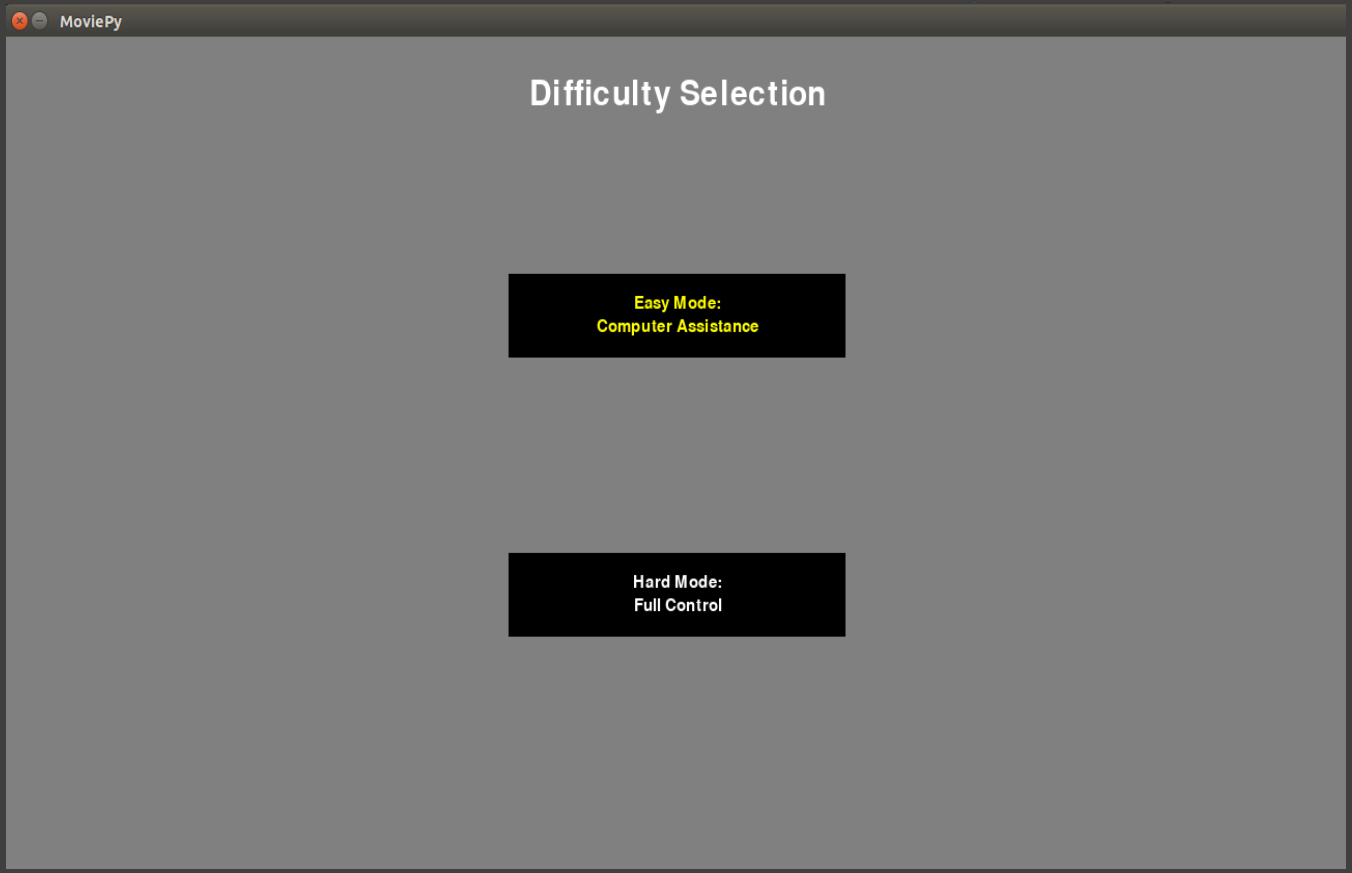
Controls

- Mapping of controls
- Allows for inversion of X and Y axis control



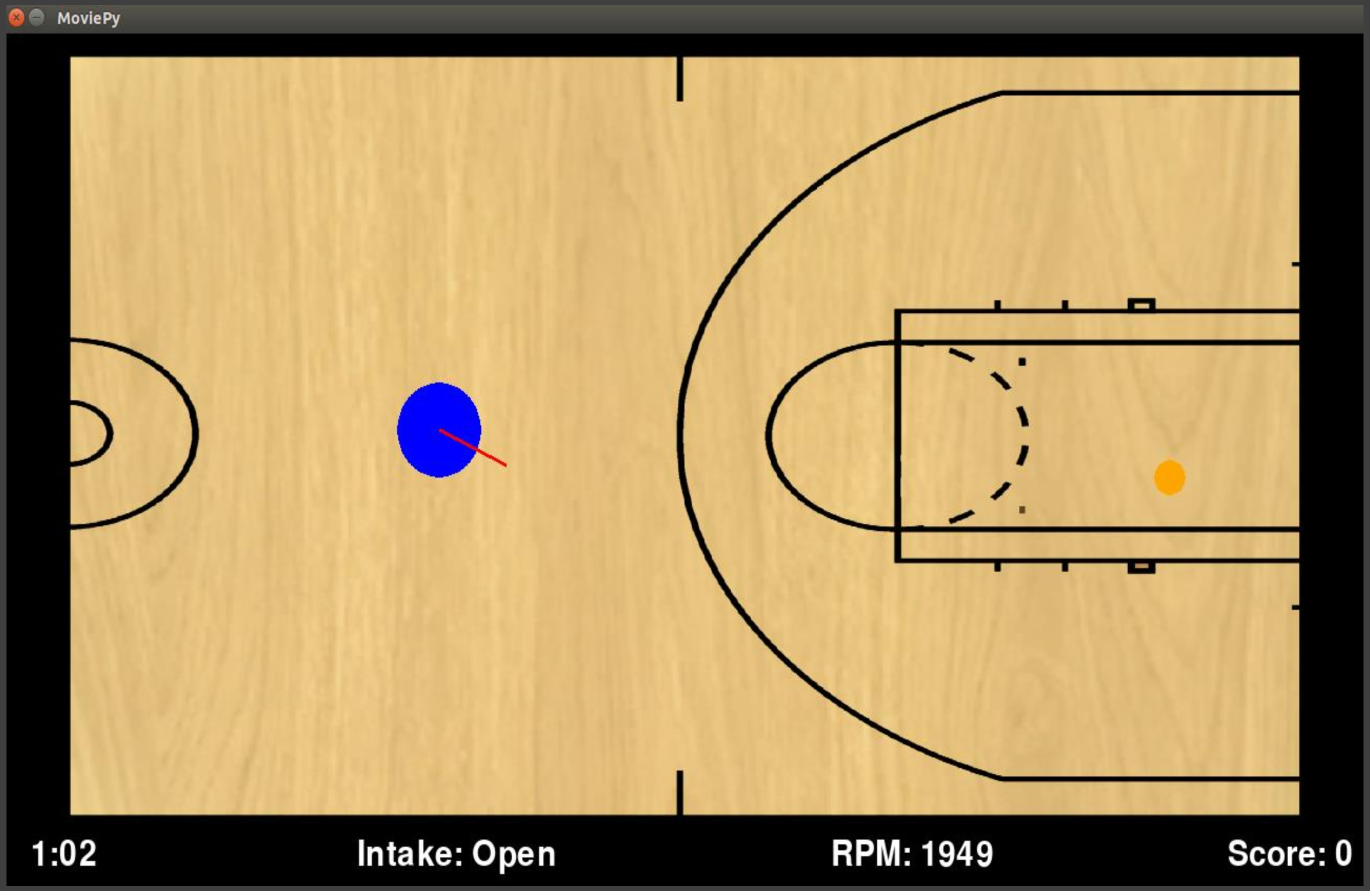
Difficulty Selection

- 2 modes
  - Easy
    - Computer assistance on aiming/shooting
  - Hard
    - Full manual control only



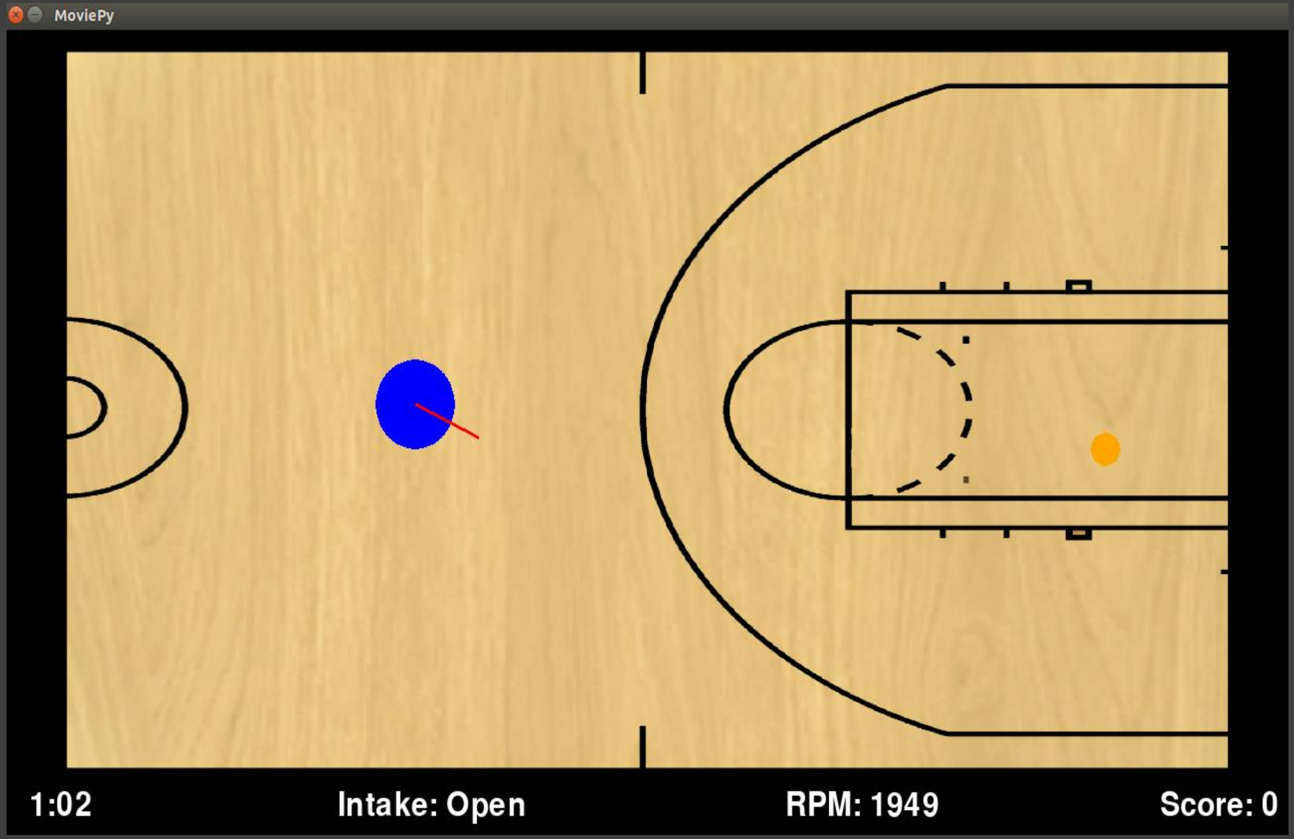
Autonomous Control in Easy Mode

- Alignment
  - Proportional Control minimizes angle to hoop
- Flywheel Speed
  - Linear Function
  - Positional Data from computer vision



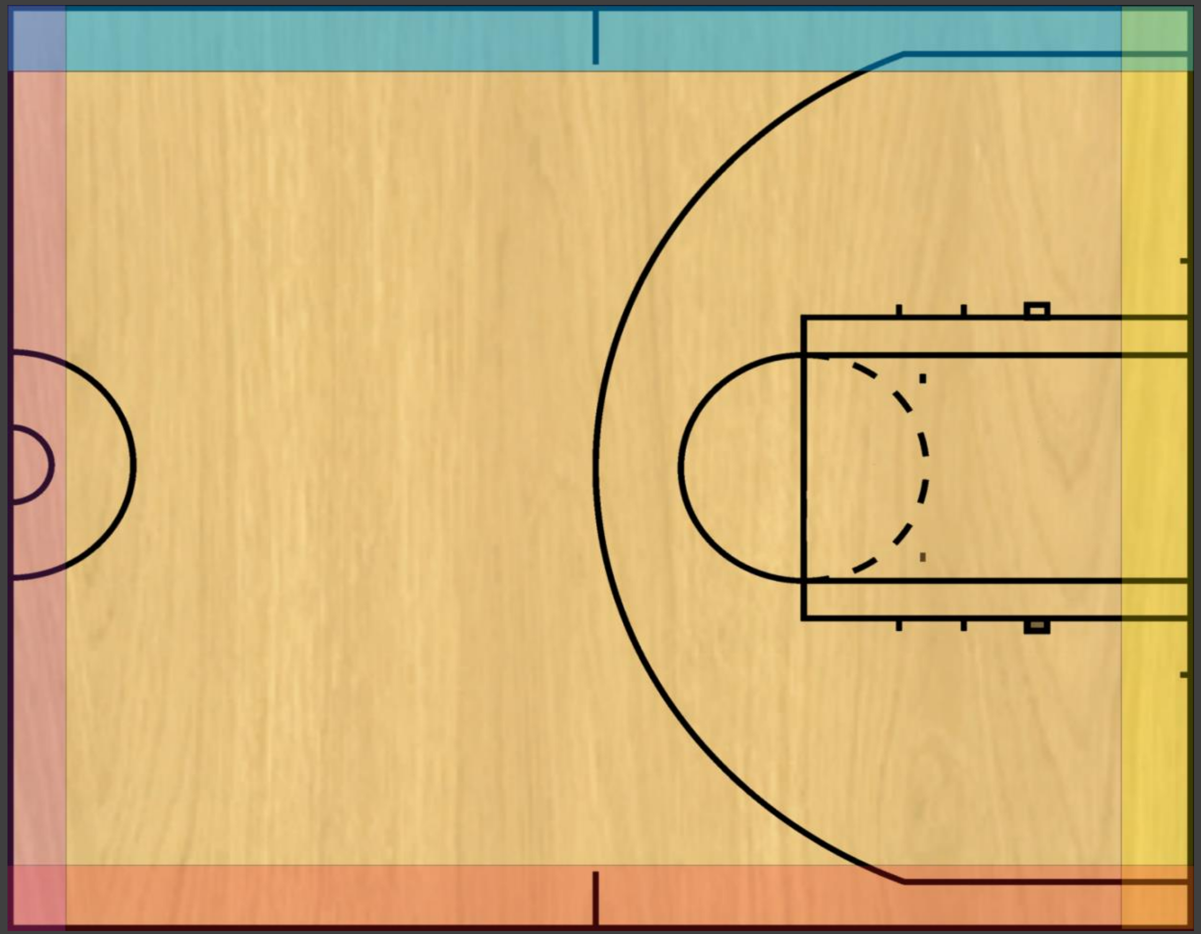
Playback

- The game will replay positional data for the robot and ball when a goal is made.



Collision Detection

- Prevents robot from being driven off arena
- Transform Robot Space to Task Space
  - Check if components would take robot off arena, if so, remove component from vector
  - Rotate new vector back to Robot frame



Critical Interfaces: Robot <-> Arena

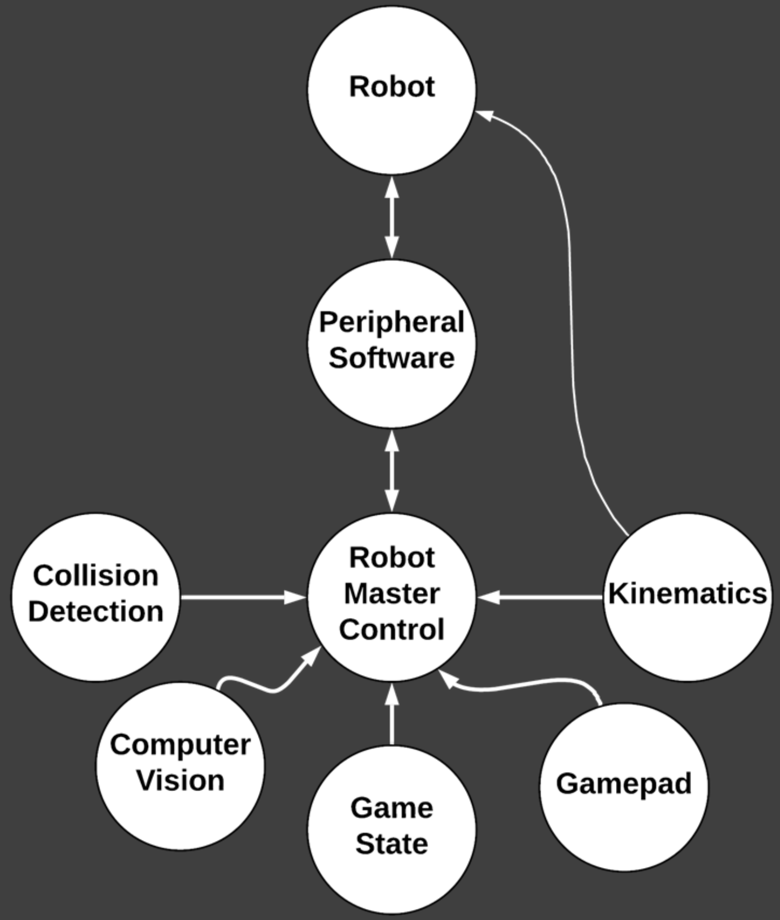
- Data transferred to and from both Robot and Arena over channel (Bluetooth)
- Critical interface due to the data being transferred needing a clearly defined type and meaning (For example, linear velocity sent from Arena to Robot is an integer corresponding to some velocity in m/s)
- Control data sent as 2 Hex characters (1 Byte of resulting Data)
- Data is interpreted as -100% to 100% of the Robot’s max joint speed / position
- Flow control is implemented to prevent buffer overflow

TO Robot PACKET (32 BYTES)

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Start (^)	Header (Packet #, Changes, State)						Sep(,)	Drive Vx		Sep(,)	Drive Vy		Sep(,)	Drive w		Sep(,)	Launcher Speed		Sep(,)	Intake Position		Sep(,)	Spare	Spare	Sep(,)	Spare		Sep(,)	Spare		End (\n)

Critical Interfaces: Arena <-> Game

- Uses serial and UDP socket connections
- 4 main systems integrating
  - Computer vision
  - NeoPixels
  - IR Break Beam
  - Game



Budget & Spending - Robot

Budget Item	Quantity	Budget ($)	Budget Subtotal ($)	Item	Supplier	Price ($)	Subtotal
Launching Hardware	1	$20.00	$20.00	Assorted	Various	$25.00	$25.00
Drive Hardware	1	$30.00	$30.00	Assorted	Various	$10.00	$10.00
Servo Bracket	4	$5.00	$20	Lynx-motion servo bracket	Robotshop	$3.48	$13.90
Wheels	4	$15.00	$60	Omni-Wheel	VEX	$5.00	$20
Intake Hardware	1	$20.00	$20.00	Assorted	Various	$10.00	$10.00
Intake Motor	1	$15.00	$15.00	Servo	Parallax	$3.00	$3.00
Drive Motor	4	$20.00	$80.00	High speed Servo	Parallax	$27.00	$108.00
Launch Motor	1	$20.00	$20.00	3600 RPM DC Motor	Skycraft	$7.00	$7.00
Controller	1	$20.00	$20.00	ATMEGA328P-AU	Microchip	$2.00	$2.00
Battery	1	$30.00	$30.00	1300 mAh 3S LiPo	Amazon	$27.00	$27.00
PCB	1	$40.00	$40.00	Assorted	Various	$38.82	$38.82
Bluetooth Module	1	$10.00	$10.00		Sparkfun	$16.00	$16.00
Total per Robot			**$345.00**				**$280.72**

Budget & Spending - Arena

Budget Item	Quantity	Budget ($)	Budget Subtotal ($)	Item	Supplier	Price ($)	Subtotal
Frame Hardware	1	$ 100.00	$ 100.00	PVC Tube, Wood, Screws, PVC Fittings	Home Depot	$125.00	$125.00
Camera	1	$ 60.00	$ 60.00	Logitech C920	Amazon	$63.50	$63.50
Controller	1	$ 100.00	$ 100.00	Jetson Nano	NVIDIA	$100.00	$100.00
Power Supply (AC-DC)	1	$ 40.00	$ 40.00	Power Strip, 5A Power Supply, LED Driver	Amazon	$11+$11+$20	$42.00
Bluetooth Module	1	$ 10.00	$ 10.00	Intel Dual Band Wireless-Ac w/ BT	Amazon	$23.00	$23.00
Court Hardware	1	$ 25.00	$ 25.00	Flooring	Home Depot	$16.00	$16.00
LEDs	1	$ 25.00	$ 25.00	Neopixels	Adafruit	$32.00	$32.00
Gamepad	1	$ 25.00	$ 25.00	Xbox Controller	Amazon	$25.00	$25.00
TV Display	1	$ 70.00	$ 70.00	720p 19in Display	Amazon	$70.00	$70.00
Total			**$ 455.00**				**$496.50**

Work Distribution

	Primary	Secondary
Robot Mechanical	Brandon	Mat
Robot Electrical	Suvrat	Brandon
Robot Software	Brandon	Mat
Arena Mechanical	Cory	Mat
Arena Electrical	Suvrat	Cory
Arena Peripheral Software	Brandon	Suvrat
Computer Vision	Cory	Mat
Game	Mat	Brandon

Thank you

- Questions?