UCF

UNIVERSITY OF CENTRAL FLORIDA

Robot Basketball

Group 9 - Summer/Fall 2019

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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 capable of full-court shots & high accuracy

Realistic Design Constraints

- Economic: Budget, scalability
- Health and Safety: Flying projectiles & mechanical components
- Manufacturability: Hardware component fabrication
- Sustainability: Easy to repair, and easy to add additional components

Requirement Specifications - Robot

Requirement
Weigh no more than 8 lbs.
Be capable of holonomic locomotion at a maximum speed of at least 1 ft/s
Support an embedded controller capable of processing controls for a minimum 6 motors
Communicate with the arena at a rate of at least 30Hz
Contain a launching mechanism capable of launching a 2.0" diameter rubber ball
Contain an intake mechanism for acquiring a 2.0" diameter rubber ball from ground level
Maintain at least 70% shot accuracy from anywhere on the court

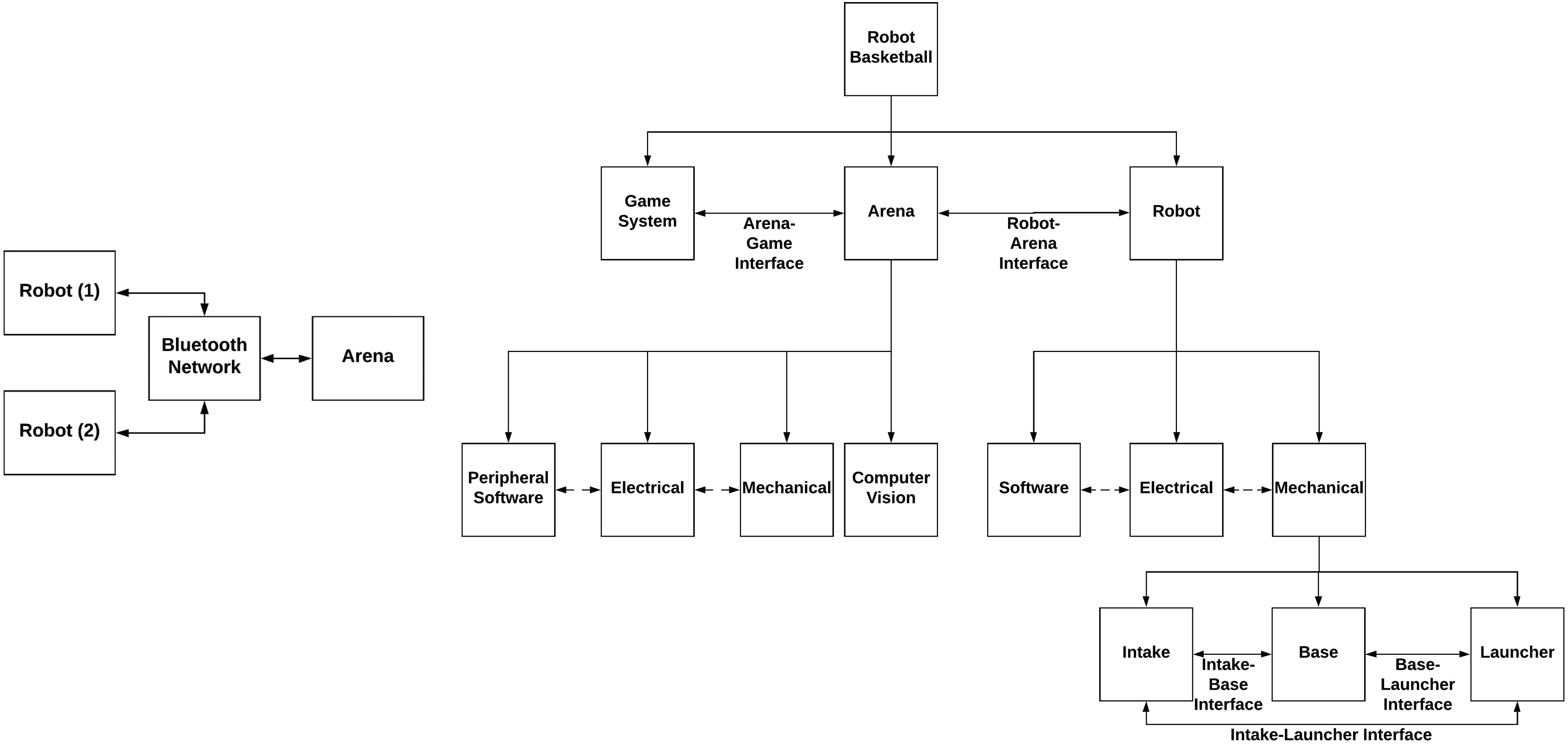
Requirement Specifications – Arena

Requirement
Be no larger than 6’ length, 5’ width, and 5’ height
Weigh no more than 75 lbs. total
Contain at least 1 rubber ball that is no smaller than 2.0” diameter
Contain at least 1 basketball hoop no smaller than 3.0” diameter
Contain a surface that is level within 1°
Support an Embedded Controller capable of running an Operating System
Support vision-based position tracking of the ball and robots in the court with update rate of at least 30 Hz

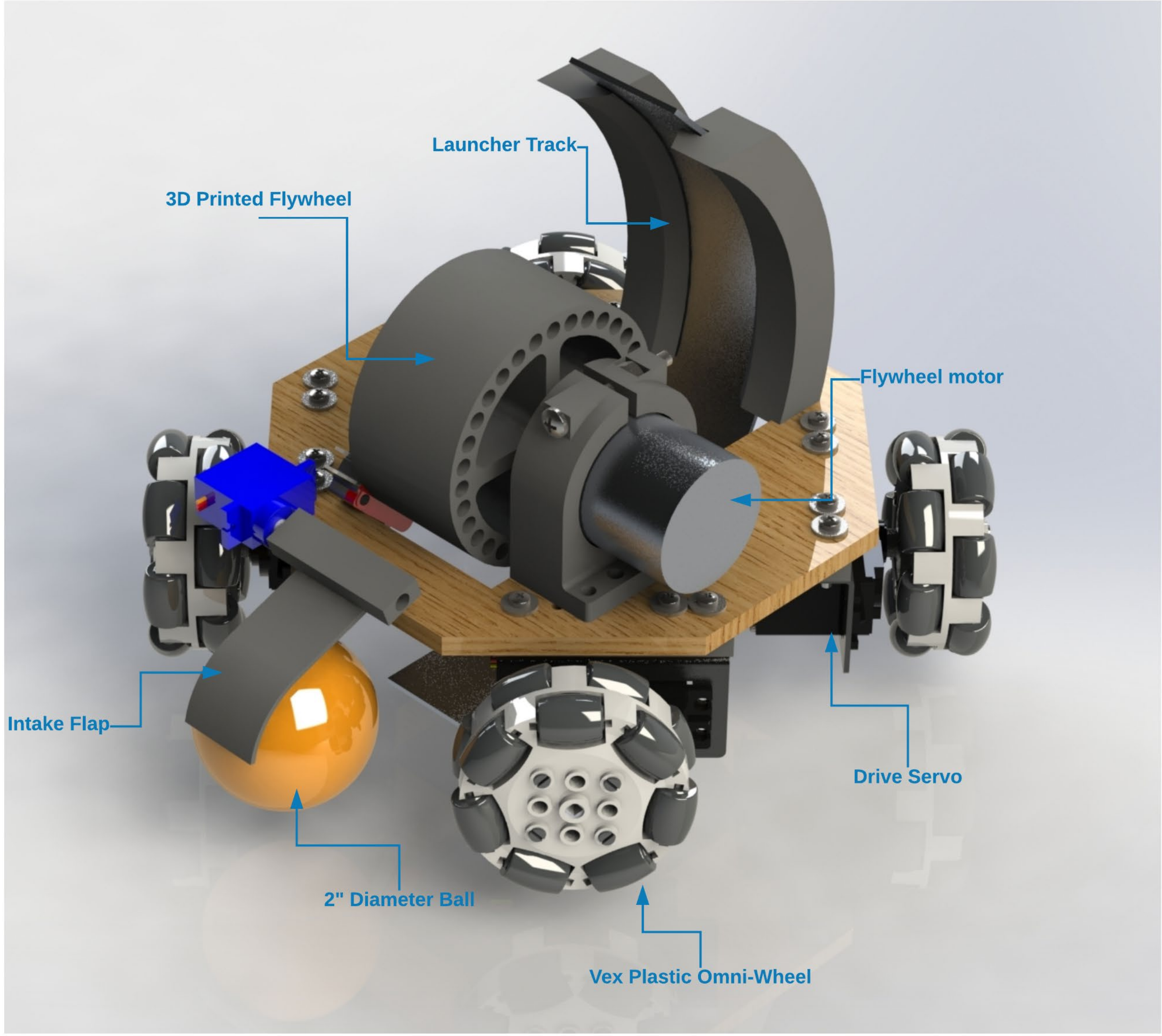
Requirement Specifications - Game

Requirement
Create a 2D visual representation of the Arena and Robot Status
Have a menu to start, pause, and reset a timed match
Display current score and game time
Playback past 10 seconds of gameplay upon a goal
Perform collision detection between the different objects

System Architecture Design

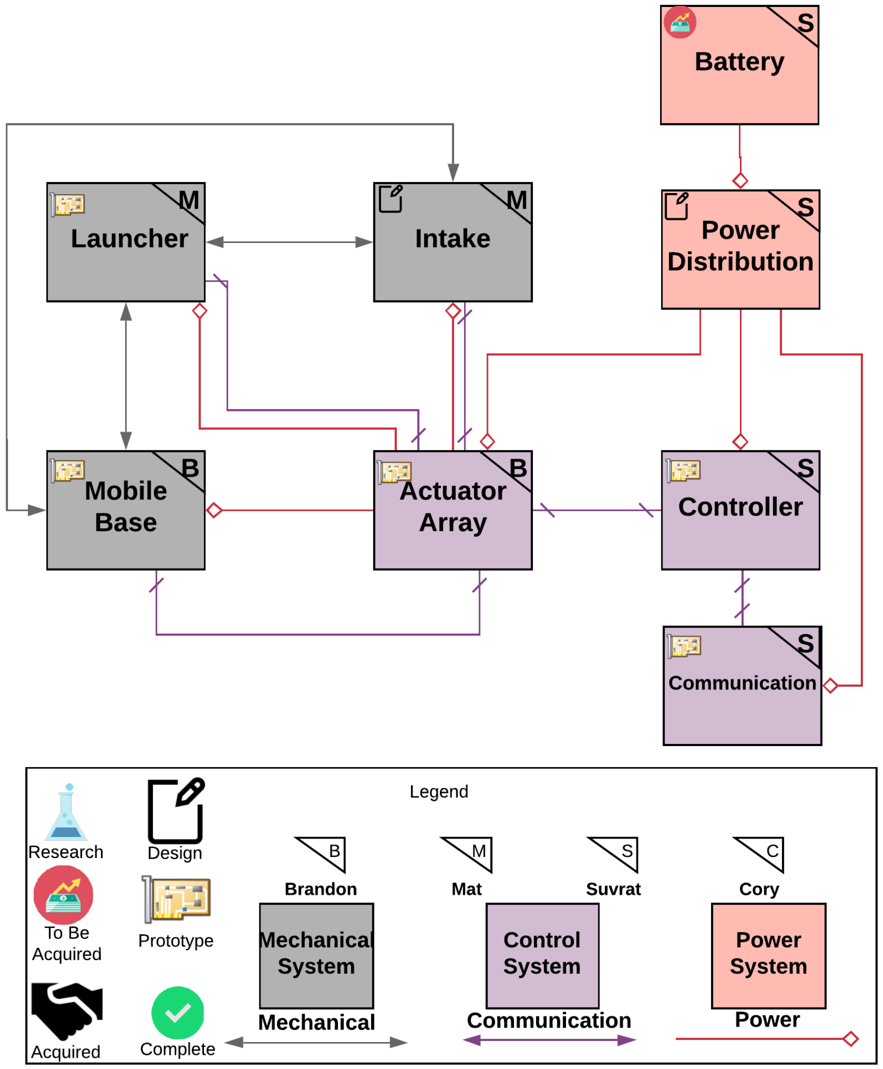


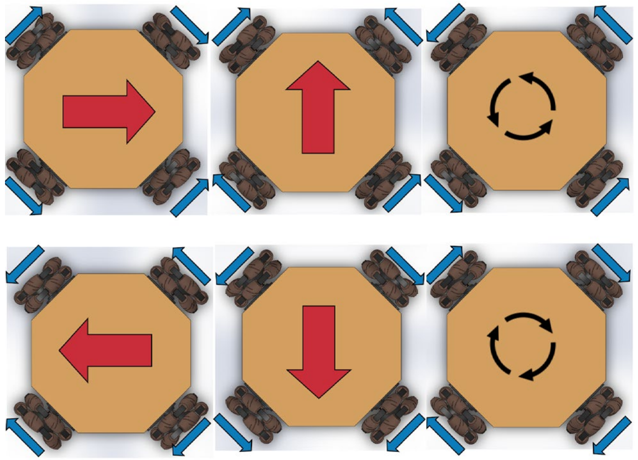
Robot

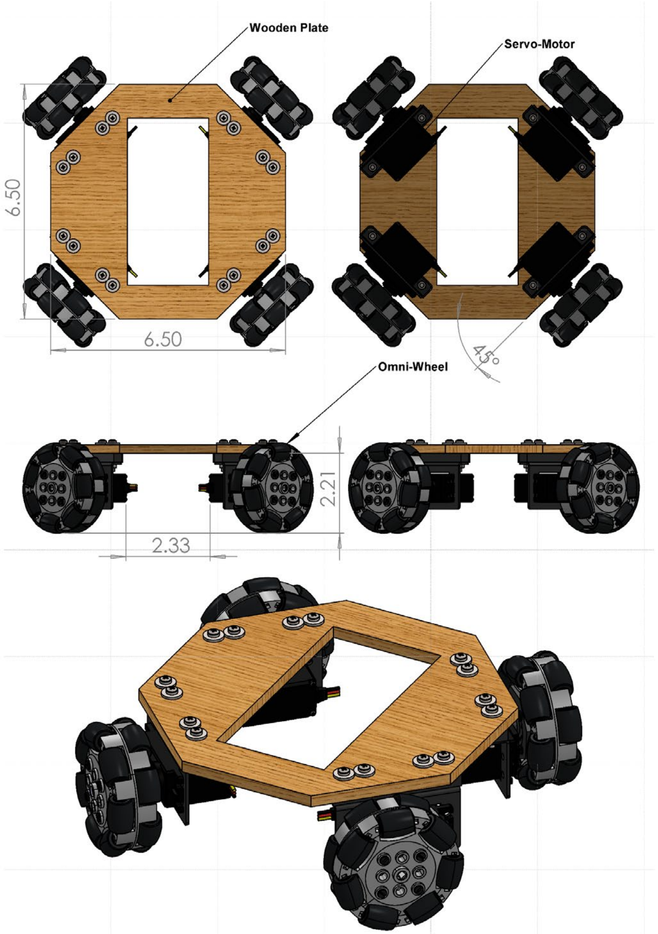

Launcher Track
3D Printed Flywheel
Flywheel motor
Intake Flap
Drive Servo
2" Diameter Ball
Vex Plastic Omni-Wheel

Robot Block Diagram

- Battery
  - Single power source for all robot systems
- Power Distribution
  - Includes convertors / Regulators to support loads
- Controller
  - MCU to process sensor data and control loads
- Communication
  - Transmit data to/from the Arena
- Actuator Array
  - Motor controller rail to support up to 6 DC motors/Servos
- Intake
  - Mechanism to capture and hold the ball when not launching
- Launcher
  - Launches the ball as a projectile toward a hoop
- Mobile Base
  - Locomotion platform for traversing the court





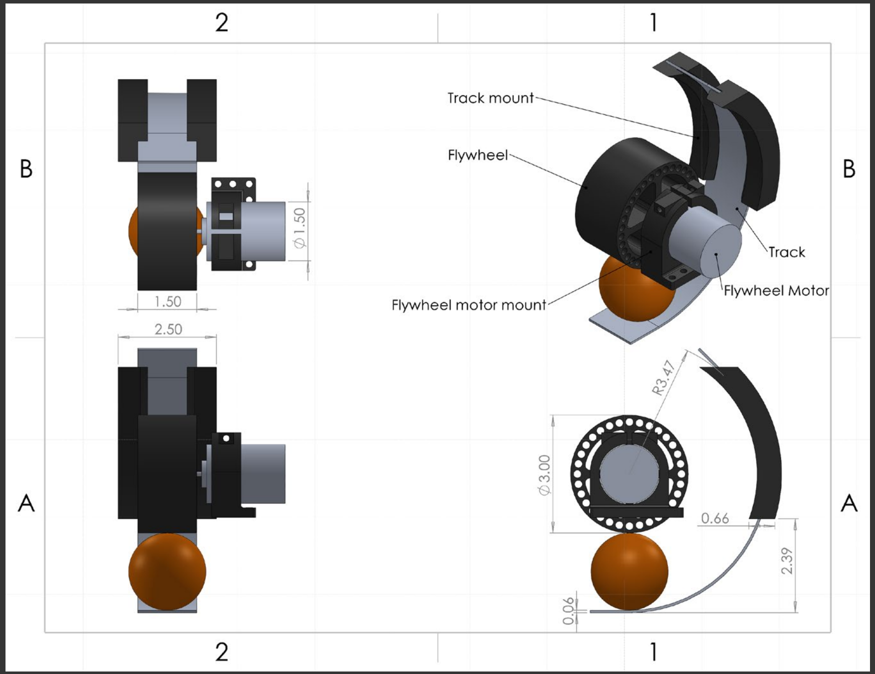


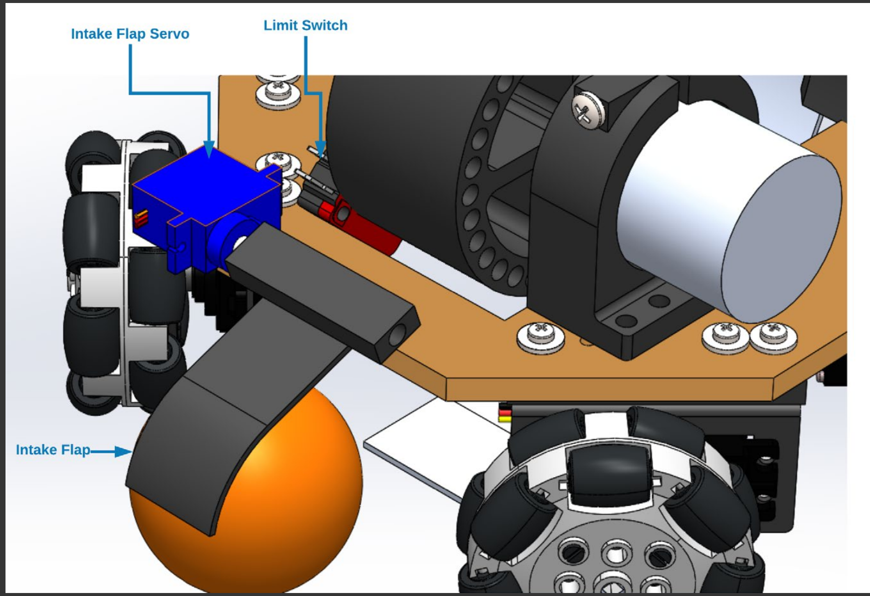
Mobile Base Design

- 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 (V)	Operational Current (mA)	Power (W) (Peak)	Cost ($)
Base	**Drive Motors**	Servos (4)	Parallax	6.5	1000	26	112
Launcher	**Flywheel**	DC Motor (1)	Johnson Electric	12.0	3000	36	6.00
Launcher	Rotatory Encoder	TLE4946-2K (1)	Infineon	5.0	50	0.25	0.74
Intake	Flippers	Servos (2)	Parallax	6.5	1000	13	26
Communication	**Bluetooth**	RN-42 (1)	Roving Networks	3.3	30	0.1	15.73
Electrical	**Microcontroller**	ATmega328p (1)	Microchip Technologies	5.0	200	1	1.46
Electrical	**Motor Driver**	DRV8871 (1)	Texas Instruments	12.0	10	0.12	2.13
Electrical	PWM Driver	PCA9685 (1)	NXP	5.0	400	2	2.33
Power	Battery	3S LiPo	Turingy	12.6	5000	63	27.00
Power	DC – DC converter	TPS56637RPAR	Texas Instrument	6.5	6000	39	1.10
Power	5V Regulator	R-78E5.0-1.0 (1)	Recom	11 - 12	1000	12 (max)	3.26
Power	3.3V Regulator	R-78E3.3-1.0 (1)	Recom	11 - 12	1000	12 (max)	3.26
Total						**~204**	**$201.01**

Component Selection - Microcontroller

- Microcontroller needs to be able to support various chip drivers such as motor driver, PWM driver
- 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 ($)	1.46	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 (Eliminates complexity in PCB)

Actuator	Cost ($)	Manufacturer/Distributor	RPM	Torque (Kg-cm)	Voltage, Current (V), (A)	Power (W)	Control	Feedback
Heneng DC Motor	15	Amazon	100	2	9, 1.2	10.8W	External MC	2 CPR Quadrature Encoder
Feedback 360 High Speed Continuous Rotation Servo	28	Parallax	140	2.5	6, 1.2	7.2 W	PWM	2 CPR Hall Effect (Absolute Encoder with PWM Output)
High Speed Continuous Rotation Servo	17	Parallax	180	2.2	7.4, 0.6	4.44W	PWM	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

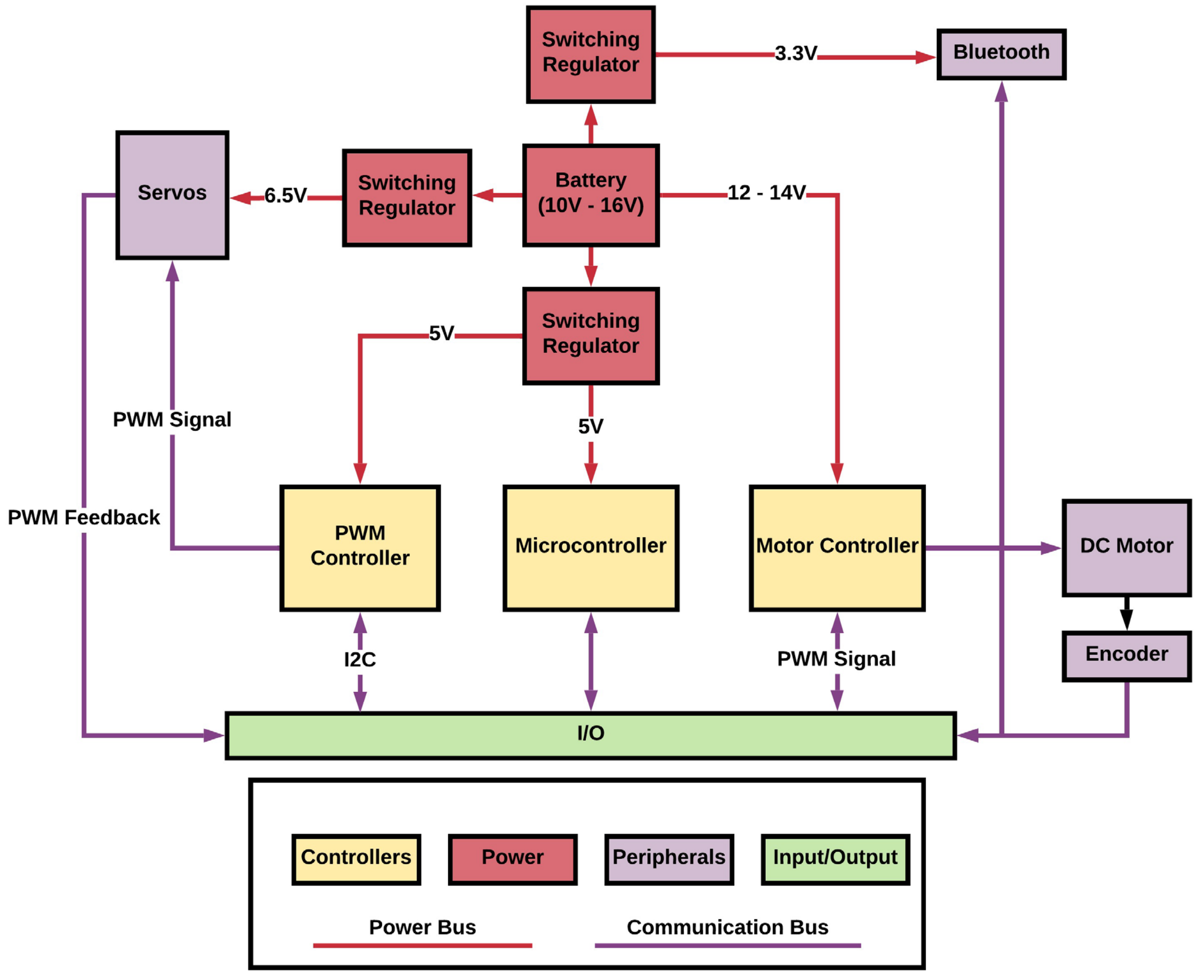
Driver IC	L293D	L298	DRV8871
Supply Voltage (V)	5 - 36	6.5 - 45	6.5 - 45
Output Current (A)	0.6	4	3.6
Number of Channels	2	2	1
Footprint (mm^2)	12.6 x 7.4	15.8 x 10.9	4.90 × 6.00
Cost($)	2.95	4.86	2.13

Component Selection - Communication

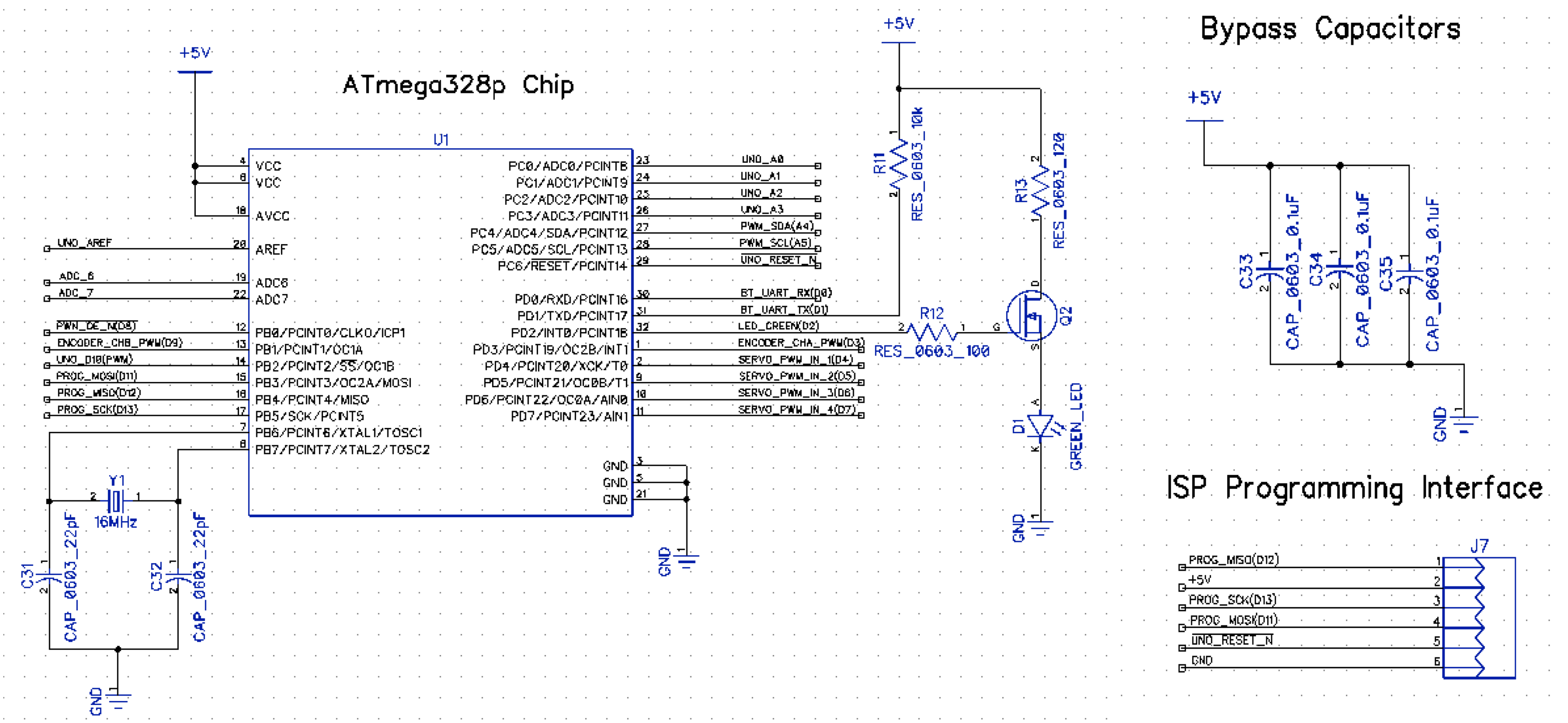
- The Communication device must be wireless
- The Communication device must be compatible with the Robot's MCU and Arena's computer
- The Communication device must be low energy

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	~18

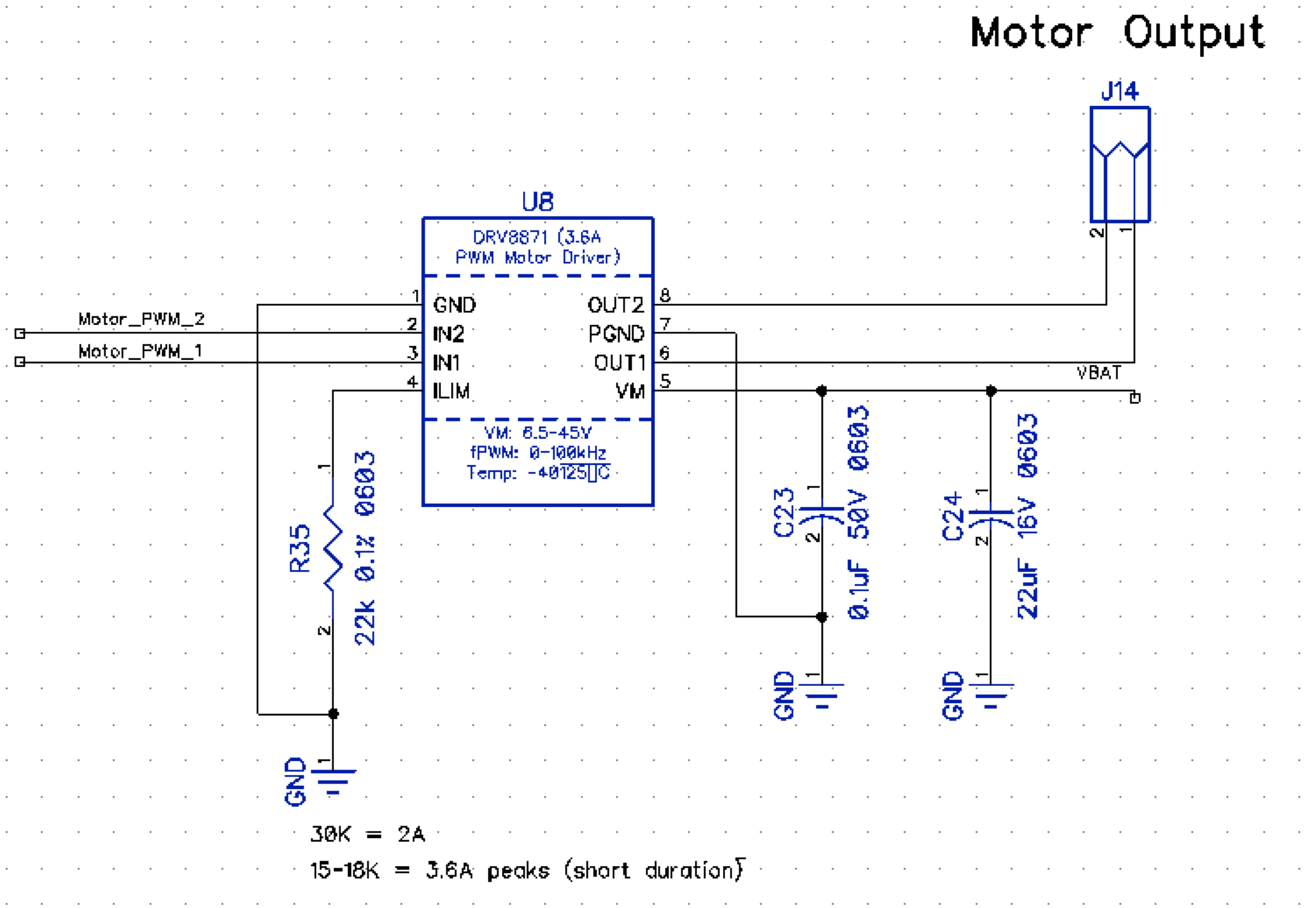
Robot PCB Overview



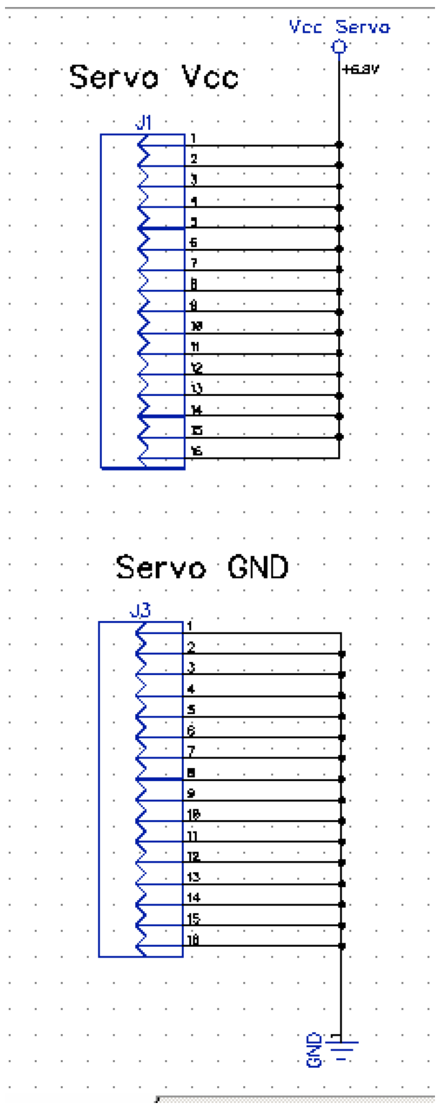
Robot Schematic: Microcontroller

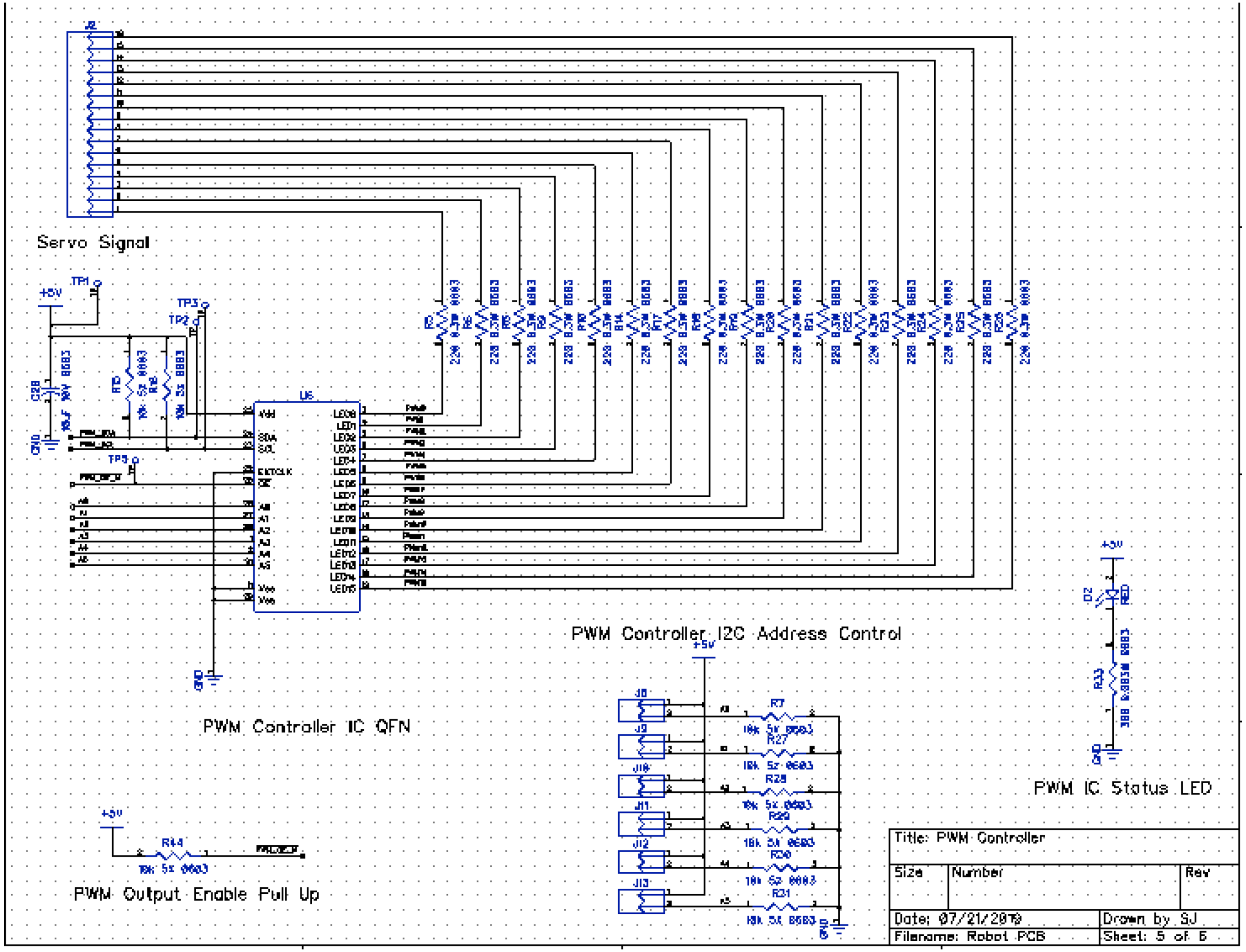


Robot Schematic: Motor Controller

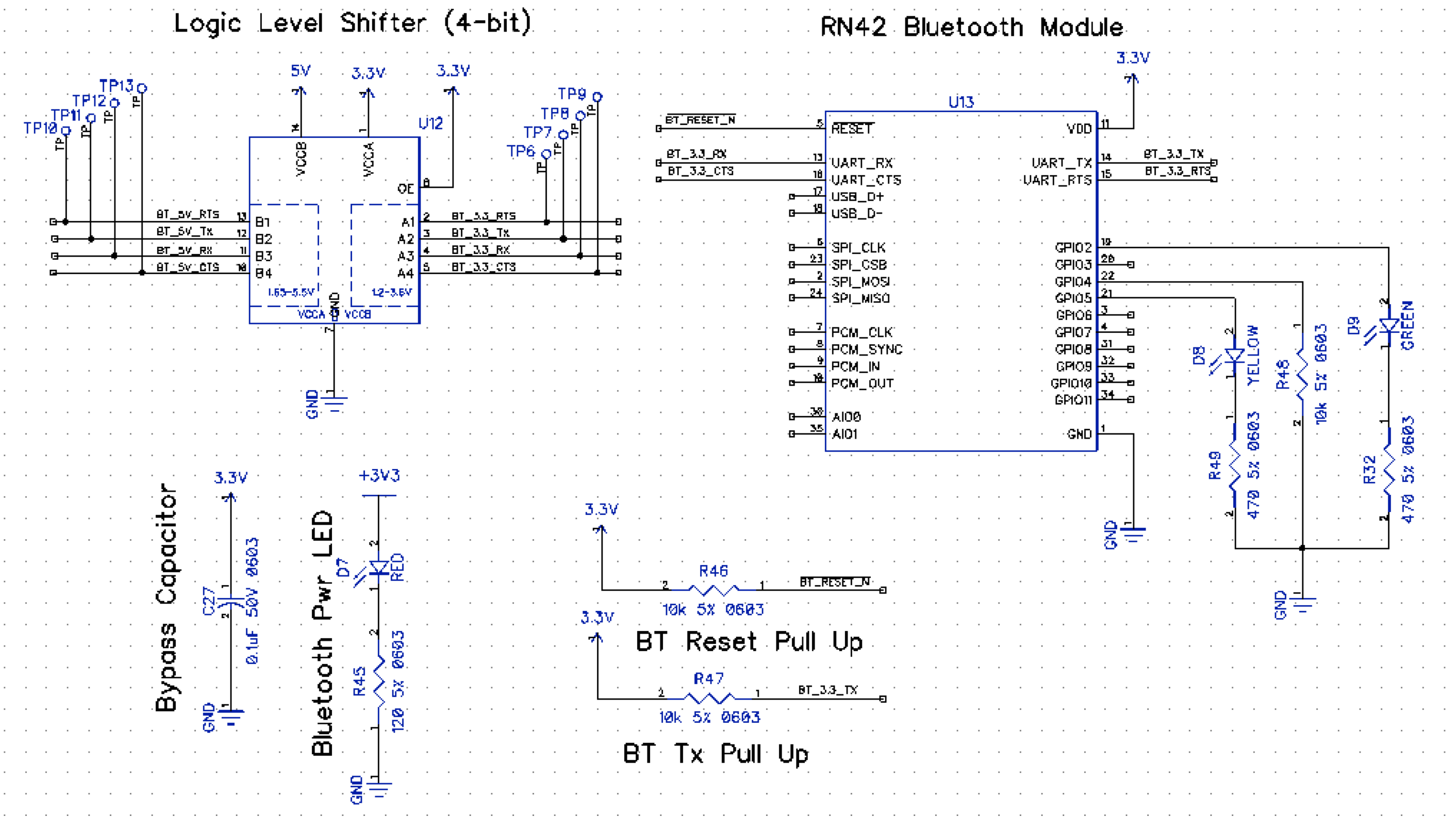


Robot Schematic: PWM Controller

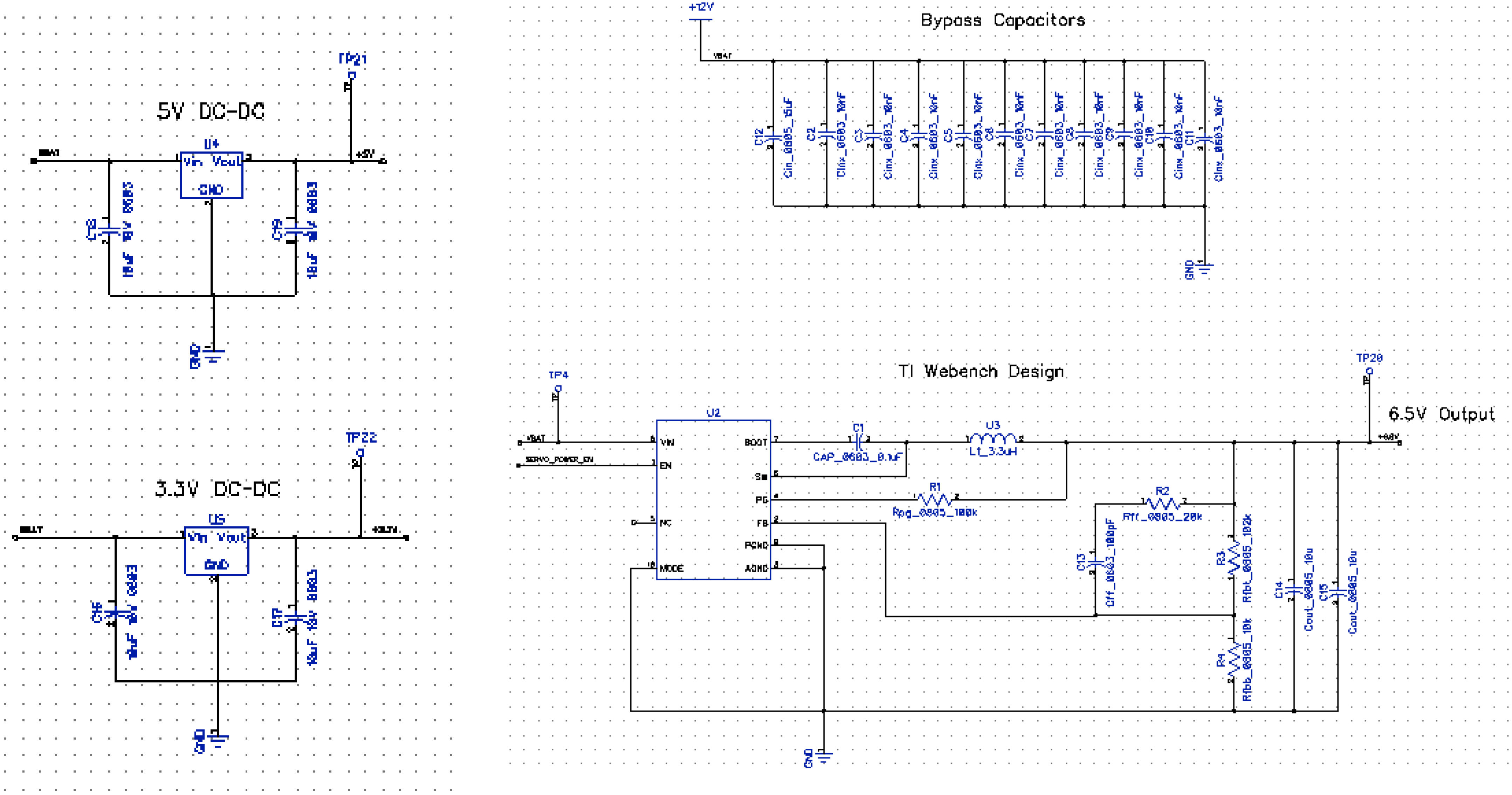




Robot Schematic: Bluetooth

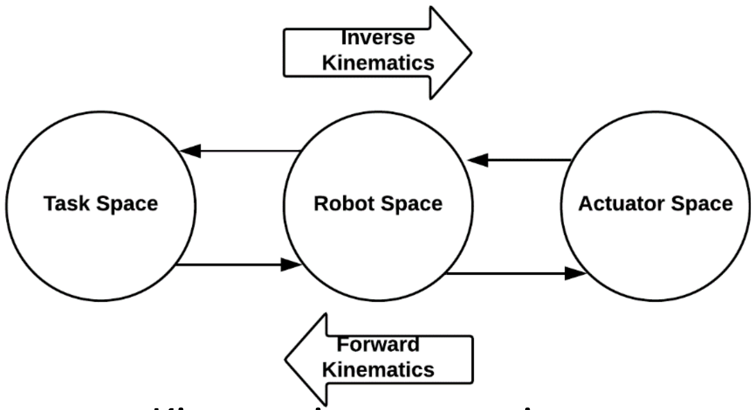


Robot Schematic: Switching Regulators

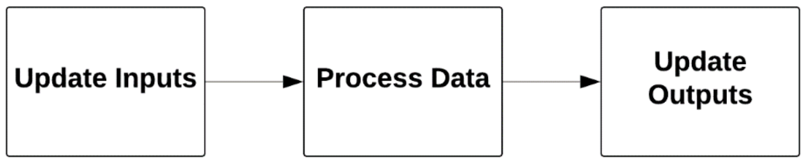


Robot Software Design

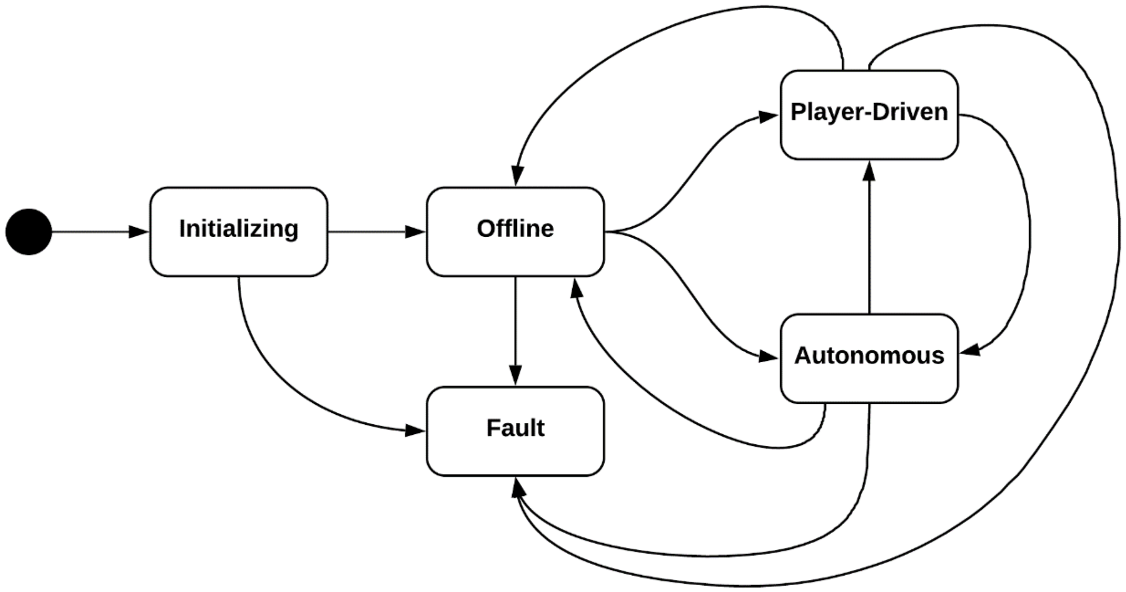
- Robot acts as an I/O device that takes in data from sensors and commands from the Arena, and then executes the commands through actuations
- The robot itself follows a master state machine that is driven primarily by Arena commands
- Kinematics are done on the robot to abstract the control to the Game system



Kinematics processing



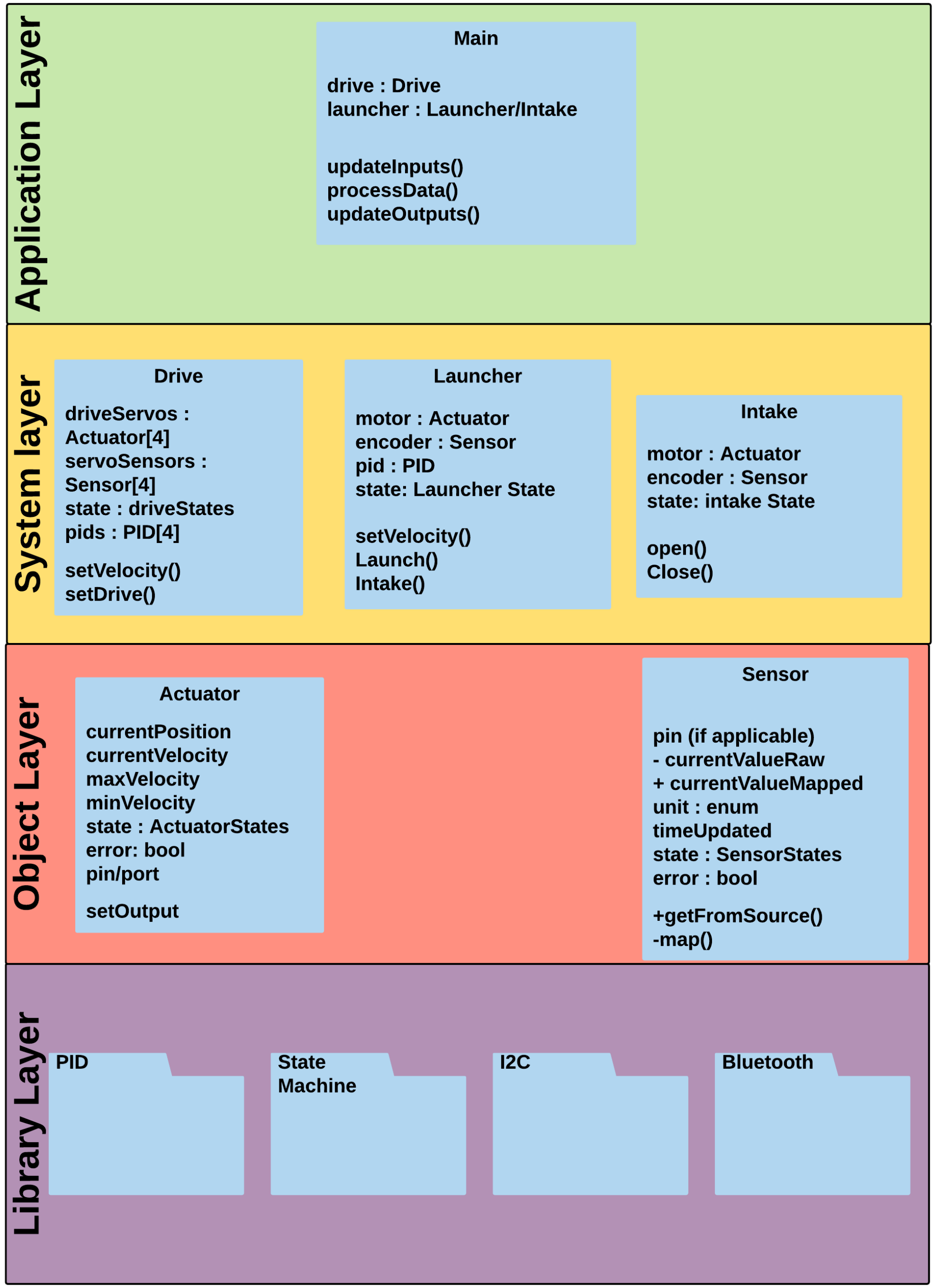
High-level data-flow



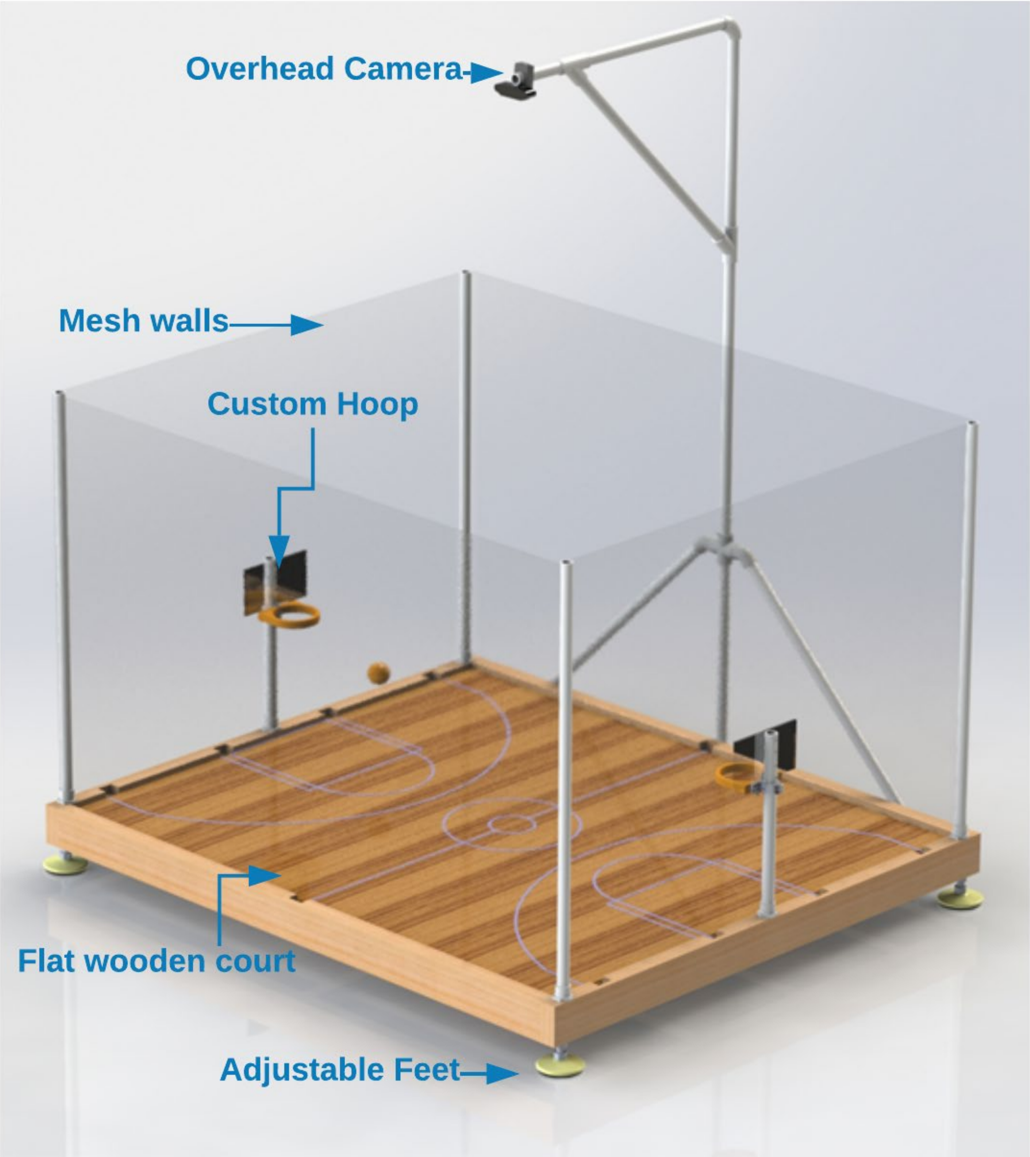
Robot state flow

Robot Software Model

- Main
  - Cyclic calls and master state
- Drive
  - Provides functionality to move the robot. Implements kinematics
- Launcher
  - Handles velocity control of the flywheel
- Intake
  - Handles Intake servo flap and limit switch
- Actuator
  - Provides functionality for controlling outputs
- Sensor
  - Provides functionality for controlling inputs
- PID
  - Implements closed-loop control functionality
- I2C
  - Wrapper for PWM generation by the PCA9685 device
- Bluetooth
  - Provides functionality for communication with the Arena

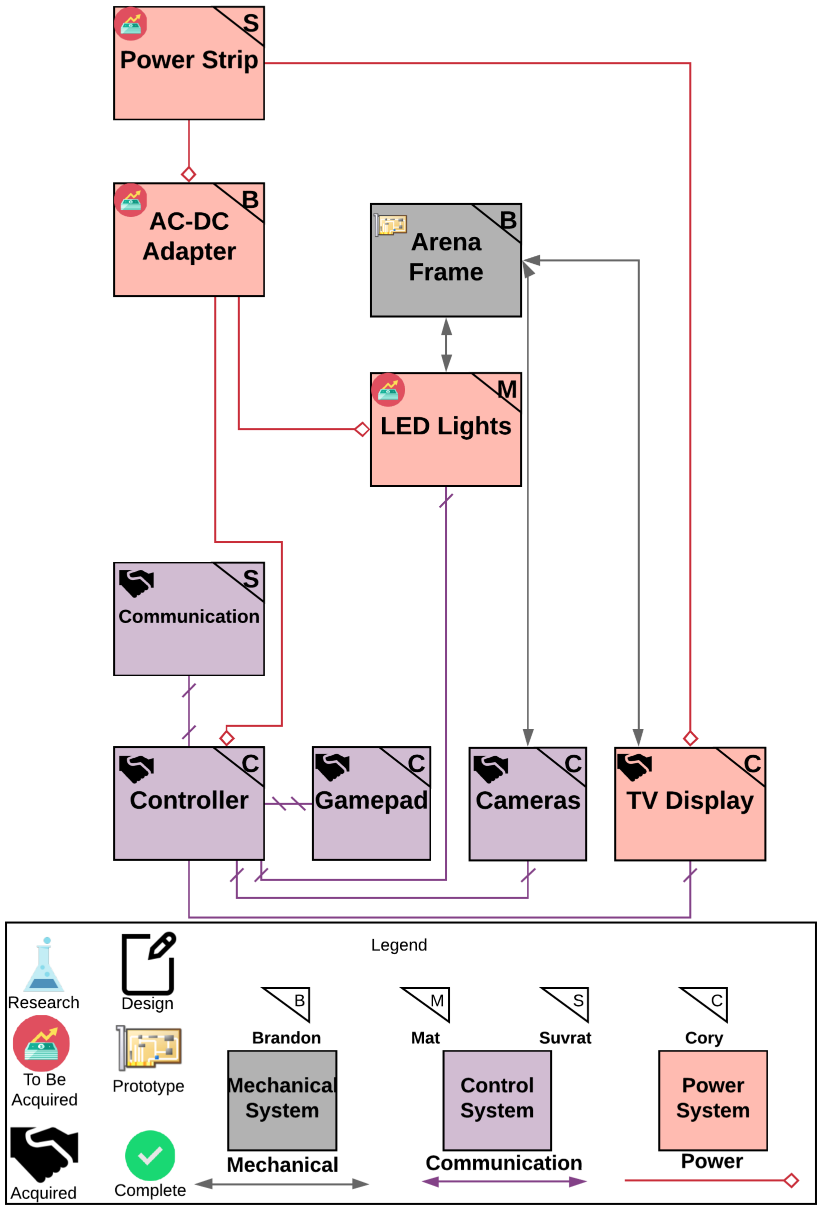


Arena


Overhead Camera
Mesh walls
Custom Hoop
Flat wooden court
Adjustable Feet

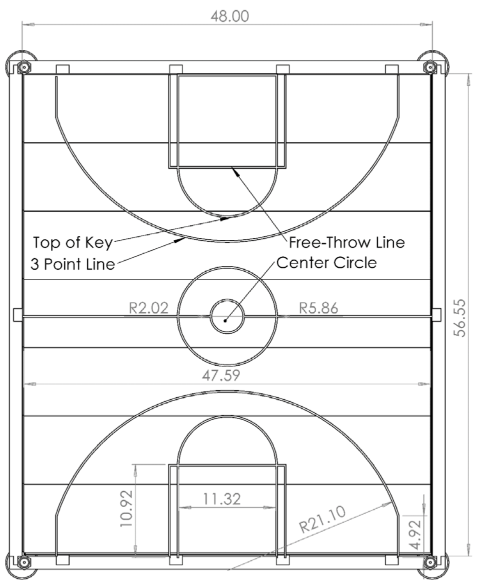
Arena Block Diagram

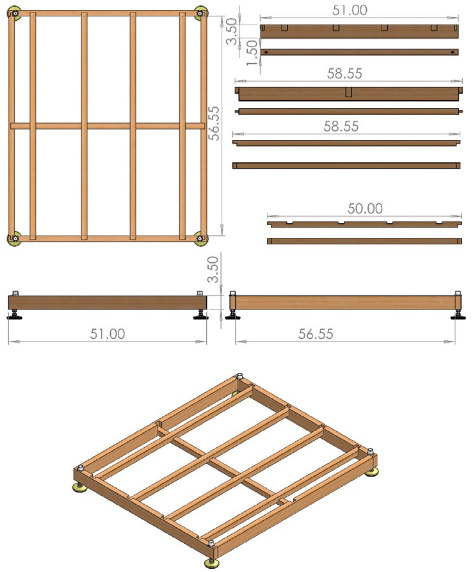
- Power Strip
  - Plugs into wall outlet and splits power between AC/DC Adapters and TV
- AC-DC Adapter
  - Converts 120V AC to DC power for Controller & LED Lights
- LED Lights
  - Colorful animated lights for player engagement
- Arena Frame
  - Mechanical structure to support court, robot, and other devices
- Communication
  - Device to transfer data between Arena and Robot(s)
- Controller
  - Embedded computer to process vision and game data
- Gamepad
  - Player-input device
- Camera(s)
  - Computer vision is performed to determine robot and ball positions
- TV Display
  - Display and sounds for the player

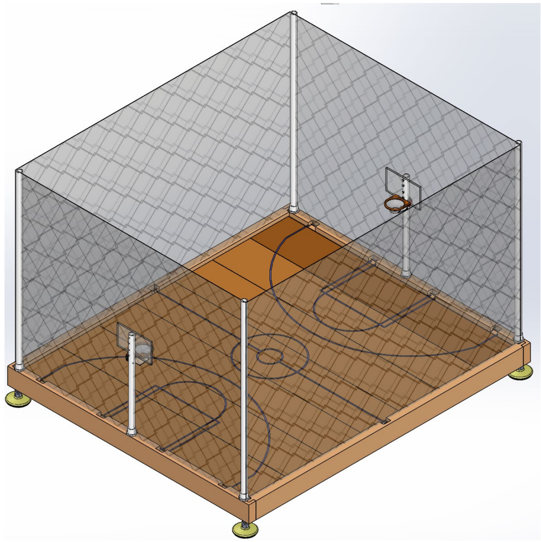


Arena - Frame & Court Design

- 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

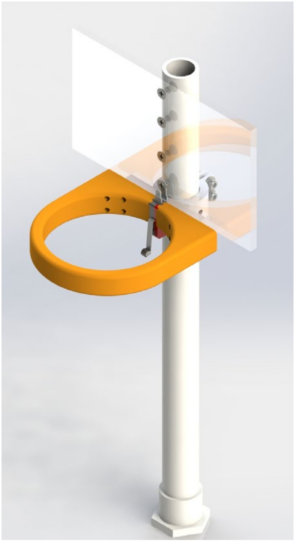


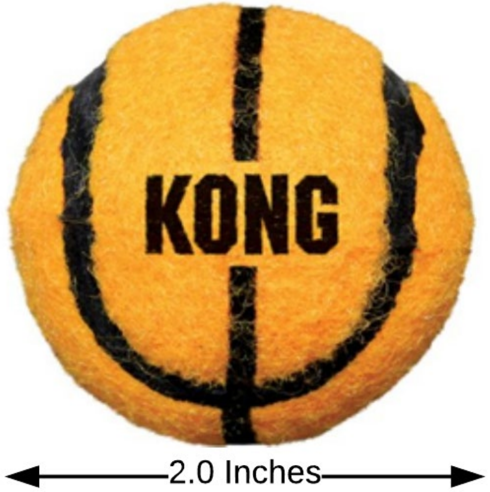


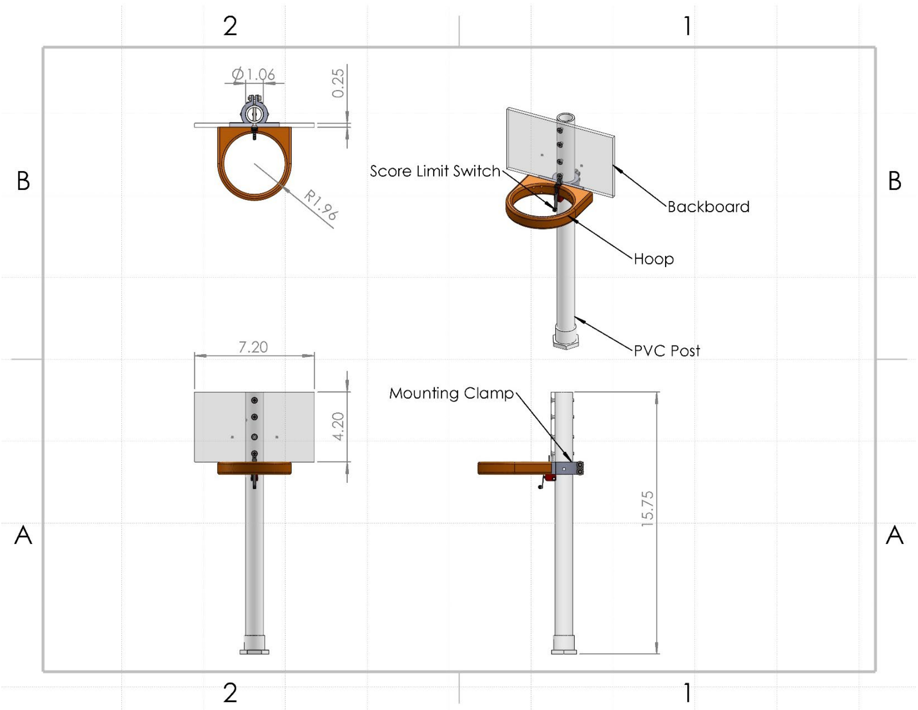


Arena - Ball & Hoop Design

- 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
- Limit switch mounted such that the ball always hits it if makes it through the hoop







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

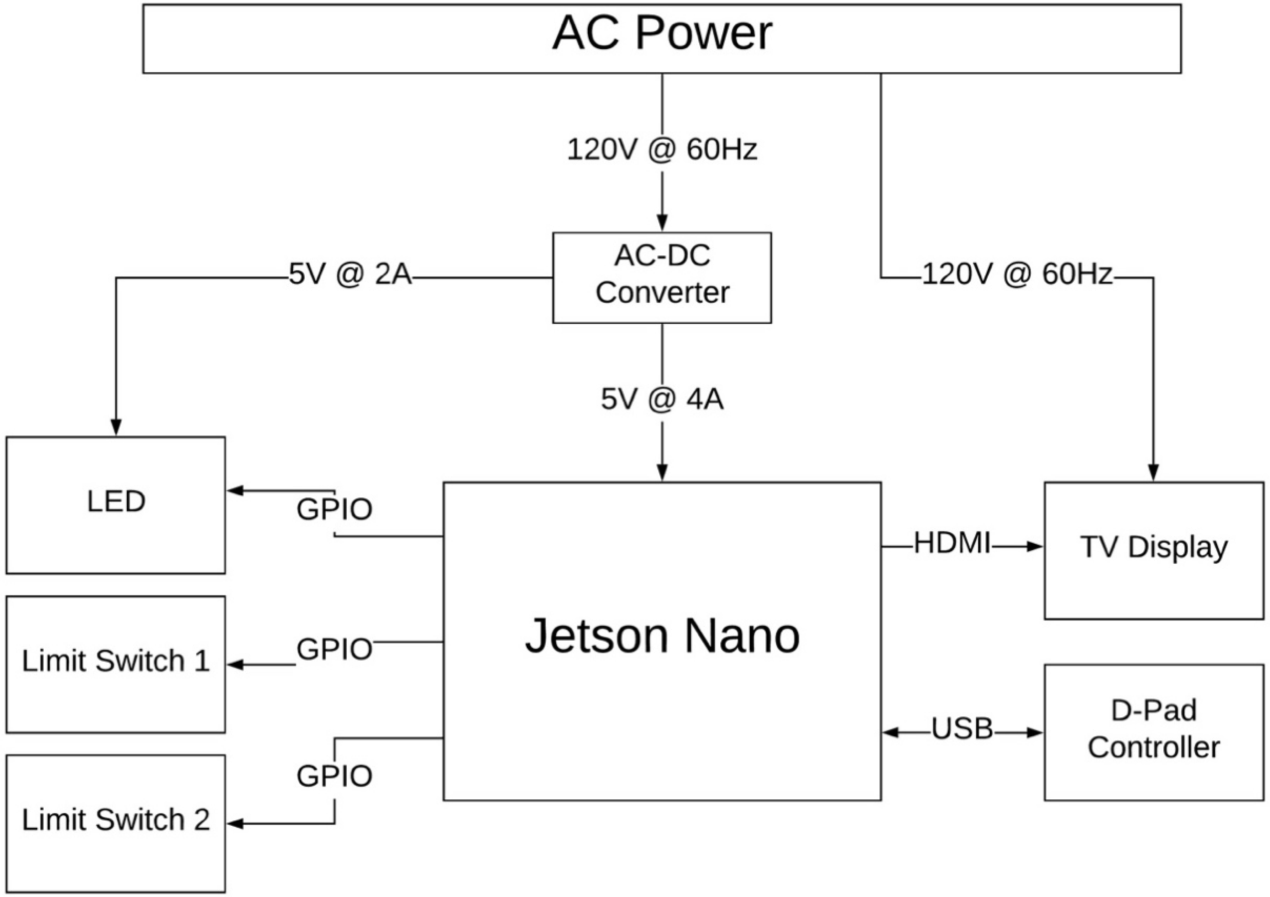
Feature	Raspberry Pi 3 Model B+	Jetson Nano
CPU	1.4 GHz 64-bit Quad-Core ARM Cortex A53	1.4 GHz 64-bit Quad-Core ARM Cortex A57 MPCore
GPU	Broadcom VideoCore IV	128-Core Nvidia Maxwell
RAM	1 GB LPDDR2 SDRAM	4GB LPDDR4
Operation Performance	21.4 GFLOPs	472 GFLOPs
Wireless	Dual-band 802.11ac wireless LAN, 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

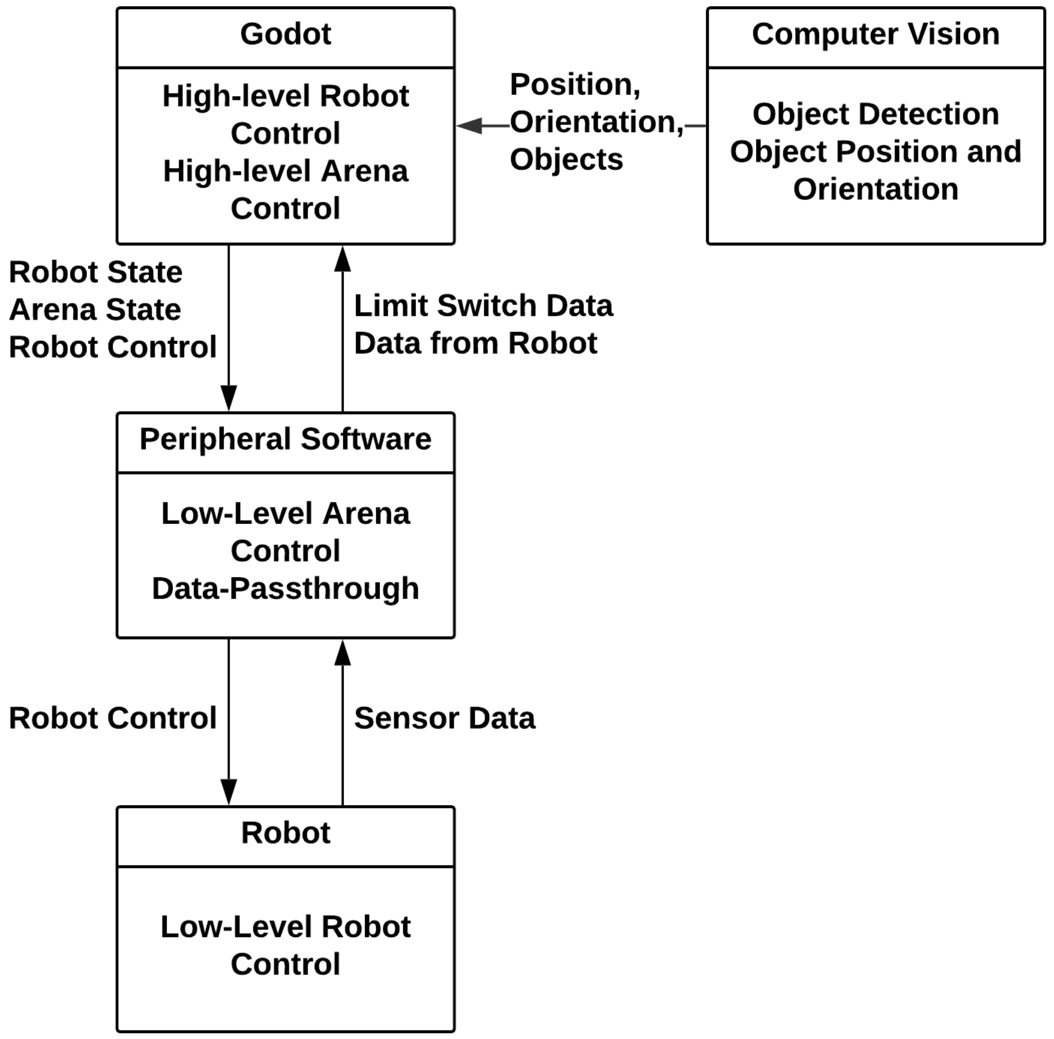
Arena - Electrical Design

- The Arena is AC Powered
- A 120V to 5V AC-DC converter is used to power the Nano
- Nano does most of the processing onboard and controls LEDs and Limit Switches
- The controller commands are accepted using USB and sent to the Robot via communication system (ideally Bluetooth)
- The TV/Display is powered from an AC outlet as well



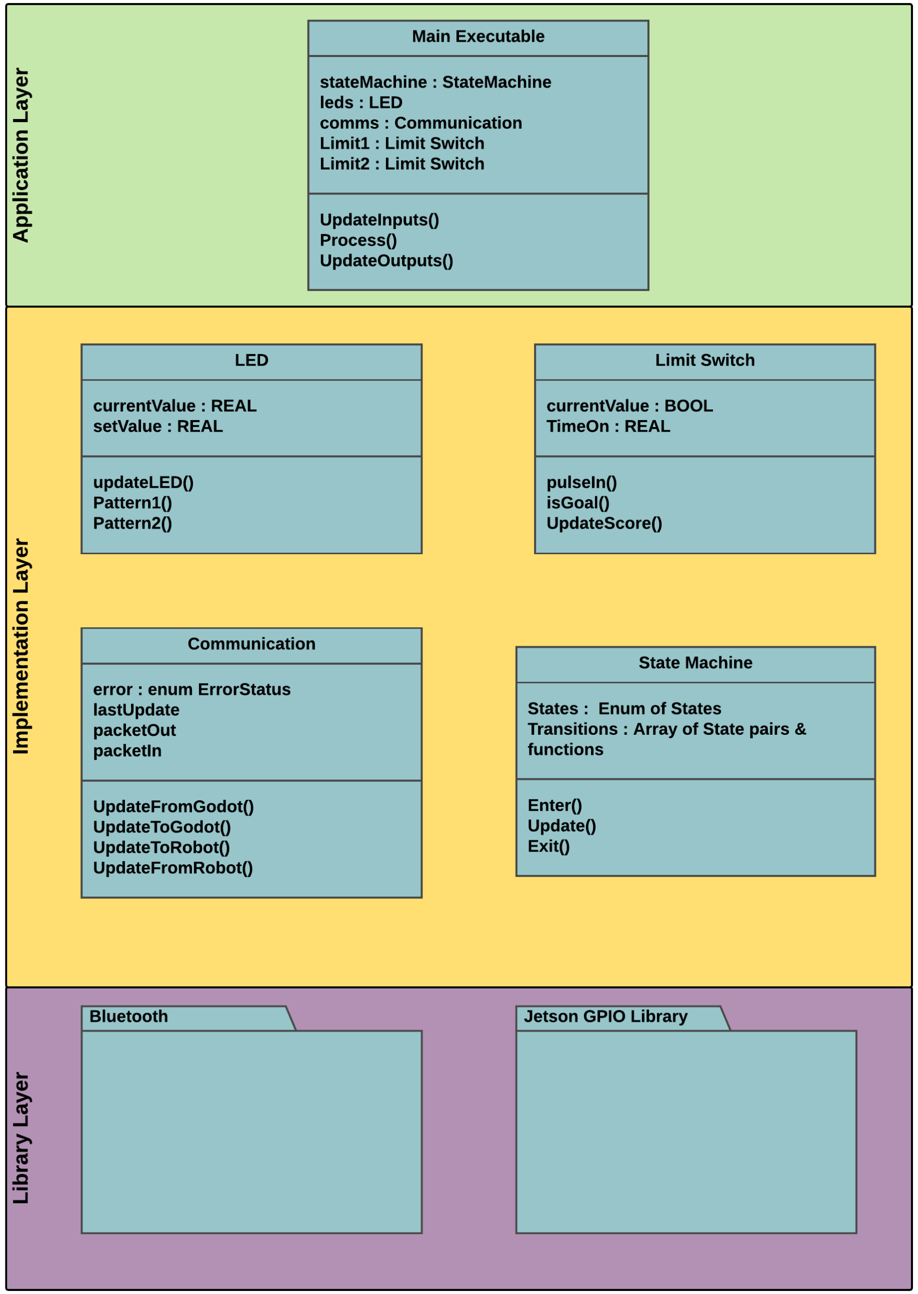
Arena Software Design

- Peripheral software will send and receive data from the game engine as well as control local I/O from the arena.
- Peripheral software will handle calculations to send to robot for velocity and position control.
- Critical issue
  - Jetson Nano cannot directly control NeoPixels due to the lack of real-time control over the GPIO. An extra external device such as an ATMEGA328 may be required.



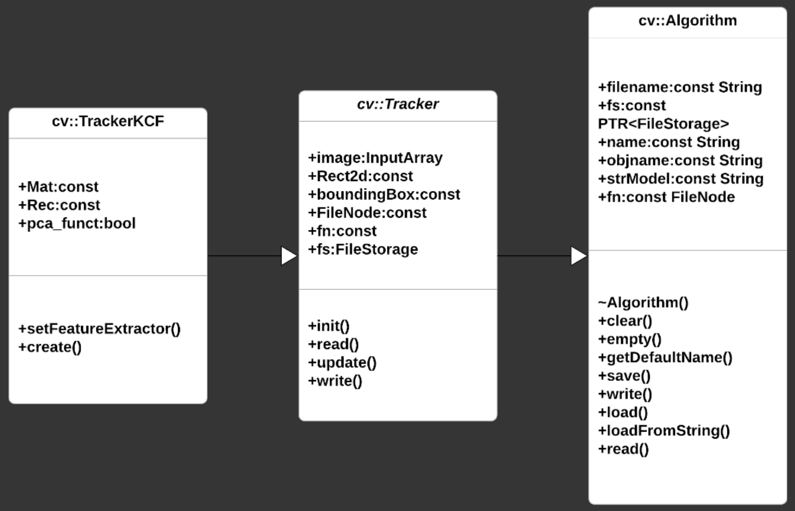
Arena Peripheral Software Model

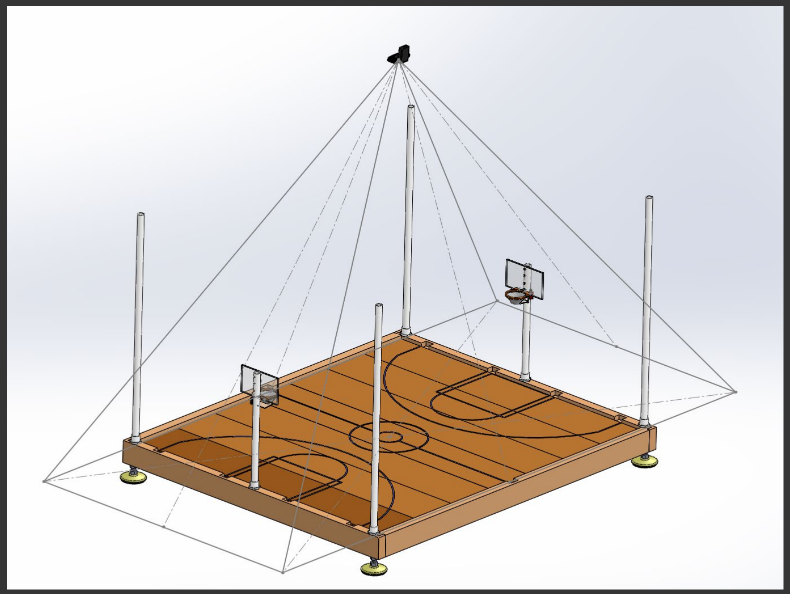
- Main Executable
  - Cyclically checks I/O through subsequent layers, reports data to the game engine
- LED
  - Responsible for controlling the LED GPIO
- Limit Switch
  - Responsible for determining when a goal is achieved
- Communication
  - Responsible for communicating between the Game engine and Computer Vision Systems
- State Machine
  - Ensures non-blocking behavior
- Bluetooth:
  - Library to provide low-level Bluetooth network control
- Jetson GPIO Library
  - Library to provide low-level hardware functionality



Arena Computer Vision System

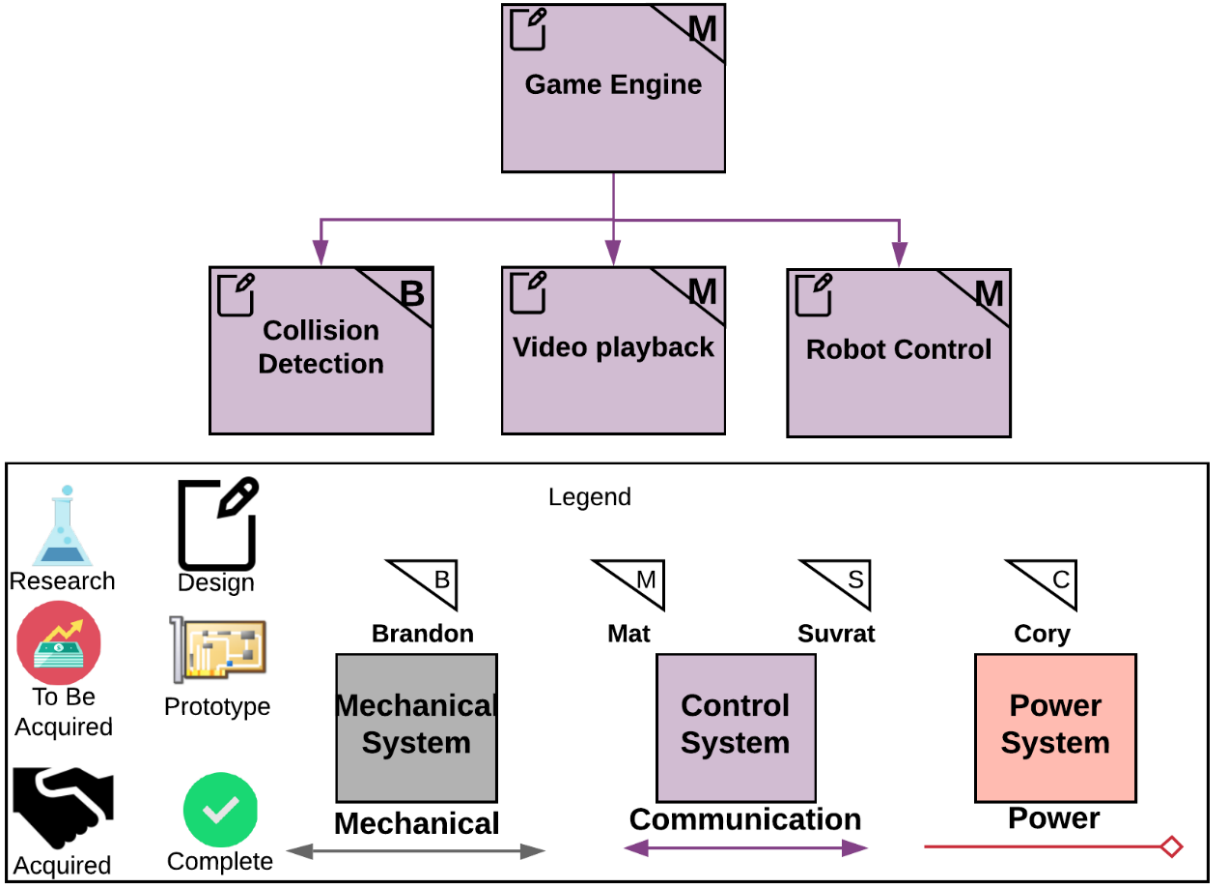
- Position data from the robots and ball to be passed to the robot master control
- 2D image from single camera with a relatively high resolution, and 30 Frames per second
- Camera must be mounted high enough to see the entire field and objects on the field
- Implemented using the open source OpenCV computer vision libraries and third party KCF tracker package along with background subtraction





Game Block Diagram

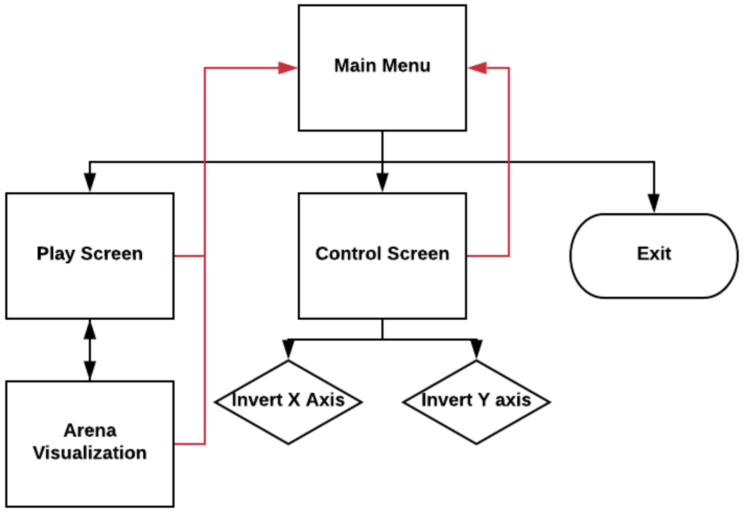
- Game Engine
    - Godot
- Collision Detection
    - Alerts user when they are getting closer to the edge of the arena.
- Video Playback
    - Data playback after made or missed shot
- Robot Control
    - Joystick input and positional data

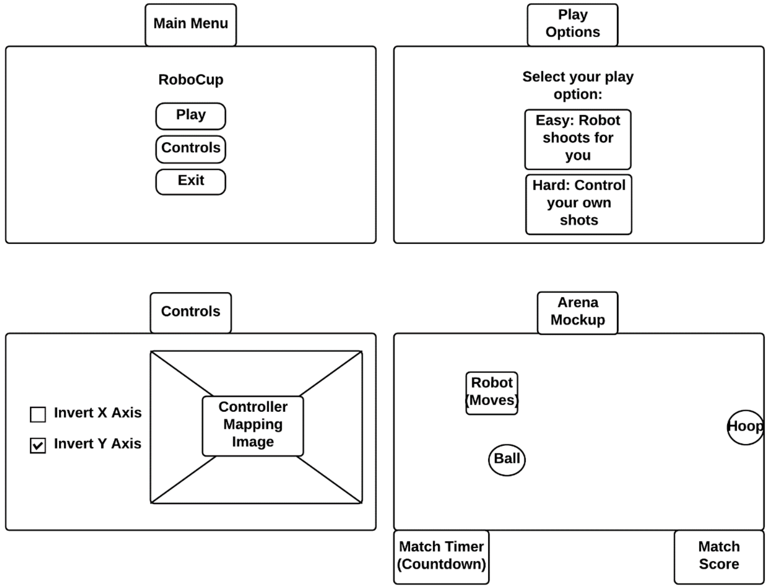


Component Selection – Game Engine

	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

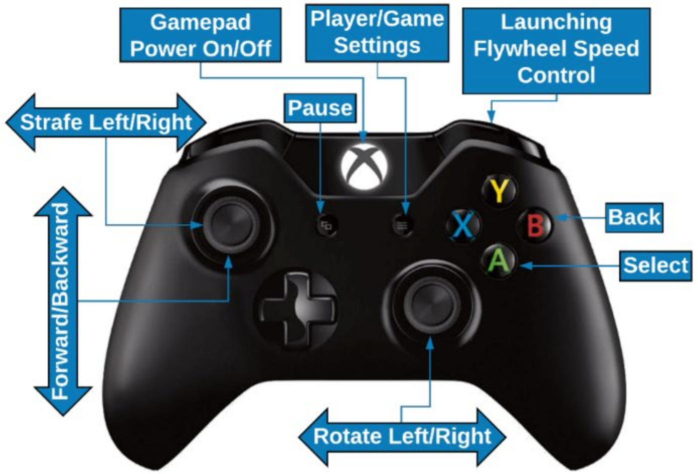
Game Interface Design





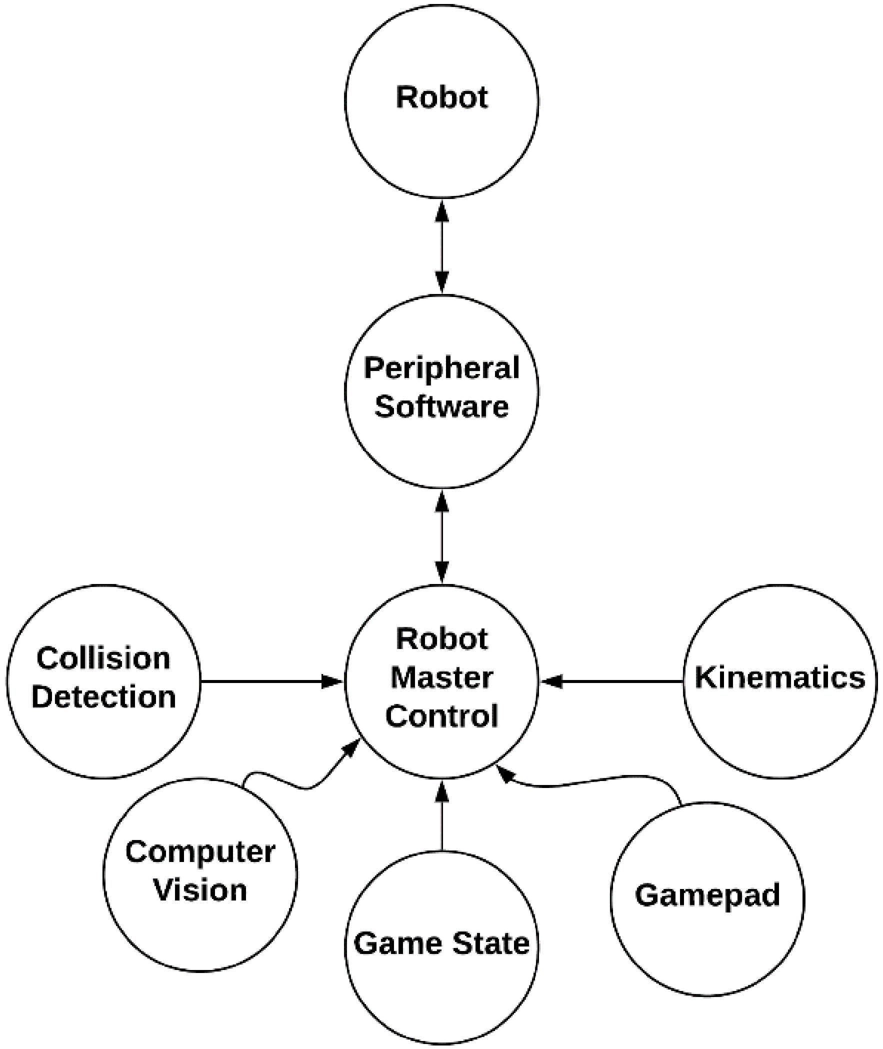
Gamepad

- Xbox One controller will be used for controlling the robot
    - More readily available to use
    - Interfaces well with Godot

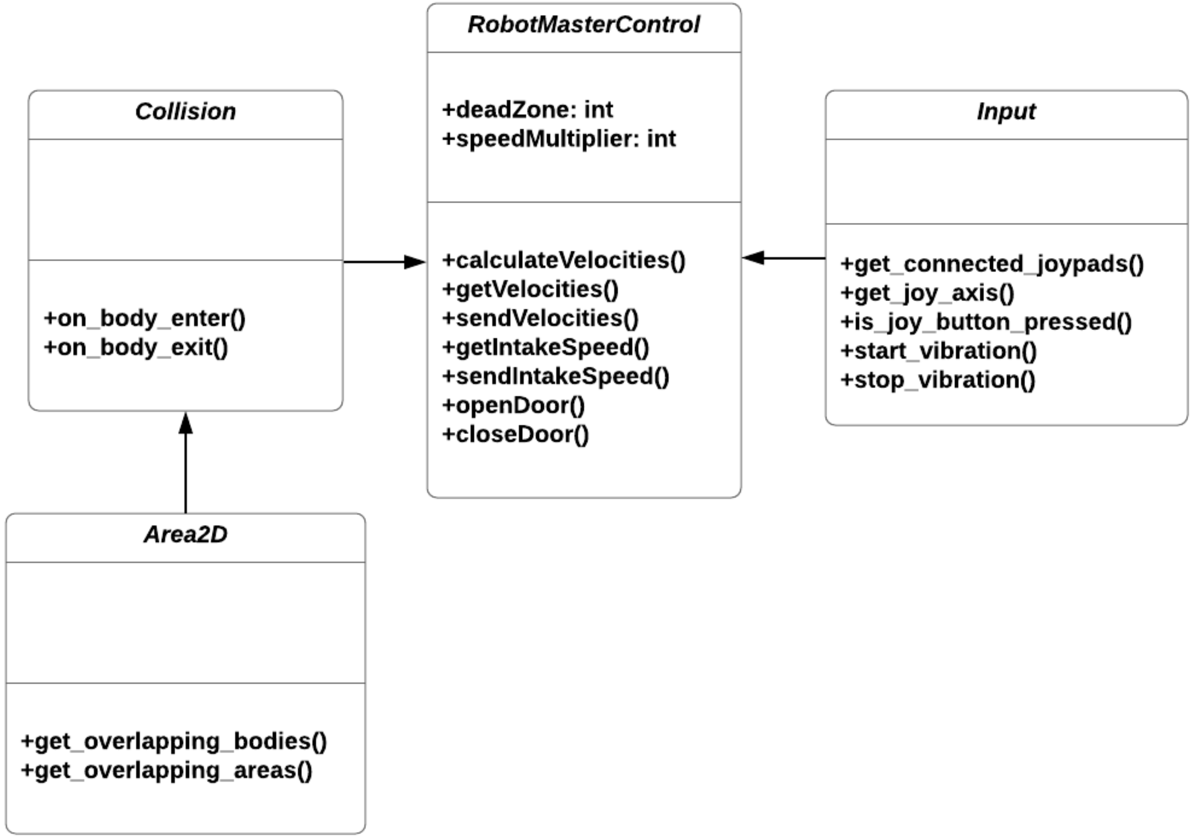


Game - Robot Master Control

- Game software handles the overall control of the robot by taking inputs from the user, processing the data, and then sending the processed data to the peripheral software component. The peripheral software component (Arena software) communicates with the robot(s).
- The data processing includes smoothing/filtering user inputs, determining robot state, and determining the required robot velocities for the drive and flywheel to drive and shoot appropriately.



Game - Software Model



Critical Interfaces

- **Arena <-> Game (Software/Communications Interface)**
  - Defined as the interface between the Arena and the Game
  - Although the Arena and Game currently live on the same device, it is not required for the Game software to strictly live on the I/O device
  - Like the Robot<->Arena interface, the type and meaning of transferred data must be clearly defined such that translation errors do not occur
  - Arena to game: Estimated Vx, Vy, ω, flywheel velocity, error status, hoop limit switch
  - Game to Arena: Vx, Vy, ω, state
- **Robot <-> Arena (Software/Communications Interface)**
  - Defined as the interface between the Robot(s) and 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)

Budget & Spending - Robot

Budget Item	Quantity	Budget ($)	Budget Subtotal ($)	Item	Supplier	Price ($)	Subtotal
Launching Hardware	1	$20.00	$20.00	Assorted	Various	$14.00	$14.00
Drive Hardware	1	$30.00	$30.00	Assorted	Various	$6.00	$6.00
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	$5.00	$5.00
Intake Motor	1	$15.00	$15.00	Servo	Parallax	$20.00	$20.00
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**				**$277.72**

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	$85.00	$85.00
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	2	$ 25.00	$ 50.00	Xbox Controller	Amazon	$25.00	$50.00
TV Display	1	$ 70.00	$ 70.00	720p 19in Display	Amazon	$70.00	$70.00
Total			**$ 480.00**				**$481.00**

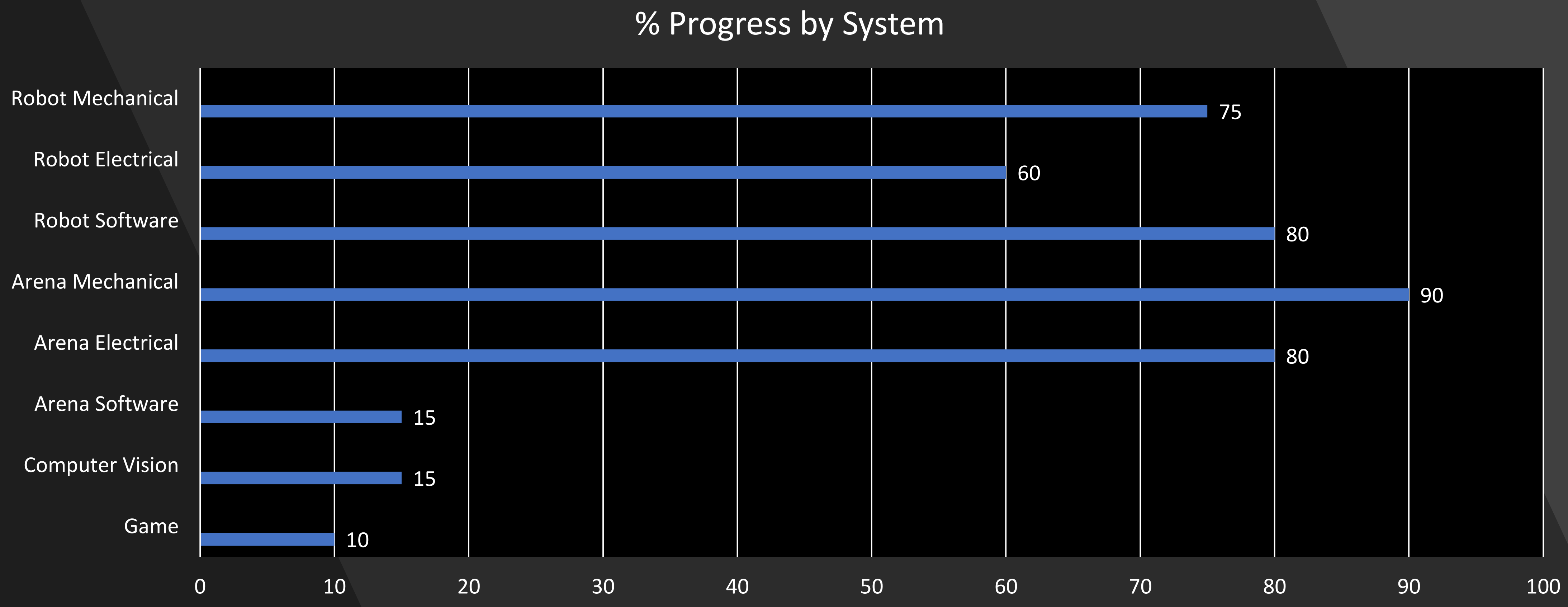
Timeline

Sprint #	Start	End	Important Deadline	Must-Complete
Sprint 1	8/27	9/3	-	-
Sprint 2	9/3	9/10	-	-
Sprint 3	9/10	9/17	-	-
Sprint 4	9/17	9/24	-	-
Sprint 5	9/24	10/1	10/26 CDR	Arena Hardware
Sprint 6	10/1	10/8	-	Robot Hardware (Minus PCB)
Sprint 7	10/8	10/15	-	Robot Software
Sprint 8	10/15	10/22	10/21 Mid-Term Demo	-
Sprint 9	10/22	10/29	-	PCB
Sprint 10	10/29	11/5	-	Game
Sprint 11	11/5	11/12	-	Arena Software
Sprint 12	11/12	11/19	-	Testing
Sprint 13	11/19	11/21	11/21 Final Demo	-

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 Software	Brandon	Suvrat
Computer Vision	Cory	Suvrat
Game	Mat	Brandon

Progress



% Progress by System
Robot Mechanical
Robot Electrical
Robot Software
Arena Mechanical
Arena Electrical
Arena Software
Computer Vision
Game
75
60
80
90
80
15
15
10
0
10
20
30
40
50
60
70
80
90
100

Immediate Plans

- **100% Arena hardware complete**
  - Requires wall mesh weaving, 1 hoop print, and electrical box
- **Finalize robot hardware design & construction**
  - Requires intake design & construction, and manufacturing final components
- **Complete working bread-board prototype of electrical system**
  - Requires launcher, drive, and intake motor and sensor testing
- **1st PCB iteration purchase & Manufacturing**
  - Long lead-time, many issues can arise

Questions?