Rock 'N' Rover: RC Car

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1. Introduction

In the world of remote-controlled cars, exciting progress is constantly being made to make them better and more fun to use. The Rock ‘N’ Rover is a prime example of this progress, representing a major step forward in remote-controlled car technology. This impressive vehicle is designed with a range of cool features to make it safe and enjoyable to use. For instance, it's equipped with special sensors that help it detect obstacles so it can navigate safely. Plus, it has a speaker and headlights to make interacting with it more fun and to help you see better when it's dark. With a built-in camera and Bluetooth connection, you can even see what it sees and control it from your phone. And thanks to its easy-to-use controller and app, switching between different modes of control is a breeze. Powered by strong motors and precise steering, the Rock ‘N’ Rover moves smoothly and can handle many different tasks. With its simple yet advanced features, the Rock ‘N’ Rover is leading the way in remote-controlled car technology, offering something exciting for everyone.

2. Project Description

The Rock ‘N’ Rover, a cutting-edge remote-controlled car is designed to provide an array of features for enhanced functionality and enjoyment. This vehicle boasts advanced capabilities, including obstacle detection through strategically placed Ultrasonic Sensors, ensuring safe navigation. Additionally, it features an integrated speaker for interactive experiences and front headlights for improved visibility in low-light conditions. With a built-in camera and Bluetooth connectivity, users can enjoy a visual perspective through the companion app and seamless communication with external devices. The intuitive Controller and App interface allows for effortless switching between manual and remote control modes, ensuring ease of use. Powered by reliable DC Motors and a precise Steering Servo, the Rock ‘N’ Rover offers responsive movement suitable for a variety of applications. With its user-friendly design and versatile features, the Rock ‘N’ Rover represents the forefront of remote-controlled car technology.

2.1 Motivation and Background

The beauty of engineering is how something so small can change the world. A few electrons move in a certain direction, and now you have current flowing through a component. You combine these components together, and you create life-saving technology. We took inspiration from the biomedical field, and started brainstorming all types of ideas for a prosthetic arm. The only problem was the scope of the project. We have four senior engineering students, and we can do better than slapping together some servos and sensors. We kept thinking about all of the applications for robotic arms and hands, and that led us to a bomb defusal robot. These robots are able to get explosives away from people, and dispose of them in a safe environment. This takes our small idea, and adds way more challenges to it, so we focused on the idea of a remote controlled car.

Through our years of education, we have learned the skills to complete a project such as this. The thing we still need to learn is how to work as a team, all striving towards a common goal. We need to design and create a fully functioning robot that includes dozens of sensors, hundreds of parts, and thousands of lines of code, and we need to do it in a timely and cost effective manner.

Originally, our group was going to create a smart mirror that would display the weather, time, and would have other features such as an alarm clock and being able to play music through Spotify. After careful consideration, our group ultimately decided to create a remote control car with a robotic arm for our project. This idea arose because one of our team members, Michael Patalano, has an interest in robotics. He pitched the idea of creating a prosthetic arm and then we discussed making a robotic arm with a hand and fingers. We decided not to go with the prosthetic arm or the robotic arm idea for the project due to it being too complex because it would require a lot of mechanical parts and the 3-D printing needed for the project would require skills that none of us have. While discussing our project idea, someone had also mentioned a bomb defusal robot so naturally we decided to make a remote control car instead. Bomb defusal robots can either defuse the bomb or grab it and move it far away, and ours will be able to grab objects and move them away. This has many more applications, from organizing in factories to building a way stronger robot and moving much heavier objects.

2.2 Goals and Objectives

The main goal is to build a remote controlled car, with a bunch of features. We will also design a companion app. The most important feature is to be able to see what the car sees, by using cameras on the body of the car and displaying it on the app. Some of the other mandatory goals are to control the arm and drive the car simultaneously, place ultrasonic sensors around the car's body to alert the driver of any objects they couldn't see from the front and rear cameras, and include a speaker that can be controlled by the app. The controller being hand held, instead of on the app, allows the driver for much more accurate control, which is very important in high pressure situations. The ultrasonic sensors will give the driver feedback about terrain and any incoming objects. The speakers allow us to get a message to someone if you are not trying to alert others where the driver is. An underrated goal that we need to reach is the battery life. We want the car to be able to drive for at least an hour. This means more powerful motors, servos, and a larger PCB that can properly disperse the current to all of the components.

Some of the advanced goals we would like to reach include being able to speak directly from the controller to the speaker, headlights with different settings or using a night vision camera, and having the battery life displaced on the app. We are going to use a classic gaming controller that has a place to plug in a headset. The driver could plug in a microphone and speak directly out of the speaker. The realistic goal is hard programming statements into the speaker that will play with a couple of buttons, but this way allows us complete control. We could even put a microphone on the body of the car, and have a conversation with someone standing next to it. The headlights or night vision camera is a very practical addition. It gets dark pretty early in Florida, so having a way to know where you are driving at night is important. We would choose the headlights first, because it is just connecting it to the microcontroller, but the night vision light means programming and additional cost. A regular camera is significantly cheaper than a night vision one. The last feature was about showing the battery life on the app, but it covers all of the features on the car. We only need the app to show the driver where it is going, the rest is extra. Having a screen that controls camera angles, manual subsystem turn offs for battery consumption, controlling the brightness of the headlights, and even a driving setting that retracts the arm for optimal wind resistance in long distance driving is an amazing feature. The less stuff we need to control with the controller the better. This allows the driver for more intuitive driving.

We have a few long term stretch goals, and we will hit some of these, but since we are in the Spring and Summer semesters, it will be much harder to hit all of them. The first one is to use the ultrasonic sensors like a radar detector, and have that be available in the app for the driver. This is most likely not needed, because we will be driving on streets or flat areas, so there wouldn't be terrain to stop the car from driving.

2.3 Features/Functionalities

The Rock ‘N’ Rover is equipped with a range of features to ensure efficient and versatile functionality. An Ultrasonic Sensor facilitates obstacle detection for safe navigation, while a speaker adds an audible element for user interaction and entertainment. Front headlights provide visibility in low-light conditions. The camera offers a visual perspective for enhanced navigation, and Bluetooth connectivity enables seamless communication with external devices. The inclusion of a Controller and App interface ensures user-friendly manual and remote control. DC Motors for the rear wheels and a Steering Servo for the front wheels contribute to precise movement. Together, these features create a sophisticated yet user-friendly robotic car suitable for diverse applications.

Features	
Ultrasonic Sensor	Controller
Speaker	Mobile Application
Headlights/LED lights	DC Motors For Rear Wheels
Camera	Steering Servo For Front Wheels
Bluetooth	

The design features of the Rock ‘N’ Rover robotic car align with various robotics and IoT projects that integrate sensors, actuators, and multimedia elements for enhanced functionality. Projects such as autonomous robots and IoT-controlled vehicles often employ ultrasonic sensors, cameras, Bluetooth connectivity, and motor systems for navigation, interaction, and entertainment purposes. Examples of platforms like Arduino or Raspberry Pi-based robotic projects may serve as general references for integrating similar features.

2.3.1 Customer Input and Market Analysis

The project features have been identified through customer input gathered from surveys, ensuring alignment with user expectations. Additionally, a detailed marketing analysis of comparable products has been conducted to identify successful features and innovative strategies. This input forms the foundation for the following key features:

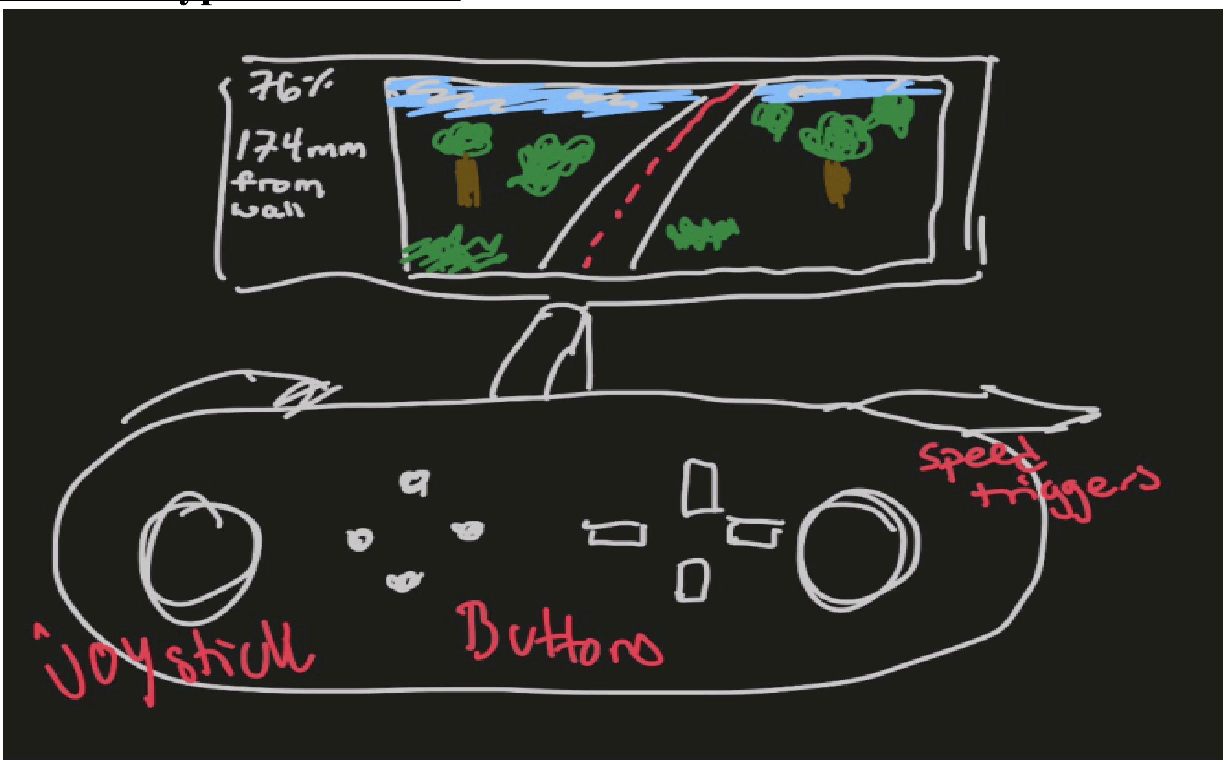
2.3.2 Advanced Mobility

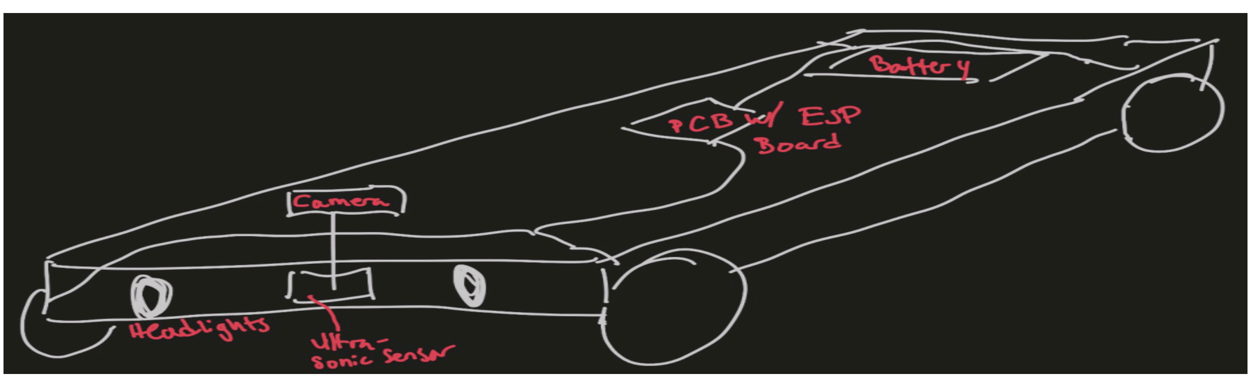
Drawing inspiration from various smart robot cars, our robotic machine incorporates high-performance motors, precision control algorithms, and obstacle avoidance sensors. This ensures smooth navigation and collision-free operation, addressing user expectations for a versatile and mobile platform.

2.3.3 User-Friendly Interface

Building on the success of user-friendly interfaces seen in existing products, our project integrates intuitive controls for both remote and app-based operation. Customizable settings, inspired by customer preferences, provide an enhanced user experience. In addition, the innovative features of the 360-degree camera, headlights, and music speaker enhance the functionality and user appeal of our robotic machine.

2.4 Prototype Illustration



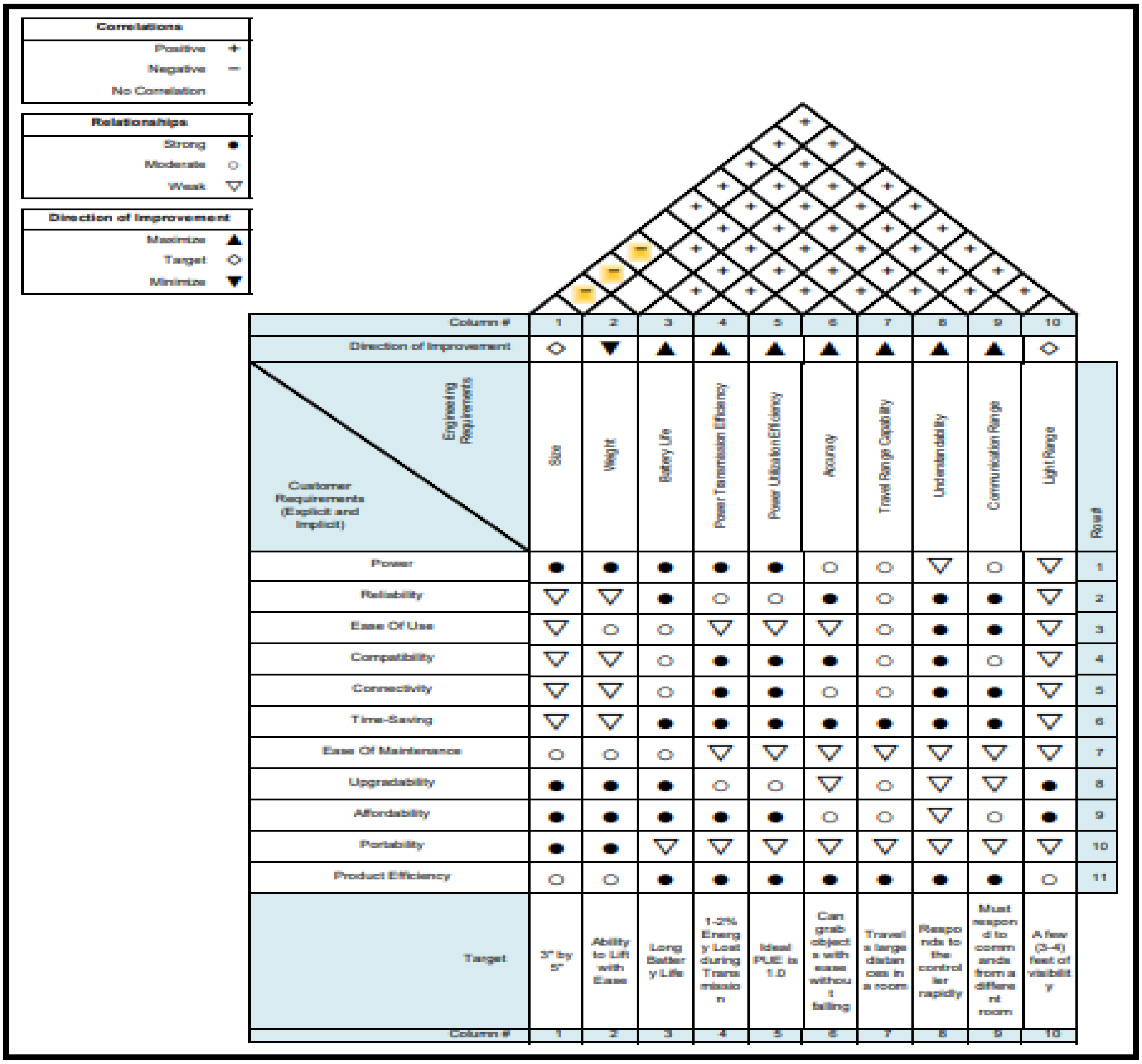


The drawn prototype for the Rock ‘N’ Rover serves as a visual representation of the envisioned design. The prototype showcases a well-defined body structure equipped with four wheels to facilitate mobility. Positioned at the front is a robotic arm, providing an extended range of functionalities. The inclusion of headlights enhances visibility in the front, contributing to the overall practicality of the design. Additionally, a camera is strategically incorporated for navigation purposes, allowing users to view the surroundings through a visual feed. The hardware components essential for the car's operation are thoughtfully secured within the central region of the car's body, ensuring a compact and organized layout. This prototype not only captures the physical attributes of the Rock ‘N’ Rover but also highlights its potential capabilities, combining both mobility and utility in a single, innovative design.

2.5 Engineering Specifications

Key Specifications
Body of the car must be at least 3 inches in width and 5 inches in length
Battery must be able to power car for at least 1 hour
Car must be able to move forwards and backwards and turn left and right
Cost of the car must be at a maximum of $800 ($200 per team member)
Headlights must be visible from at least 3 feet away
Must be able to drive a distance of at least 10 feet

2.6 House of Quality



Automotive History

The first step in building an RC car is to learn what it is we are trying to replicate. The automobile was invented by Carl Benz in 1879, in Mühlburg, Germany . It was not fully completed until 1885. It had a single-cylinder two-stroke engine, and Benz was able to focus on improving it to eventually having a lightweight car with a gasoline engine. The 1885 version included a single-cylinder four-stroke engine, a steel tube frame, and three wire-spoked wheels. If you are just as automotively inclined as us, you are probably wondering what that means. There have been hundreds of different engines designed over the years, but this is where it all started. A four-stroke engine refers to the steps it takes to work. It uses a piston, which is the moving component in engines, pumps, and compressors. Its job is to transfer the force of the gas being pushed from the cylinder into the intake. Once this is achieved, our four-stroke steps begin.

The steps are as followed: Intake, Compression, Combustion, and Exhaust. Intake is when gas is being transferred into the engine. This is caused by the piston. The intake is open and when the air gets forced into, it creates a negative space in the engine, which causes a build up of pressure. Compression is when the fuel mixture is being added to the gas that is sitting there. Combustion is where the power is created, as the crankshaft goes around in 360 degrees, and causes even more of a buildup in the engine of pressure, which leads to the final step. Exhaust is when the pressure is so forceful, that the valve holding the air-fuel mixture is opened, releasing the pressure and making the engine work. This process runs indefinitely. The single-cylinder is where that whole process is held in. Being only one cylinder, it is more compact, and it is used for smaller machines. Some modern examples are motorcycles, scooters, and go-karts. The cylinder allows for much more airflow than multi-cylinder designs, so you do not have to worry about cooling. The air takes care of all the heat from the mini-explosions caused by the engine. Because all of this is only happening in one tube basically, it leads to a ton of vibrations. There is only one surrounding it, so that is what takes the outer force. Using this engine, Benz was able to output 0.75 horsepower, or 0.55 kiloWatts. He filed his patent for a “vehicle powered by a gas engine” on January 29th, 1886.

The history of automobiles does not just start in Germany, as the whole invention of an internal combustion engine was in France, by Jean Joseph Étienne Lenoir in 1859. Benz has the claim for the first official automobile, but in 1901, Wilhelm Maybach created the first motorcar, which shares real similarities in the cars we drive today. It had a 35 horsepower engine, and topped out at just over 50 miles per hour. Even though Germany and France were the first to this industry, the United States would quickly take the mantle as the premier country for the automotive industry. Innovation was coming soon, but the first Mercedes was made in 1901, and had all of those features. The automobile offered in America was made by Old Motor Works, and it was a one-cylinder, 3 horsepower, horse buggy. This might still seem insane, but the crazy part is not even the vast difference in the horsepower, it is the fact that Mercedes was able to do this for 5 more years. The Old Motor Works company sold those cars for 5 years in 1901-1906, and they sold more than any automobile before, all while being so behind in technology. This was largely due to the price point being so more affordable to middle class Americans. Decent, but affordable productions will always sell much more than high quality, expensive products.

The United States being far behind would quickly end, as Henry Ford came out with the Model T in 1908. America and Europe are extremely different areas. Europe had been settled for hundreds of years at that point, and the United States was still this massive country of land. If you ever wanted to explore and expand, you needed an automobile to get around. The American economy was also doing better than many in Europe, so people had more means to purchase these cars. Henry Ford not only revolutionized the automotive industry, but he changed the entire world, when he introduced mass production. This is where the assembly line was created, and it was discovered that it was much more efficient to have a worker specialized in a specific part of the process, hand it off to the next person in line, and then restart the process. By specializing, it made someone extremely talented at their job, and allowed for production to increase exponentially. This industrial revolution led to the United States making just over 80% of all cars in 1913. Other American companies started to use these mass production techniques as well, so the massive volume of sales they were having led to the elimination of all small American producers. Only the big guys could stay in business.

The industry kept getting larger and larger, because everyone wanted an automobile. This eventually stopped when everyone already had one, so the companies had to turn their focus on making better cars that people could trade their old ones in for. The Model T was the first mainstream car in America, and it did its job. The whole goal was to make something that works and gets the job done. Since there were not many new buyers, and there were only so many advancements to make at the time, they started to focus on aesthetics. Companies thought that if you did not need a new car, because your car already works, then the only way to increase sales is to make you want a new one. By focusing on design and details, the industry was able to make another turn up. Companies were making more money, but the product itself took a dip, because they were more focused on styling and cost-cutting measures, than making the best automobile possible.

World War II had a massive impact on the automotive industry. They were responsible for producing vehicles and other various materials during World War I, but now they were asked to do much more. The American Automotive industry produced millions of military vehicles, and the majority of them were not even a domestic motorcar. They produced almost $29 billion worth of materials, and that was one-fifth of all of the United States production. Not only was the industry making a bunch of money during the war, but post WWII was going to be prosperous, as there was a massive demand for new cars. So many of the materials required to build them were going to the military, so people had to keep their cars way longer than they wanted.

The United States was not the only country to fund their automotive industry during the war. This led to Europe and Japan also becoming big automotive producers, and that led to a massive shift later on. The United States did not go away from the idea of "reskinning" their cars. They made a bunch of similar cars, but changed to look and feel, in hopes of people buying new cars. This mass production led to cars that were big, bulky, not fuel efficient, and oozed air pollution. The United States passed multiple laws from 1965-1975 to help combat these issues. Another issue arose as there were massive increases in oil prices during 1973 and 1979. Because of these issues, the United States companies started producing less and less, and were importing a lot of more fuel-efficient and functional cars from Japan. The Volkswagen Bug was also incredibly popular from Germany as it was deemed "a modern Model T." The sale of American cars went from 12.87 million in 1978, to just 6.95 million in 1982. During that time, imports rose 10%, going from only making up 17% of the United States market, to 27%. Japan also became the leading producer of automobiles, and it is still currently the leading producer.

In order to combat these drastic shifts in the industry, America started a massive overhaul. They invested $80 billion to remake the factories, and they aimed at a smaller production, but good product model. If they did not make the change to smaller, more efficient cars, the United States would have lost all market share. They even started implementing "computerized" designs and manufacturing. This allowed for companies to still turn a profit, even with lower production, and still take care of their employees.

The automotive industry has a massive impact on not only American history, but also world history. It plays a massive factor in multiple industries alive like petroleum, steel, and industrial products. It also allowed for travel and tourism to flourish. It led to service stations, restaurants, and motels. It also led to the Interstate Highway Act of 1956, which kick started the hundreds of highways we have across the nation. It was also one of the largest public work programs in history.

How Cars work

The first step in building an RC car is to learn what it is we are trying to replicate. Modern day cars can be broken down into 6 subsystems: body and frame; engine; transmission/drivetrain, suspension system, wheels, and tires; control systems; and electrical systems; engine subsystems, and climatic equipment. These subsystems are all extremely critical to making a car run properly. Before we break down specifics, it should be noted that every car is different, so every car will have an engine, but there are a bunch of different types of them. It all depends on what the purpose of that car is to the market.

Body and Frame: The body of the car is an empty structure. Its goal is to provide a place for the driver, passengers, and cargo. It also safely stores all of the systems inside of it. The body is also what the windows, doors, handles, trunk, hood, and the frame are attached to. The frame is what the body is on top of. If you were to look down at it, it would look like a rectangle. It is meant to be a solid and square base for the body of the car to rest upon. There are two different uses for a frame. The most common one is when the body and frame are built together. It is called a unibody. This saves time and money in the process, but there are many benefits to having them as separate pieces. The main one being that you can have similar shaped cars, but change the body based on certain criteria.It is primarily used for off-road SUVs, which are all about customizing as many parts as possible. This flexibility could save you hundreds of thousands of dollars if you use it for multiple designs. This option is called body-on-frame. Again, the flexibility is a positive, but having to pay for two separate molds is extremely expensive. Manufacturers already have to pay for a mold to make the bodies, so you might as well include the frame in that mold, and skip that step entirely.

Engine: The main goal of an engine is to take one form of energy and convert it into one that allows the car to move. They are typically located in the front of cars, right under the hood. This lets the manufacturer put a trunk in the back, allowing for plenty of storage for your items. Some cars do put the engines in the back, and that is for performance. Some even have it in the middle of the car. The engine is the heaviest part of a car, so wherever it is, will affect how you drive. There are multiple different types of “X-wheel drive.” We will discuss those later in the transmission section, but the short summary is that the engine turns the wheels. Wherever the engine is, it will put the weight on the wheels, and give it more traction. This weight helps you choose which wheel drive you want, and that depends on the cars’ application. For example, for people that live in ice places, you should have a 4-wheel drive car, because they work better to get traction everywhere. That does not matter in a place like Florida.

There are dozens of different types of engines on cars in 2024. The 3 main types are Internal Combustion Engines (ICE), Electric Motors, or Hybrid motors (a combination of the two).

Internal Combustion Engines: Before discussing all of the different kinds of ICEs there are, it is important to know how they work. ICEs are run using gasoline or diesel. Some of them can even run on natural gas, propane, biodiesel, or ethanol. There are two options: Spark ignition gasoline and compression ignition diesel engines. The spark ignition ones are the most common, but we will discuss all the types of compression ignition ones as well. ICEs work by combustion, or burning, which is what happens when we release the energy from air-fuel mixture. The fuel can be any of the types listed above.

There are four steps that an Internal combustion engine takes: Intake, Compression, Combustions, and Exhaust. Intake is when the engine sucks in a mixture of fuel and air, creating air-fuel. A piston starts this process by moving downwards. This creates a vacuum and draws air into the cylinder using the intake valve. The second step is compression. The cylinder that currently has a piston in a downward position and is filled with air-fuel, is extremely durable and is able to handle the force that is about to be put on it. The intake valve closes allowing the piston to move back up, and once the piston moves back up the air and fuel becomes compressed and causes pressure in the cylinder. The third step is combustion. Combustion is when the compressed fuel and gas explode using a catalyst. The most commonly used item to do this is a spark plug. A spark plug is ignited inside the cylinder and that creates a small explosion. This process happens over, and over, and over again as the engine is running. Each time there is an explosion, it leads us to the fourth step, which is exhaust. Both the intake and exhaust valves can open and close. The intake only opens when the engine is sucking in all of the air-fuel. During the other three steps, the intake is closed. The exhaust remains closed during steps one and two, but due to the forces from the explosion in the combustion step, it is forced open. The exhaust system leads this energy into the transmission, and that is what is connected onto the vehicle's axles. The transmission puts torque on the axles, causing the vehicle to move.

Once you find out that your engine is an ICE, there are many different types of those. Those types are the number and arrangement of the cylinders inside the engine. Since the cylinders are where all the micro explosions are happening, all the air and fuel gets compressed, the explosions sparks it, and that just keeps on pushing more and more energy to the exhaust. That energy goes to the transmission, which is putting all that energy right into the wheels and moving the car. The more cylinders you have, the more output you will generate.

Internal Combustion Engines come in three different layouts: Straight/Inline, Flat, or V-shaped. The number of cylinders is a direct way to calculate how powerful your engine will be, but then you have to figure out how you want to put the engine itself in the body of the car. An Inline layout is the most common, because it is one most frequently used in everyday cars. This is when all the cylinders are perfectly vertical in a row, straight up and down. If this row is placed parallel to the car, the engine layout is called straight and if the engine is placed perpendicular to the car, this is an in-line layout. These engines are widely used because they are extremely inexpensive. You can put it all in a row, make sure everything is perfectly up, and then install it right into the body of the car. This vertical layout of the cylinders leads to a lot of vibrations. No matter the cylinder count, all of them have the intake and exhaust at the top, and a piston at the bottom. The piston goes down to intake all the air-fuel, and that causes force downwards. The piston then shoots back up, and compresses the air-fuel. This is an extremely strong upward force. Both forces happen at different times, so the body of the car will feel the full effects of them. The four-step process is extremely fast and happens repeatedly, so these forces show themselves in vibrations. An Inline engine can have both an even or odd number of cylinders. The odd number engines have a much more noticeable vibration, and that allows the three, five, and seven cylinders to be told apart easily.

The second type is a Flat engine. This is the complete opposite of the Inline engine, as instead of the cylinders being up and down, they are laid horizonally. A flat engine can only have an even number of cylinders, unlike the Inline engine. This is because they put the engine in like a horizontal “I” shape. The middle of the “I” holds the intake and exhaust, the lines leading to the two branches are where the cylinders are. The pistons are on the branches, so the movements of the engine mirror each other. When an inline engine fires, the forces go down and then up. For a flat engine, the piston retracts towards the exterior of the car, and then moves towards the middle, when compressing the air-fuel. This happens on both sides, so while one piston is moving to the right, the other is moving to the left, and vice versa. This causes an equal reaction of forces on the car, and it does not move.The flat engine also has a low center of mass so this is because it’s much wider than something vertically. Instead of having the cylinders straight up and down, you are putting them sideways, and have them mirroring each other, so it doubles the length of a cylinder. The cars need a wider frame and they’re extremely expensive because cars that size and shape are not desired anymore. Most people do not want them, and the manufacturers do not make them anymore. This started due to what happened in the 60s, when American companies were losing market share to Japanese companies, because Japan was making smaller, more efficient cars. The bigger you make the body to fit these engines, the less efficient the car will be, and the more expensive it will be in the long run for the consumer.

The final ICE type is a V-shaped engine. It is the most common type of engine in performance vehicles. Instead of all of the cylinders being straight up and down like the inline engine, or completely horizontal like the flat engine, these are at a diagonal. When they are at an angle, that allows the engine to have more cylinders fit inside of the car body. V-shaped offers the most performance compared to its size. It can pack in a ton of cylinder, and the cylinder allows for a ton of explosions which means even higher power performance. Most people also think that they look way cooler than inline and flat engines. Even though it does have a lot of positives, it does have its flaws. It is by far the most expensive to repair, because there are so many things packed in one space, so even though it has great performance, you will have to pay for it. One of the other big issues is the vibrations. It has the most vibrations out of the three options, due to the cylinder layout. This is because it’s going left and right at an angle so those angles are not that force is not gonna be offset by the other one like it would for the flat engine, but the good thing is that they are smaller.

- <u>Single Cylinder Engine:</u> As discussed earlier, when breaking down the history of the automobile industry, there are multiple types of engines. The most basic one is a single cylinder engine. This is where all of the fuel is put inside of it, then the cylinder gets compressed via the piston, and then there’s a spark, which goes right out the exhaust. Since there’s only one cylinder and one explosion and one exhaust release, it is the least powerful, but it is the simplest and the cheapest most basic option.

- Twin Cylinder Engine: This is rarely found on cars now, because it is still super slow. Just like the single cylinder, it can be found on motorcycles or smaller things such as pressure watchers and go karts. It is similar to the V-shape design, where both cylinders are at an angle, but they also can be vertical. Most the time, the vertical ones have more than two cylinders.
- Three Cylinder Engine: Three cylinders are very, very popular and they're known for the humming type of sound that they produce. They have an odd firing sequence, due to having an odd number of cylinders. This means that instead of just going one after another, they alternate and this causes a weird sound that we can immediately detect. They are more powerful than the two cylinder and the one cylinder, and sometimes these have inclusions of turbo chargers, which increase the power and maintain the efficiency of the engine. These are used on compact SUVs mainly.
- Four Cylinder Engine: A four-cylinder engine is most commonly used now because it is powerful and it's efficient. These are almost exclusively seen in the inline layout, because it's extremely easy to manufacture that way. There is no reason to put them in a V-shape because it is just four cylinders. You don't need to have them in diagonal because there's plenty of space inside the car because it is compact. This is the best option when looking for the balance of performance, power, and cost effectiveness. These are very popular in Honda and Hyundai cars that are used today.
- Five Cylinder Engine: An extremely rare configuration is the five cylinder. These are only found in luxury cars like Audi and Volvo. This is again because it has an odd number of cylinders just like the three cylinder configuration. Even though the three cylinder ones are odd, they are easier to repair and work on. A five cylinder is much harder to work on, hence it only being used in very nice cars. The five cylinder one also has a weird sound, called warbling.
- Six Cylinder Engine: A six cylinder engine is most commonly found on sports cars and they have a very high-pitched sound. This configuration is either built in the inline or the V-shaped engine. This is all depending on the car. If the manufacturing company is going for a slightly larger build, then it should be the V-shape. The V-shape is compact compared to how much power it outputs, but compared to an Inline engine, it is slightly larger horizontally (because the cylinders are at an angle).If it has a little bit of space to operate, it'll go with the straight line. The inline is much easier to work on and prepare, versus a V-shape being way more difficult and expensive, but you can fit more stuff in the V shape and get more performance out of it, compared to a similar size inline. With that being said, the inline saves you way more time and money during repairs. It can also be paired with a turbocharger/supercharger, and it gives it an immense amount of power. They are typically used in luxury cars like the BMW or Mercedes-Benz.
- Seven Cylinder Engine: Even though three cylinder engines are extremely common, they are basically the only odd number of chambers that you see. Luxury cars have 5, but those are obviously exclusive. You almost never see a seven cylinder engine. They almost never manufactured, and they do have the humming noises that other odd number engines have.
- Eight (or more) Cylinder Engines: Eight cylinder configurations are used in supercars. These are almost always in a V-shape engine layout, because again you don't have unlimited space. You want to have it in a compressed area, all while having the most amount of power possible, and the V-shape is the best option for that. These are found in

Bugattis, Ferraris, and even Lamborghinis. The base is eight cylinders, but then it goes ten, twelve, skips fourteen, and ends at sixteen. Manufacturers noticed that the difference between twelve and fourteen was not a good enough reason to justify building it, so they went straight up to sixteen cylinders. Sixteen cylinders is a very clever design, because they are placed in a W-shaped layout, rather than a V-shape. Manufacturers achieve this by taking the eight cylinders and slapping another one to the side of it. Together, the two V-shapes make a W. The sound of these engines are very similar to a lion, or a large cat's roar.

Electric Motors: The next major category of engines is electric motors. This is extremely important, because they are just larger versions of what we will use in our RC car build. Before getting into the five different types of electric motors, it is important to discuss how they all generally work. The most basic electric motor we have is a DC motor. It can be connected in series to a battery and a switch, and will run when the switch is closed. Electricity is the movement of electrons when there is a potential difference between two points. This is also what we refer to as current in Electrical Engineering. Current flows from the positive end to the negative end, so the orientation of a battery will determine what way the current flows.

[Insert two drawings for circle w bat, switch, and mot]

Current can be turned on and off, so this directional flow can be stopped. A magnet is a metal object with two poles: north and south. A magnet will attract metals to it, but it has a different reaction to other magnets. Since magnets, no matter the shape or size, always have two poles, this property will always apply: opposites attract, and the same side repels. This means that if the N side of a magnet gets close enough to the S side of another magnet, they will attract. If the N side of a magnet gets close enough to the N side of another magnet, they will repel. A magnet never turns off, so you have to create one that is similar. An electromagnet is when you wrap wire around metal and run a current through it. It does nothing when powered off, but when there is current flow, it will become a magnet with two sides. Electric motors work by placing an electromagnet on an axis, known as a rotor, and surrounding it with two other magnets, like two letter "C"s cupping a circle. One of the stators will be a S pole, and the other will be a N pole. It is important to note that they have a gap between them. Those stationary magnets that surround the rotor are known as the stator, because they do not move. The rotor having a N and S side, will spin downwards depending on whether or not it is in front of a N or S stator. If there is nothing else to this apparatus, the rotor will move down because it is attracted to one side, but then repel from the other side, and end up stationary in the gap. In order to change the force from repelling and keeping the rotor in the gap, you can flip the current by switching the orientation of the battery. When you switch the flow of electricity, you cause whatever side of the electromagnet was N, to be S, and vice versa. If you switch the flow of current right as the rotor is about to reach the gap, this causes it to attract again, and pull up the electromagnet. If you constantly switch the flow of current, the rotor will spin indefinitely. You could do this manually, but it is by no means realistic, so you use a component known as a commutator and a brush. A commutator is connected to the brushes like a wheel on an axle. As current flows through the brush, it causes the commutator to start the flow of electricity in the electromagnet. This allows the process of attraction to begin, and the rotor moves to the other side. Just as it reaches the point where reputation would start, the commuter hits the brush on the other side, and this causes the current to switch. Once it switches, the poles on the rotor change again, and it attracts again. Electric motors use wire coils as the rotor for a much smoother transition of attraction and repulsion. There is an increase of torque, as the wire coils increase, and that causes the motor to spin even faster. In smaller applications, there is an extension of the rotor, and that axis is connected to an object, which spins/turns something else. In larger applications like a car, the energy gets output into the transmission and that turns the axle of a car, just like the ICEs do.

The transmission is connected directly to an engine, so that takes all of the output from the engine, and transmits a torque into the wheels. For an ICE, that output is all that exhaust from the mini explosions. The output in an electric motor is very different. Electric motors are always found in electric vehicles EV's and they're being extremely prevalent on our roads today. This means way more care is being taken into making sure those people have power stations to charge their vehicles. The way an electric motor operates is on electromagnetic fields: an electric current flows through a coil of wire, and in the presence of a magnetic field, it generates force, and that force causes the rotor to turn. These rotors are in direct drive with an electric motor that can control a pair of wheels so once these motors are getting turned then, these wheels are also being turned. One benefit compared to ICE is its instant torque. It is also extremely quiet and it has zero emissions. Electric Vehicles are going to continue becoming more and more improved, whereas we're almost at the absolute cap for ICEs, because there's only so much you can possibly do without turning it into a hybrid. There are five types of electric motors: DC Series Motor, Brushless DC Motors, Permanent Magnet Synchronous Motor (PMSM), Three Phase AC Induction Motors, and Switched Reluctance Motors (SRM).

- <u>DC Series Motor:</u> The first type is the DC series motor. These are the most popular because they are powerful and efficient. These motors all vary in size, whether you're putting it in a truck or a SUV, or even a scooter, they all vary in size depending on the body of the car. DC Series Motors work by having a DC current coil, and that generates a magnetic field. Once the magnetic field is created, that creates rotational motion. Rotational motion is then put into the wheels, and that drives them. Some of the advantages are electricity consumption. Their efficiency increases as the speed decreases, which means instead of always having a minimum amount of consumption if you are going slower, you are going to consume less. This is great when you are in cities because electric vehicles do not have the longest battery life, so having a motor that consumes significantly less when you are just driving in a city, or when you are parking, or even when you are waiting in traffic. Also, when you just have to go slow because you are in a school zone. All these situations make it much better for electric vehicles over traditional ICE powered automobiles. The last thing they do is provide excelent speed control. This is because the motor is specifically working with exactly how much you put into the pedal. When you ease up on that, the machine immediately reacts to it and puts in less torque, so you can make it go faster and slower and control your speed just by moving your foot. Obviously the same thing goes for ICEs, because they are driven using gas pedals, but EVs are much more responsive than an ICE. Electric motors produce an immense amount of heat during operation so you need to have a bunch of temperature monitoring sensors, fans and a large cooling system installed around the motor. This requires maintenance and sometimes can be replaced, and the more you replace the cooler it will be, and the better the car will be in the long run.

- Brushless DC Motors: The brushless motors are very similar to the DC series motor. The difference is it doesn't have any brushes, which means the motor itself can be more compact and have a simpler design, so heat management and efficiency are both increased. This motor does not need any mechanical communication. It does not need bearings, which saves on parts right there, and the less parts that it has it means less initial costs in buying the materials to build a motor. It also means there are less things that can cause issues, so there are less manufacturing issues and upkeep costs with maintenance. Again, because this system is so simple, brushless DC Motors have even lower energy losses compared to a DC series motor. They have a higher energy saving, and the whole purpose of getting an electric vehicle is to save gas mileage, and have the most effective and efficient ride possible. This is an incredibly good option, as it has even more benefits including having lower friction so longer life expectancy is longer than a DC series motor. It also has higher torque capacity and it's quieter than the DC motor.
- Permanent Magnet Synchronous Motor (PMSM): The third option is the permanent magnet synchronous motor (PMSM). These are way more efficient than the previous options. It is more energy efficient due to its relationship between the stator and rotor. It requires less current compared to other models, while still receiving the same exact output of torque and speed. The rotor design also has advantages for torque because this permanent magnet can be adjusted to accommodate all needs. You can also have different configurations. A brushless DC motor just has a rotor and stator, whereas a PMSM has different types, all depending on how many poles are used. You can either have a single phase or three phase version, and those are the two that are most commonly used in electric vehicles. You can also have different winding options.
- Three Phase AC Induction Motors: Three phase AC induction motors are a really great option for multiple reasons. They have a much higher torque control compared to other electric vehicles, and that means that they get an extremely precise power output. These also are extremely power efficient so they are used in situations where energy conservation is important, such as areas where there is not a lot of sunshine, so you can not charge them using solar panels, or if you are not close to outlets. In those cases, you need to get as much charge as you possibly can out of it. These motors also have an amazing cooling system. The motors have a much lower risk of overheating, but the downside is that it only has a specific power output. It does not vary for many applications, so if you were looking for a car that just goes extremely fast and in a straight line, or even if it is a truck, you need to really get some power out of it when you are putting a bunch of stuff in it. Whereas, if you are looking for an everyday vehicle, not being able to control the amount of power you are getting out of the car, when you need to be able to go fast on the highway or slow down a random street. This is not gonna be a great everyday car, but a positive about that extremely precise power control is how power efficient it is. This extreme power efficiency will save you money in the long run with charging, and this will allow you to go further if you're gonna be driving out and about with your electric vehicle.

- Switched Reluctance Motors (SRM). The last option is switched reluctance motors (SRM). These are an extremely great option for torque, but they are way more cost-effective, compared to three phase induction motors. These are both very good comparisons because they both give precise power output. SRMs are made with an arrangement of electromagnets, and these produce magnetic fields when they're turned on This creates mechanical force required to drive the rotor, and makes a low variation as it rotates. This leads to a far more accurate torque, and is way easier to operate than other motors. They are also extremely efficient and have very low heat dissipation, which further their cost efficiency. The main benefit of a switched reluctance motor is how cost-effective it is while providing you a precise torque and speed ratings than all the other alternatives out there. It also has superior performance qualities like reduced levels of noise, pollution, and extreme reliability over time.

Hybrid Engines: The very last type of engine is a hybrid engine. These are a combination of internal combustion engines and electric motors. They operate on electric power at low speeds, and then switch to a combustion engine at a higher speed. The reason for this is because it does not need as much power at the lower speed, so it can use electricity, but it needs way more power at higher speeds, so it can use a combustion engine to get the most efficiency. The main advantages here are going to be fuel efficiency, because you're using electric power for city driving and then switch over onto a highway and you're able to go away faster when you need to. There is also reduced emissions, because Hybrids typically produce zero emissions. This means a clearer environment, and that was one of the issues that the United States was having back in the 60s, which led to a lot of the laws being passed to make manufacturers cut back on production. The best part about these cars is the reactive braking system. They have electric motors, so when you hit the breaks, the torque is stronger, and stops the car quicker. When they stop on a dime, the kinetic energy is being converted back into electrical energy, which is stored into the battery. Every time it stops, the energy is going back into the battery, and batteries are then able to reuse it later on. It's only a small amount because the system loses energy to heating and everything surrounding it. You are still able to save some of that energy that otherwise would've been completely wasted in a regular engine.

Transmission/Drivetrain: The transmission is incredibly important, as it is what takes the energy from the engine, and puts it into the wheels. The wheels are connected to an axle, so the transmission puts a torque on it, and causes it to spin. All cars control the transmission using one of two ways: automatic or manual. Automatic makes driving much simpler, as the transmission goes on when you put the car into drive (D). For manual cars, you need to constantly change the gear number, as these cars work up to specific speeds. The number gear you are on will determine your max speed, so the higher you go up, the faster you can drive.

The other main component is what type of wheel drive the car is. Wheel drive refers to what the transmission is applying torque to. The options are front two-wheel drive, rear two-wheel drive, and four-wheel drive. The first two are simple to explain. Depending on whether you want the drive to be in the front or rear, that is where you put the engine. The engine being on top of those wheels is important, as it gives it additional traction. The transmission connects to the axle of the specific wheels, and then turns it. Because the other axle is not connected anywhere, the axle moving will cause all four tires to move, which moves the car. Four wheel different, as the transmission is connected to all four tires. This means you do not need the engine in a specific place, but there are plenty of reasons to pick where you want the engine. If the engine is in the front of a four-wheel drive car, there will be another axle running down the middle of the car, connecting the front and back axles. The front wheels will be moving from the transmission, but since the transmission is also connected to the rear view ones, it will move as well. This is great for areas that really need traction, because it gives the car more area trying to grip on the ground.

Suspension System, Wheels, and Tires: This is what is known as the “base” of the car. You can have the greatest body and engine, but if the base is ont up to par, then the car will not perform. A suspension is to absorb vertical plane impact. Going over a speed bump or into a pothole are times when this is necessary. The suspension is built up of the wheel hub, springs, shock absorbers, links/arms/beams, anti-roll bar, and the subframe. The wheel hub is where tires are connected to the car, and as the wheel hub spins, so does the wheel. Springs are used to hold the car in place. If there is a bumpy road, this allows the car freedom to move in all directions, and still maintain its shape. Shock absorbers are pads that ease all of the pressure on surrounding components. Links/Arms/Beams are what help connect the axle to the frame of the car. By having them at right angles, it gives even more support than the absorbers. An anti-roll is just a way to keep the car in place. Normally a car will keep moving, even if it is parked on a hill. This ball allows all movement to stop immediately. The last piece is the subframe. This is what the suspension connects to the body of the car, and keeps everything in place.

Control Systems: The stirring and braking systems is what makes up this section. We discussed how fast a car can go, but it needs to be able to stop, and turn the wheels.

Electrical, Engine, and Climatic Subsystems and equipment: .With how advanced cars have gotten, they are absolutely covered in wires. These all serve a purpose, and the basics found in all cars include the power sources, consumers of said power, electrical wiring, and random elements. The two sources are the battery and generator. The generator builds up energy from the engine, and then distributes it to the car battery. The car battery then distributes this energy to the entire car. The consumers of power are things like headlights, GPS systems, and charging devices. Electrical wiring is what connects all of these components, and ensures that there is a constant flow of electricity to them. The random elements include buttons on the dashboard and switches like the ones to roll down windows.

3. Project Research

In this section, we will discuss the various different parts of research involved in creating our project. We will discuss similar projects that inspired us, different technologies that will be used in our project, and we will discuss how different parts and technologies will be selected and used in our project.

3.1 Similar Past Projects

As we enter the journey of our senior design project, it's important to acknowledge the history and evolution of robotics, particularly within the realm of educational robotics. The field of robotics has seen remarkable advancements over the decades, driven by a combination of technological innovation, scientific discovery, and educational initiatives.

The concept of remote-controlled (RC) cars, in particular, holds a special place in the records of robotics history. RC cars have served as both recreational toys and educational tools, captivating enthusiasts of all ages with their combination of technology, engineering, and entertainment.

The origins of RC cars can be traced back to the early 20th century, with the invention of the first remote control systems. Early prototypes were basic and limited in functionality, relying on simple radio frequency transmitters and receivers to transmit commands to the vehicle. Despite their limitations, these early RC cars captured the imaginations of enthusiasts, laying the groundwork for future advancements.

Throughout the mid-20th century, RC cars underwent significant advancements in design, technology, and performance. The introduction of more sophisticated control systems, such as proportional radio control and digital signal processing, revolutionized the capabilities of RC vehicles. This era saw the emergence of specialized RC car kits and racing events, creating a lively community of enthusiasts and innovators.

In recent decades, the convergence of robotics and RC technology has given rise to a new generation of educational robotics platforms. These platforms, represented by products like the Hiwonder Smart Robot Car and the DEERC RC Car, offer a unique blend of entertainment, education, and hands-on learning.

The Hiwonder Smart Robot Car, for example, represents an ideal shift in educational robotics, providing users with a versatile platform for learning electronics and programming. Its modular design, customizable features, and user-friendly interface make it an ideal tool for educators and students both.

Similarly, the DEERC RC Car embodies the spirit of innovation and exploration, pushing the boundaries of remote control technology with its advanced features and immersive experience. By combining performance, entertainment, and educational value, the DEERC RC Car inspires curiosity and creativity in users of all ages.

As we indulge into our senior design project, we get inspiration from the history and legacy of RC cars, recognizing their role as pioneers in the field of robotics education. By immersing ourselves in the study of similar past projects like the Hiwonder Smart Robot Car and the DEERC RC Car, we position ourselves to obtain valuable insights, strategies, and innovations that will shape the trajectory of our own project.

3.1.1 Hiwonder Smart Robot Car

While researching past projects, we were heavily inspired by the remarkable steps made in educational robotics, particularly by revolutionary products such as the Hiwonder Smart Robot Car. This project marks a significant moment where we aim to draw from the layers of robotics history, focusing particularly on the transformative impact of the Hiwonder Smart Robot Car.

The Hiwonder Smart Robot Car stands as a representation of innovation, reshaping the world of educational robotics with its versatile platform and accessible learning experience. Its influence extends far beyond just functionality. It represents exploration and discovery that resonates deeply with our project objectives.

At its core, the Hiwonder Smart Robot Car embodies a commitment to making robotics education accessible to all. Its user-friendly assembly process transcends basic construction, creating an environment where exploration and experimentation thrive. By analyzing its assembly instructions, component layout, and interface design, we gain valuable insights into simplifying complexity without sacrificing depth.
Moreover, the car's programmable nature serves as a gateway to boundless educational opportunities. Through its codebase and software interface, we explore the interplay between theory and practice, where concepts turn into tangible outcomes.

One of the most striking features of the Hiwonder Smart Robot Car is its modular design, which allows for endless customization and expansion. This modularity not only enhances the educational experience by encouraging experimentation but also ensures adaptability to a wide range of learning objectives and skill levels. Whether students are exploring basic concepts in robotics or delving into advanced programming techniques, the Hiwonder Smart Robot Car offers a platform that can evolve with their needs.

Additionally, the Hiwonder Smart Robot Car is equipped with a comprehensive set of sensors and peripherals, further enriching the learning experience. From ultrasonic sensors for obstacle detection to motor encoders for precise control, these components provide students with hands-on experience in working with real-world sensors and actuators. Furthermore, the integration of wireless connectivity allows for seamless communication with external devices, opening up possibilities for collaborative projects and remote control applications.

As we get into our senior design project, we draw inspiration from the foundational principles embodied by the Hiwonder Smart Robot Car. Our goal is not merely to replicate its features but to embrace its versatility, accessibility, and hands-on learning. By infusing our project with these guiding principles and leveraging the innovative design of the Hiwonder Smart Robot Car, we aim to create an educational experience that empowers and inspires, fostering creativity and innovation in students of all backgrounds.

3.1.2 DEERC RC Car
The DEERC RC Car stands as a fascinating embodiment of the relationship between entertainment, performance, and education, pushing the boundaries of remote control technology with its immersive experience. Beyond its exterior, which instantly captivates the eye, lies a testament to engineering prowess and technological innovation, positioning it as a frontrunner in the realm of educational robotics.

Some of the captivating aspects of the DEERC RC Car is its seamless integration of advanced control mechanisms and robust construction. Delving into its mechanical design, is carefully engineered components working in harmony to deliver optimal performance and user engagement. Each aspect, from the precision-engineered structure to the complexly designed electronic systems, reflects a dedication to quality and excellence that elevates the DEERC RC

Car beyond being a basic toy. It is a channel for exploration, where every movement serves to spark curiosity and stimulate the imagination.

However, what truly sets the DEERC RC Car apart is its multifaceted nature, which smoothly blends entertainment with education. Beyond its role as a source of amusement, the car serves as a powerful educational tool, offering a rich array of learning opportunities for users of all ages. Through interactive features, such as programmable control interfaces and immersive simulation environments, users are encouraged to explore fundamental concepts in robotics, programming, and engineering in an engaging and hands-on manner. Moreover, the DEERC RC Car creates a sense of community through its online platforms and community engagement initiatives, providing a space for users to share knowledge, collaborate on projects, and inspire one another.

Our integration of the principles embodied by the DEERC RC Car extends far beyond surface-level replication. It represents a deep rooted commitment to excellence and innovation. By infusing our project with the aspects of performance, entertainment, and educational enrichment represented by the DEERC RC Car, we aspire to craft an experience that transcends the ordinary.

Our vision is to create an educational robotics project that not only captivates the minds of users but also inspires curiosity, fosters creativity, and cultivates a lifelong passion for learning. Through careful planning, thoughtful design, and iterative development, we aim to build upon the legacy of the DEERC RC Car, creating an experience that leaves a lasting impact on the field of educational robotics and the individuals who engage with it.

3.1.3 Integration into Our Project

The insights gathered from an in-depth examination of the Hiwonder Smart Robot Car and the DEERC RC Car serve as the foundation of our project's development journey, laying the foundation for a path guided by innovation. Through a process of integration and adaptation, we hope to create an ample combination of features and functionalities that resonate deeply with the aspirations and expectations of our target audience, setting a model for transformative advancements in the realm of educational robotics.

Our approach to integration is more than simply replicating; it is a journey characterized by exploration, creativity, and a commitment to user-centric design principles. By infusing our project with curiosity-driven exploration and innovative problem-solving, we strive not only to meet but to exceed the expectations of our users, pushing educational robotics into a new era of immersive and engaging learning experiences.

Every feature and functionality identified through our research process undergoes refinement to ensure alignment with the preferences and aspirations of our target demographic. Analyzing a diverse array of inputs, including comprehensive customer feedback, extensive market analysis, and deep insights gathered from the study of existing products, we carefully craft a roadmap toward innovation and excellence in educational robotics.

Embracing a divide-and-conquer approach, our project is structured to facilitate a comprehensive and cohesive development process. Each aspect of the design is carefully crafted to deliver maximum impact, generating a smooth integration of components and functionalities that enhance the overall user experience. By aligning our vision with the aspirations and needs of our users, we will go on a transformative journey powered by a relentless pursuit of excellence, where curiosity is nurtured and creativity flourishes.

Through dedication, perseverance, and a persistent pursuit of innovation, we aspire to redefine the world of educational robotics, leaving an undeniable mark on the field and inspiring future generations of innovators and educators. In our journey to push the boundaries of what is possible, we remain faithful in our commitment to creating educational experiences that not only empower learners but also creates a deep and enduring love for exploration, discovery, and lifelong learning.

3.2 Technology Overview and Comparison

The RC Car will be revolutionized with cutting-edge technology, as it will be controlled seamlessly through a dedicated mobile application. This innovative approach not only enhances user experience but also opens up a realm of possibilities for customization and advanced functionalities. Leveraging Arduino technology, the app empowers users to control the car effortlessly, with features such as directional control, speed adjustment, and even programmable routes. Technologies like Arduino IDE, which offers a user-friendly platform for programming Arduino boards, and libraries such as Bluetooth Low Energy (BLE) communication protocols, facilitate the development of the app. Additionally, frameworks like MIT App Inventor and platforms such as Blynk enable the creation of intuitive user interfaces and seamless connectivity between the mobile device and the Arduino-powered RC Car, ensuring a seamless and immersive control experience. With these tools at hand, the RC Car becomes not just a toy, but a gateway to explore the fascinating intersection of mobile app development and robotics.

3.2.1 Possible Technologies

1. **Arduino IDE:**
   The Arduino Integrated Development Environment (IDE) is a software platform used to write and upload code to Arduino boards. It provides a streamlined interface for writing, compiling, and uploading code to Arduino microcontrollers. Arduino IDE supports a variant of the C++ programming language, making it accessible to beginners while still offering advanced features for experienced developers. Its simplicity and compatibility with a wide range of Arduino boards make it a popular choice for programming Arduino-based projects like the RC Car.

2. **Bluetooth Low Energy (BLE):**
   Bluetooth Low Energy is a wireless communication protocol designed for short-range communication with low power consumption. It enables devices like smartphones and tablets to communicate with peripherals such as Arduino-based projects over short distances. BLE is particularly suitable for applications like controlling an RC Car from a mobile app, as it allows for reliable communication while conserving battery life. Arduino boards equipped with BLE modules or shields can establish a connection with a mobile device, enabling bidirectional communication for controlling the RC Car.

3. **MIT App Inventor:**
   MIT App Inventor is a web-based platform developed by the Massachusetts Institute of Technology (MIT) for creating Android applications without requiring extensive programming knowledge. It features a visual drag-and-drop interface that allows users to design the user interface and define the functionality of their apps using blocks of code. MIT App Inventor provides a beginner-friendly environment for developing mobile apps to control Arduino-based projects like the RC Car. Users can easily integrate features such as buttons, sliders, and sensors into their apps to control the car's movements and behavior.

4. **Blynk:**
   Blynk is a platform that simplifies the process of building IoT (Internet of Things) projects by providing a comprehensive suite of tools for developing mobile apps and connecting them to hardware devices. It offers a range of widgets and libraries that enable users to create customized interfaces for controlling and monitoring Arduino-based projects remotely. Blynk supports various communication protocols, including Wi-Fi, Bluetooth, and Ethernet, allowing users to choose the most suitable connectivity option for their projects. With Blynk, developers can quickly prototype and deploy mobile apps to control the RC Car, leveraging its intuitive interface and robust backend infrastructure.

3.2.2 Comparison of Technologies

Before diving into the comparisons of various technologies for controlling Arduino-based RC Cars, it's essential to understand the landscape of tools available for such projects. These technologies play a crucial role in shaping the development process, influencing factors such as ease of use, popularity, and complexity. By evaluating each technology against these criteria, developers can make informed decisions about which tools best suit their needs. Let's explore the ratings of Arduino IDE, Bluetooth Low Energy (BLE), MIT App Inventor, and Blynk, considering factors such as ease of use, popularity, and complexity, to gain insights into their suitability for creating apps to control Arduino-powered RC Cars.

1. **Arduino IDE:**
   - Ease of Use: 4/5 - Arduino IDE is generally considered user-friendly, especially for beginners due to its simple interface and extensive documentation.
   - Popularity: 5/5 - Arduino IDE is highly popular within the maker and hobbyist community, with a large user base and active online forums for support.
   - Complexity: 3/5 - While Arduino IDE is relatively straightforward for basic projects, more complex functionalities may require a deeper understanding of programming concepts.

2. **Bluetooth Low Energy (BLE):**
   - Ease of Use: 3/5 - BLE can be moderately challenging for beginners due to its technical nature, but there are libraries and resources available to simplify implementation.
   - Popularity: 4/5 - BLE is widely used in IoT and mobile applications, making it a popular choice for connecting Arduino projects to mobile devices.

- Complexity: 4/5 - Implementing BLE communication can be complex due to factors such as pairing, security, and compatibility with different devices.

3. **MIT App Inventor:**
    - Ease of Use: 5/5 - MIT App Inventor is exceptionally user-friendly, with a visual drag-and-drop interface that simplifies app development, particularly for beginners.
    - Popularity: 4/5 - MIT App Inventor is popular among educators, students, and hobbyists for its simplicity and accessibility.
    - Complexity: 2/5 - While MIT App Inventor is easy to use, it may lack the flexibility and advanced features required for more complex app development projects.

4. **Blynk:**
    - Ease of Use: 4/5 - Blynk provides a user-friendly platform for building IoT projects, with intuitive drag-and-drop widgets and straightforward configuration options.
    - Popularity: 4/5 - Blynk has gained popularity in the IoT community for its versatility and ease of use, with a growing user base and active community support.
    - Complexity: 3/5 - While Blynk simplifies the process of building IoT applications, setting up and configuring the platform may require some technical expertise, especially for advanced features.

3.2.3 Connecting The Controller To The Remote Control Car

A controller will be designed to control our car remotely. Three different wireless technologies will be discussed for controlling the car remotely: Wifi, Bluetooth, and infrared transmission.

3.2.3.1 Wireless vs. Wired Communication

The controller needs to be able to communicate to the remote control car. To do this, there are two types of communication that need to be considered: wired and wireless communication. The advantages of wired communication are that it would be faster and more stable because there would be less interference from other sources. However, there is no need for a higher data transfer rate because the communication between the controller and the remote control car will be simple. Also, having a wired connection between the controller and the car will mean there will be less range that the car can travel based on how long the physical connection is. Therefore, we have decided that some form of wireless connection would be the best as it would extend the range that the car can travel. Typically, toy cars are remote controlled and use a wireless connection due to this reason.

3.2.3.2 Wifi vs. Bluetooth

Two common forms of wireless communication are Wifi and Bluetooth. For our project, we can consider both for connecting the controller to the car. Both Wifi and Bluetooth operate at 2.4 GHz, so they will both have similar interferences. Wifi can also operate at 5 GHz, but the higher speed that comes with the higher frequency is not necessary as there will not be much data transfer between the controller and the car. Wifi offers higher data transfer speeds than Bluetooth. Bluetooth has higher latency than Wifi but the difference is negligible for our purpose. Wifi typically offers a higher range than Bluetooth, however, we would not need as much range as Wifi would provide. Bluetooth would be more ideal because it uses less power due to having a lesser speed and Bluetooth is typically used for connecting two devices. Also, we do not need the higher range and the higher speed that Wifi provides. The mobile application will also be using the Wifi interface, so it may not be ideal to be having both the controller and the mobile application using the same interface if for some reason we want to use both the application and the controller simultaneously. However, we will consider another option: infrared.

3.2.3.3 Bluetooth vs. Infrared Transmission

Another option of wireless communication is infrared. Both Bluetooth and infrared transmission are used to transfer data over short distances. However, Bluetooth devices do not have to be within line-of-sight of each other. Infrared transmission requires a line-of-sight connection. You will probably not be driving the remote control car unless you could see where you are driving it so this does not matter. Infrared transmission also has less range than Bluetooth, however, the person using the controller would also not be very far from the car. Bluetooth can connect up to multiple devices at a time, while infrared transmission works on a one-to-one basis where one device will communicate to the other one. Compared to Bluetooth, infrared transmission is also much simpler to use and there is less interference. In addition, infrared transmission is typically used for remote control cars.

3.2.3.4 Selecting Technology To Connect The Controller To The Remote Control Car

To summarize, three different wireless technology options were discussed and compared: Wifi, Bluetooth, and infrared transmission. It was ultimately decided to use infrared transmission to connect the controller to the remote control car because it is simple, there is less interference from other devices, and both Bluetooth and Wifi offer higher ranges that are not needed. Also, Wifi offers higher speeds that are not necessary for simple communication between the controller and the remote control car. The Wifi interface will also be used to connect the mobile application to the remote control car, so it would not be ideal if we wanted to use the controller and the mobile application simultaneously. Also, it is typical for remote control cars to communicate with the controller via infrared transmission, so it is clearly a good option. Infrared transmission is also much simpler compared to Bluetooth and Wifi. In conclusion, we chose infrared transmission because there is less interference and it is simple compared to Bluetooth or Wifi.

3.2.4 Infrared Transmission Protocols

In this section, we will discuss two of the more common protocols used in infrared transmission. The two protocols we will be discussing are: the NEC protocol and the RC5 protocol.

3.2.4.1 NEC Protocol

The NEC protocol is an infrared transmission protocol based on a technique called pulse distance encoding. The NEC protocol uses a carrier frequency of 38 kHz. The protocol distinguishes between 0’s and 1’s by using pulses of different lengths. In the NEC protocol, a logical 1 is encoded in a 562.2 microsecond burst followed by a 1.687 ms low period. A logical 0 is represented by a 562.2 microsecond burst followed by a 562.2 microsecond low period.

Therefore, in the NEC protocol, the difference between a logical 1 and a logical 0 is in the width of the low period. The message frame for the NEC protocol consists of a 9 ms leading burst to start the transmission, a 4.5 ms low period, the 8-bit address of the device, the logical inverse of the first 8 bits, the 8 bit command, the logical inverse of the last 8 bits, and a 562.2 microsecond burst to end the transmission. To summarize, the first 8 bits of the message is the device address and the second 8 bits is the command. The inverse of the first and the second 8 bits is used to check that the address and the command were sent and received correctly. The NEC protocol can support repeat commands to send repeat messages to the receiver.

3.2.4.2 RC5 (Philips) Protocol

The RC5 protocol, also called the Philips protocol, is based on an encoding technique called Manchester encoding. The RC5 protocol uses the order of the pulses and breaks in the message to represent the different bits. The RC5 protocol uses a 36 kHz carrier frequency, whereas the NEC protocol uses a 38 kHz carrier frequency. In the RC5 protocol, a logical 1 is represented by a 889 microsecond low period followed by a 889 microsecond burst. A logical 0 is represented by a 889 microsecond burst followed by a 889 microsecond low period. Therefore, the width of the pulse does not vary between bits and the value of the bit is determined by whether the burst is first or if the low period is first. The message frame contains two start bits, which are both high, to determine the start of the message, a toggle bit, five address bits, and six command bits. The toggle bit is used to determine whether a repeat message is being sent. For example, if a button is being pressed once, the infrared emitter will just send one message and each time the button gets pressed, the toggle bit will be toggled so the device can know if the same message is repeated by a button press or by the button being held down. If a button is held down, the infrared emitter may send multiple repeat messages, so each time the toggle bit will remain the same unless it is a new copy of that message, so that the receiving device can detect repeat messages. In the RC5 protocol, a message takes approximately 24.892 ms to send.

3.3 Part Overview and Comparison

Once we decided that we were going to make an RC car, we needed to figure out all the components we needed. The smartest option would be to buy a kit and work off that. After doing research, we got three different options: (REORDER THESES THREE) ELEGOO Conqueror Robot Tank Kit, Metal Smart Robotic RC Tank Chassis Kit, and ELEGOO UNO R3 Project Smart Robot Car Kit V4.

The first option is the tank Chassis Kit. It is the cheapest option, which is a huge factor, coming in at only $25.99. It comes with a metal frame, a four DC motors, four plastic driving wheels that connect to the motors, and two plastic engineering tracks. The best parts about this kit is the price, the physical looks, because everyone thinks tanks look awesome, and the metal frame is flat and wide, so it is very easy to build off of. It also has a lot of holes in it, so you can feed all of the wires through, and screw all of the components down. The worst part of this kit is how basic it is. It leaves a lot of room for a creative design, but we have to purchase everything. Components are cheaper when you buy a bunch of them together, and we have to order every single part. This means it'll be more expensive in the long run, and we could make a mistake by either buying the wrong stuff, or completely forgetting some parts. All in all, buying a more complete kit is a much better option.

The second option is the ELEGOO Conqueror Robot Tank Kit. This kit is $129.99, so it is the most expensive of the three options, but is also the most complete of them. It comes with a four part metal frame, an arduino uno copycat, extension shield, a camera module that can film and upload the recordings with a switch of a button, two servos and an ultrasonic sensor, two large DC motors, driver chips that are connected to the shield, an infrared remote that sends signals to a sensor on the extension shield, two large tank tracks, a 7.4v Lithium Battery Pack, and a bunch of nuts and bolts to connect everything. It also comes with a photoelectric sensor, which is used for line tracking and will automatically follow a black line on ground. The arduino also has a WI-FI module, so you can download their companion app and then connect to the robot. The app is very similar to what we were planning on doing, as it shows what the camera sees, and it lets you drive the car remotely. Our app will be more detailed than this, but it is still good to use their app first, to test all of the components and make sure they work. Overall, the tank is an awesome design, its large frame still has room to add on your own components, and it comes with every single part you could need, but it is really expensive. Being $50 more than the next closest is a big deal.

The last option is the ELEGOO UNO R3 Smart Robot Car Kit. It is $80, so it is right in the middle of the other options. It is extremely similar to the second option, because it comes with a body, arduino copy cat, shield extension, camera module, ultrasonic sensor, one servo, four DC motor and motor drivers, four wheels, and an infrared remote. It also has the photoelectric sensor, the same 7.4v battery, and WI-FI module that lets you connect the app to it. The biggest difference is the design of the car. The other two are tanks and have tracks as wheels, whereas this one is a car and has four wheels. This is probably the biggest fault of this option, because again, tanks are awesome. With all that being said, it is the best option. The price is perfectly reasonable and it has all the needed components, so that is why we decided to go with this kit!

At the time of ordering the Smart Robot Kit, it was on sale for (INSERT EXACT PRICE). Here are is the exact breakdown of all the components in the kit:

We are going to use our own PCB to control the car, but there are

3.3.1 Microcontroller

In this section, we will discuss and compare several different microcontrollers to be considered for our custom PCB for the controller. The microcontroller will be reading from inputs such as buttons and an analog stick, and will be sending information over an infrared transmitter to the remote control car. The four microcontrollers that we will be considering are: the ESP8266, the RP2040, the ATmega328P, and the ESP32.

3.3.1.1 ESP8266

The ESP8266 microcontroller is designed by Espressif Systems. The ESP8266 features integrated WiFi, a 32-bit RISC processor, a GPIO interface, an SDIO interface, an SPI interface, an I2C interface, an I2S interface, a UART interface, a PWM interface, an IR remote control interface, and an ADC. The integrated WiFi has 802.11 b/g/n support with a maximum speed of 72.2 Mbps at 2.4 GHz. WiFi channels 1 through 14 are also supported. The 32-bit processor is a Tensilica L106 32-bit RISC processor, which has a maximum clock frequency of 160 MHz. The

ESP8266 also has 50 KB of SRAM. The microcontroller has no internal memory, so the code must be stored in an external flash memory module. The microcontroller requires a minimum of 512 kB of external flash memory and can support up to 16 MB of external flash memory. The ESP8266 has a total of 32 pins. 17 of those pins are GPIO pins which can be multiplexed with the I2C, I2S, UART, PWM, IR remote control, and the ADC functions. The ESP8266 requires a minimum operating voltage of 2.5V, and a maximum operating voltage of 3.6V. So, the ESP8266 has an operating voltage of 3.3V. The maximum current the ESP8266 can draw is 12 mA. The ESP8266 is currently available at a cost starting from $1.60 on the Mouser Electronics store.

3.3.1.2 RP2040

The RP2040 microcontroller is designed by Raspberry Pi Ltd. It is used by the Raspberry Pi Pico microcontroller board and other microcontroller boards. The RP2040 contains a 32-bit dual-core ARM Cortex-M0+ processor, 264 kB of SRAM, 30 GPIO pins. Like the ESP8266, the RP2040 does not have internal memory, so the code must be stored in an external memory module. Like the ESP8266, the RP2040 can support up to 16 MB of external flash memory. Of the 30 GPIO pins, 4 of those pins can be used as analog inputs and 2 pins support UART. There are 2 SPI controllers and 2 I2C controllers, there are 16 PWM channels, there is a USB 1.1 controller, and 8 PIO state machines. Unlike the ESP8266, The RP2040 does not have integrated WiFi. Like the ESP8266, The RP2040 has an operating voltage of 3.3 V. The RP2040 has a maximum current of 50 mA.The RP2040 also has a maximum clock frequency of 133 MHz. The RP2040 is currently available at a cost starting from $0.70 on the Mouser Electronics store.

3.3.1.3 ATmega328P

The ATmega328P is a 8-bit microcontroller designed by Atmel. The ATmega328P is used by the Arduino Uno R3 microcontroller board and other microcontroller boards and is also used in the automotive industry. The ATmega328P includes 2 KB of SRAM, 6 PWM channels, an SPI interface, an I2C interface, and an 8-channel 10-bit ADC. Unlike the ESP8266 and the RP2040, the ATmega328P has 32 KB of internal flash memory. It does not have external flash memory support nor does it have integrated WiFi. The microcontroller also has a maximum clock frequency of 16 MHz. The ATmega328P has a minimum operating voltage of 2.7 V and a maximum operating voltage of 5.5 V. At a clock frequency of 16 MHz, and an operating voltage of 5 V, the ATmega328P has a maximum current draw of 14 mA. The ATmega328P is available at a cost starting from $1.56 on the Mouser Electronics store.

3.3.1.4 ESP32 Series

The ESP32 microcontroller is designed by Espressif Systems. The ESP32 features integrated WiFi, integrated Bluetooth, a 32-bit Xtensa LX6 processor, 520 KB of SRAM, 34 GPIOs, a 12-bit ADC, two 8-bit DACs, 10 touch sensors, 4 SPI interfaces, 2 I2S interfaces, 2 I2C interfaces, 3 UART interfaces, an ethernet interface, a motor PWM, and an LED PWM with up to 16 channels. The ESP32's integrated WiFi has 802.11 b/g/n support and can transfer up to 150 Mbps. The CPU for the ESP32 requires an external clock source by default. Depending on the specific model number, the ESP32 can come with internal flash storage or no internal flash storage so it may or may not require external flash memory depending on the model number purchased. The ESP32 can support multiple flash memory modules and RAM modules via a QSPI interface. The minimum operating voltage is 1.8 V, and the maximum operating voltage is 3.6 V. So, the ESP32 can operate at a voltage of 3.3V. The maximum current that can be supplied is 500 mA. The ESP32 is currently available at a cost starting $1.85 on the Mouser Electronics store.

3.3.1.5 Microcontroller Summary

The comparisons above can be summarized in the table below:

	ESP8266	RP2040	ATmega328P	ESP32 Series
WiFi?	Yes	No	Yes	Yes
Bluetooth?	No	No	No	Yes
Internal Flash Storage?	No	No	Yes	Depends on model number
SRAM Capacity	50 KB	264 KB	2 KB	520 KB
# of GPIO Pins	17	29	23	34
# Of I2C Interfaces	1	2	1	2
# Of SPI Interfaces	2	2	1	4
# Of UART Interfaces	2	2	1	3
Operating Voltage	3.3 V	3.3 V	3.3 V/5 V	3.3 V
Maximum Current Draw	12 mA	50 mA	14 mA	500 mA
Price	$1.60	$0.70	$1.56	$1.85

To summarize, the RP2040 is the only microcontroller of the four considered that does not have integrated WiFi. The ESP32 is the only microcontroller that has integrated Bluetooth. The controller does not require Wifi or Bluetooth capability, so that was not a factor in determining which microcontroller to use. The ESP32 has the most SRAM capacity at 520 KB and the ATmega328P has the least SRAM capacity at 2 KB. The RP2040 has 264 KB of SRAM capacity and the ESP8266 has 50 KB of SRAM capacity. The ATmega328P may not have enough SRAM for our project, so that microcontroller will not be considered because we do not want that to constrain the performance. Also, since the controller will have a limited number of peripherals, the number of I/O interfaces and the number of GPIO pins does not matter too much. All of the microcontrollers are also priced similarly so that is not a factor in choosing a microcontroller to use. The ESP32 has more features than is needed so it is not necessary. Therefore, the ESP8266 microcontroller will be chosen for our controller for the remote control car because it is a simplistic microcontroller with minimal features and has sufficient SRAM capacity. The ESP8266 also draws the least power, which will be advantageous to extend the battery life of the controller. The number of GPIO pins and I/O interfaces on the ESP8266 are also sufficient.

3.3.2 Infrared Emitter

The custom PCB for our controller will require an infrared emitter to send data to the remote control car. The ESP8266 has an in-built infrared remote control interface, however, this will not be sufficient for our project because the range is limited to about 1 meter. Ideally, we will want an IR emitter that emits a wavelength of 940 nm, as the maximum spectral sensitivity is at that wavelength for an IR emitter, so the IR emitter will have the maximum range at that wavelength. Also, we will want an IR emitter with a side view because the controller will need line of sight to the remote control car and will need to be pointed at the remote control car. In this section, we will discuss and compare three different options to use for our infrared emitter.

3.3.2.1 CSL1501R3T1

The CSL1501R3T1 is an IR LED created by ROHM Semiconductor. The CSL1501R3T1 is a side view, surface mount IR LED. This model has a maximum power dissipation of 100 mW, a maximum forward current of 50 mA, and a maximum peak forward current of 200 mA. The forward voltage across the LED is 1.5 V. The radiant intensity of the LED is 2.5 mW/sr. The wavelength of this LED is 940 nm. The CSL1501R3T1 also has a viewing angle of 70 degrees. The CSL150R3T1 is currently available at a cost of $0.71 on the Mouser Electronics store.

3.3.2.2 VSMB10940

The VSMB10940 is an IR LED created by Vishay Semiconductors. It is a side view, surface mount IR LED. This IR LED has a maximum forward current of 65 mA, a maximum peak forward current of 130 mA, and a maximum power dissipation of 104 mW. The forward voltage across the LED is 1.3 V. The radiant intensity of the LED is 3.05 mW/sr at a forward current of 65 mA. The wavelength of this LED is 940 nm. The viewing angle of the LED is 75 degrees. Compared to the previous model, this is a very similar model. The viewing angle is slightly higher, the power dissipation is slightly higher, the maximum forward current is slightly higher, and the radiant intensity is slightly higher. However, this is a cheaper model than the CSL1501R3T1. The VSMB10940 is currently available at a cost of $0.39 on the Mouser Electronics store.

3.3.2.3 IN-S126ESGHIR

The IN-S126ESGHIR is an IR LED created by Inolux. It is a side view, surface mount IR LED. This IR LED has a maximum power dissipation of 180 mW, a maximum forward current of 100 mA, and a maximum peak forward current of 1000 mA. The forward voltage across the LED is 1.5 V. The radiant intensity of the LED is 92 mW/sr. The wavelength of this LED is 940 nm and the viewing angle is 30 degrees. Compared to the other two models, this IR LED is a higher power LED with a higher radiant intensity. The viewing angle is also more narrow, which means this IR LED will have better range and connectivity than the other two. The IN-S126ESGHIR is currently available at a cost of $0.55 on the Mouser Electronics store.

3.3.2.4 Infrared Emitter Summary

The comparisons above can be summarized in the following table:

	CSL1501R3T1	VSMB10940	IN-S126ESGHIR
Max. Power Dissipation	100 mW	104 mW	180 mW

Max. Forward Current	50 mA	65 mA	100 mA
Max. Peak Forward Current	200 mA	130 mA	1000 mA
Forward Voltage	1.5 V	1.3 V	1.5 V
Radiant Intensity	2.5 mW/sr	3.05 mW/sr	92 mW/sr
Viewing Angle	70 degrees	75 degrees	30 degrees
Wavelength	940 nm	940 nm	940 nm
Cost	$0.71	$0.39	$0.55

In summary, all three models compared were side view IR LEDs with a wavelength of 940 nm. The CSL1501R3T1 and the VSMB10940 both had similar power dissipation, similar forward current, similar forward voltage, similar viewing angle, and similar radiant intensity. The VSMB10940 was cheaper than the CSL1501R3T1 and had slightly higher maximum power dissipation, maximum forward current, radiant intensity, and viewing angle. This means that this LED was slightly more powerful than the CSL1501R3T1 and would have slightly better transmissivity and slightly better range. However, the IN-S126ESGHIR was the most powerful LED out of the three and was in the middle in the price range. The maximum power dissipation for this model was 180 mW, which is substantially higher than the other two models. The maximum forward current was 100 mA. The forward voltage was 1.5 V, which was similar to the other two models. The IN-S126ESGHIR also had a radiant intensity of 92 mW/sr, which was substantially higher than the other two models and had a narrower viewing angle of 30 degrees. This means the infrared beam would be more concentrated and higher power, so this LED would have the best range and the best transmissivity out of the three models. In conclusion, the IN-S126ESGHIR would be the best IR emitter out of the three and that was what was chosen for the project.

3.3.3 External Flash Memory

For the ESP8266 microcontroller on the custom PCB, external flash memory is required for storing our code. The ESP8266 microcontroller will need to be configured to read our code from the external flash storage module via an SPI interface. In this section, we will discuss and compare different options to use for our external flash storage module. The different options we will be discussing are two similar models from ISSI, three similar models from Winbond Electronics, and a model from onsemi.

3.3.3.1 IS25WP016D/IS25LP016D

The IS25WP016D model and the IS25LP016D model are flash memory storage chips created by ISSI. This model has a memory capacity of 16 Mb. This model has a maximum clock frequency of 133 MHz in fast read mode and has a maximum clock frequency of 50 MHz in normal mode and supports up to 66 Mbytes/s of data throughput. Data is stored in 256 byte pages. This model offers 100,000 erase cycles and more than 20 years of data retention. The IS25WP016D has a supply voltage between 1.65 V to 1.95 V and the IS25LP016D has a supply voltage between 2.3 V to 3.75 V, so the IS25LP016D would be more ideal for our project because our microcontroller requires a supply voltage of 3.3 V, so both could use the same supply voltage. This model has a maximum current usage of 25 mA. The IS25WP016D model is currently available for $0.65 at the Mouser Electronics store and the IS25LP016D model is currently available for $0.57 at the Mouser Electronics store.

3.3.3.2 W25Q16RV/W25Q16JW/W25Q16JV

The W25Q16RV, the W25Q16JW, and the W25Q16JV models are flash memory storage chips created by Winbond Electronics. Similar to the ISSI models, all of these Winbond Electronics models have a memory capacity of 16 Mb and a maximum clock frequency of 133 MHz. Also, the Winbond Electronics models have a data transfer rate of up to 66 Mbytes/s. The Winbond Electronics models have 256 byte programmable pages. These models can withstand a minimum of 100,000 erase cycles and have more than 20 years of data retention. The W25Q16JW model requires a supply voltage between 1.65 V and 1.95 V. The W25Q16RV model and the W25Q16JV model require a supply voltage of 2.7 V to 3.6 V. Either the W25Q16RV model ro the W25Q16JV model is more ideal because it could use the same supply voltage as the microcontroller. The W25Q16JV model uses a maximum current of 25 mA, the W25Q16JW model uses a maximum current of 20 mA and the W25Q16JV model uses a maximum current of 15 mA. Therefore, the W25Q16JV model would be more ideal because it uses slightly less power. The Winbond Electronics models are almost identical to the ISSI models except the Winbond Electronics W25Q16JV model uses slightly less current. The W25Q16JV model is currently available starting from $0.50 at the Mouser Electronics store.

3.3.3.3 LE25U40PCMC-AH

The LE25U40PCMC-AH model is a flash memory storage chip created by onsemi. This model has a memory storage capacity of 4 Mb, which is less than the 16 Mb of capacity offered by the ISSI and the Winbond Electronics models. This model has a clock frequency of 30 MHz and has a supply voltage between 2.3 V and 3.6 V, so it can use the same supply voltage as the microcontroller. Each programmable page is 256 bytes. Similar to the ISSI and Winbond Electronics models, this model offers 100,000 erase cycles and 20 years of data retention. This model does not have QSPI, whereas the Winbond Electronics models and ISSI models support QSPI. This model only supports dual read. This model has a maximum current usage of 15 mA. The LE25U40PCMC-AH is currently not available.

3.3.3.4 External Flash Memory Summary

The comparisons above can be summarized in the table below:

	IS25LP016D	W25Q16JV	LE25U40PCMC-AH
Suppy Voltage	3.3 V	3.3 V	3.3 V
Memory Capacity	16 Mb	16 Mb	4 Kb
Clock Frequency	133 MHz	133 MHz	33 MHz
Maximum Current	25 mA	15 mA	15 mA
QSPI Support?	Yes	Yes	No

Price	$0.57	$0.50	N/A

To summarize, the three models that were considered were the IS25LP016D from ISSI, the W25Q16JV from Winbond Electronics, and the LE25U40PCMC-AH from onsemi. The W25Q16JV model was chosen to be used as the external flash memory storage chip to be used in our project. All three models are NOR flash memory chips, and all three models require a supply voltage of 3.3 V. So, those two things were not a determining factor in which model we used. The IS25LP016D and the W25Q16JV both have a memory capacity of 16 Mb, which is higher than the memory capacity of the LE25U40PCMC-AH. The LE25U40PCMC-AH also has a lower clock frequency compared to the IS25LP016D and the W25Q16JV, which means there will be slower data transfer. The LE25U40PCMC-AH also does not have QSPI support; it only supports up to dual read. Therefore, the options were narrowed down to either the IS25LP016D and the W25Q16JV. The W25Q16JV was chosen over the IS25LP016D because although both options were nearly identical, the W25Q16JV uses slightly less power and the W25Q16JV has greater availability online currently than the IS26LP016D. The LE25U40PCMC-AH flash memory storage did not have any availability online currently.

4. Standards and Design Constraints

In this section, we will discuss the different standards involved in creating the Rock 'N' Rover. We will also discuss some design constraints that will affect the development of the project.

4.1 Standards

Standards form the backbone of any engineering project, serving as a blueprint for safety, reliability, and efficiency across various domains. In the realm of safety, adherence to established standards ensures that equipment, processes, and structures meet rigorous criteria, minimizing risks to personnel and the environment. In software development, standards guarantee interoperability, compatibility, and security, facilitating seamless integration and reducing vulnerabilities. Electrical standards ensure that systems operate reliably, preventing hazards such as short circuits or overloads. Mechanical standards dictate design specifications and manufacturing processes, optimizing performance and longevity while mitigating failure risks. Communication standards foster interoperability among disparate systems, enabling seamless data exchange and collaboration. Documentation standards establish clear guidelines for recording project details, facilitating comprehension, maintenance, and future modifications. Finally, quality assurance standards provide a framework for consistent evaluation, verification, and validation, ensuring that products and processes meet predefined criteria for functionality and performance. Ultimately, adherence to these standards is paramount, as they collectively safeguard against potential hazards, ensure operational integrity, and uphold the overall quality of engineering endeavors.

The Rock 'N' Rover project underscores the critical importance of meeting all necessary standards for optimal success. In every aspect of its design and implementation, from safety protocols to software integration, electrical systems, mechanical components, communication interfaces, documentation practices, and quality assurance measures, adherence to established standards is paramount. Ensuring that the Rock N Rover project complies with these standards not only mitigates risks but also enhances performance, reliability, and efficiency. By meticulously following industry best practices and regulatory guidelines, the Rock N Rover team fosters confidence in the project's outcomes, bolstering its potential for groundbreaking achievements in exploration and discovery.

4.1.1 Safety Standards

Safety standards are an indispensable aspect of product development, crucial for ensuring occupational health and safety in various industries. These standards establish a comprehensive regulatory framework aimed at identifying, assessing, and mitigating risks and hazards associated with product development and utilization across different sectors. They entail meticulous evaluation of potential threats, strict adherence to statutory directives, and the integration of preventive measures throughout the design, manufacturing, and operational phases. Adhering to robust safety protocols not only minimizes the risk of accidents and injuries but also enhances overall workplace efficiency and productivity. By prioritizing safety standards, organizations demonstrate their commitment to safeguarding employee well-being, fostering a culture of safety, and complying with regulatory requirements. This ensures a conducive working environment and contributes to the promotion of occupational health and safety practices across industries. Here are several key points highlighting the importance of safety standards in a project:

1. **Protection of Personnel:** Safety standards are primarily in place to protect the lives and health of all personnel involved in a project. Whether it's construction workers, engineers, technicians, or any other professionals, adherence to safety standards minimizes the risk of accidents, injuries, and fatalities in the workplace.

2. **Legal Compliance**: Most jurisdictions have stringent laws and regulations governing workplace safety. Compliance with these standards is not only a moral imperative but also a legal requirement. Failure to adhere to safety standards can lead to legal repercussions, fines, lawsuits, and even project shutdowns.

3. **Risk Mitigation:** Projects often involve various hazards, whether it's working at heights, handling heavy machinery, or dealing with hazardous materials. Safety standards help identify, assess, and mitigate these risks through measures such as personal protective equipment (PPE), safety procedures, and hazard controls.

4. **Enhanced Productivity:** Ensuring a safe working environment can contribute to increased productivity. When workers feel safe and secure, they are more focused, motivated, and efficient in their tasks. Conversely, accidents and injuries can disrupt workflow, lead to downtime, and hamper project progress.

5. **Cost Savings:** Implementing safety standards may require an initial investment in training, equipment, and safety measures. However, the long-term benefits often outweigh the costs. Fewer accidents mean lower medical expenses, reduced insurance premiums, and avoidance of costly legal battles. Moreover, avoiding project delays due to accidents can help maintain budgetary targets.
6. **Reputation and Stakeholder Confidence:** A commitment to safety reflects positively on the reputation of the project stakeholders, whether it's the project owner, contractor, or

subcontractors. Demonstrating a proactive approach to safety not only attracts skilled workers but also instills confidence in clients, investors, and the public.

7. **Sustainability:** Safety standards often incorporate environmental considerations, promoting sustainable practices and minimizing the project's ecological footprint. By adhering to environmentally friendly practices, projects can mitigate negative impacts on ecosystems and communities, contributing to long-term sustainability.

8. **Continuous Improvement:** Safety standards are not static; they evolve over time based on advancements in technology, changes in regulations, and lessons learned from past incidents. Incorporating feedback, conducting safety audits, and fostering a culture of continuous improvement ensure that safety remains a top priority throughout the project lifecycle.

Safety is of utmost importance in every phase of the Rock 'N' Rover project's development. Before delving into the intricate technical aspects, a comprehensive foundation of safety standards is conscientiously established to ensure the well-being of users, bystanders, and the integrity of the project. Rigorous adherence to industry-specific safety regulations is paramount, supplemented by the implementation of fail-safe mechanisms tailored to the project's unique requirements. Among these measures are strategically positioned emergency stop buttons, equipped to halt operations swiftly in unforeseen circumstances, and cutting-edge obstacle avoidance systems designed to navigate complex terrains with precision and reliability. Furthermore, comprehensive risk assessments are conducted, addressing potential hazards and identifying mitigation strategies to proactively manage risks throughout the project lifecycle. These meticulous safety protocols not only prioritize the protection of individuals and property but also exemplify a commitment to excellence in project execution. By integrating safety measures seamlessly into the project framework, we are fostering a culture of responsibility and accountability, elevating the project's reputation and setting a standard for excellence in safety practices within the industry.

4.1.2 Electrical Standards

Electrical standards are crucial guidelines and specifications that govern the design, installation, operation, and maintenance of electrical systems and equipment. They are established by national and international organizations such as the International Electrotechnical Commission (IEC), the National Electrical Manufacturers Association (NEMA), the Institute of Electrical and Electronics Engineers (IEEE), and others. These standards serve as benchmarks for ensuring safety, reliability, interoperability, and efficiency in electrical systems across various industries and applications. Here are some key reasons why electrical standards are important:

1. **Safety:** Perhaps the most critical aspect of electrical standards is ensuring the safety of individuals, property, and the environment. Standards provide guidelines for the proper handling of electrical equipment, wiring, and installations to prevent hazards such as electric shock, fire, and explosions. Compliance with these standards minimizes the risk of accidents and injuries.

2. **Reliability:** Electrical standards help to ensure the reliability and performance of electrical systems and equipment. By specifying design criteria, testing methods, and performance requirements, standards facilitate the development of products that meet quality benchmarks and perform consistently under various operating conditions. This reliability is particularly important in critical sectors such as healthcare, telecommunications, and manufacturing.

3. **Interoperability:** In today's interconnected world, interoperability—the ability of different systems and devices to work together seamlessly—is crucial. Electrical standards define interfaces, protocols, and communication protocols that enable interoperability between diverse electrical components and systems. This is essential for the integration of technologies in areas such as smart grids, automation, and the Internet of Things (IoT).

4. **Efficiency:** Standards play a vital role in promoting energy efficiency and sustainability in electrical systems. They establish requirements for energy-efficient equipment, design practices, and performance metrics that help minimize energy consumption, reduce greenhouse gas emissions, and optimize resource utilization. Adhering to these standards not only lowers operational costs but also mitigates the environmental impact of electrical infrastructure.

5. **Compliance and Regulation:** Electrical standards form the basis for regulatory requirements and codes that govern electrical installations and products. Compliance with these standards is often mandated by government agencies and regulatory bodies to ensure public safety and industry best practices. Failure to meet these standards can result in legal liabilities, fines, or penalties.

6. Global Trade and Market Access: Harmonized electrical standards facilitate international trade by eliminating technical barriers and promoting product interoperability. Manufacturers and exporters can demonstrate compliance with recognized standards to gain access to global markets and compete on a level playing field. Standardization also simplifies procurement processes and reduces costs associated with product testing and certification.

Electrical integrity stands as a fundamental pillar in ensuring the reliable operation of the Rock 'N' Rover, particularly given its dynamic and technologically sophisticated nature. As the vehicle navigates through various terrains and executes intricate maneuvers, adherence to stringent electrical standards becomes paramount. To this end, the implementation of industry-approved wiring practices, such as those outlined by organizations like the International Electrotechnical Commission (IEC) and the National Electrical Manufacturers Association (NEMA), ensures that the wiring is capable of withstanding the rigors of off-road exploration. Meticulous selection of components boasting appropriate voltage, current, and temperature ratings is imperative to withstand the harsh environmental conditions encountered during missions. For instance, components with high ingress protection (IP) ratings are chosen to shield against dust and water ingress, while those with wide temperature ranges ensure reliability in extreme climates. Through these measures, we not only safeguard against potential electrical failures but also ensure the stability and longevity of the vehicle's electrical system.

Moreover, rigorous testing protocols are employed to validate the integrity and resilience of the electrical infrastructure under diverse operational conditions. This includes environmental testing to simulate the vehicle's exposure to temperature variations, humidity, vibration, and mechanical shock. Electrical stress testing evaluates the performance of components under high voltage and current conditions, ensuring they can handle peak loads without degradation. Furthermore, functional testing verifies the proper functioning of sensors, actuators, communication systems, and power distribution modules under real-world scenarios.

This proactive approach not only enhances the safety and reliability of the Rock ‘N’ Rover but also underscores our unwavering commitment to excellence in engineering and adherence to industry best practices. By adhering to established electrical standards and conducting thorough testing, we mitigate risks associated with electrical failures, thereby maximizing the vehicle's operational uptime and mission success. Additionally, compliance with recognized standards facilitates interoperability with other systems and promotes seamless integration of future upgrades and enhancements. As a result, the Rock ‘N’ Rover stands poised to fulfill its mission objectives with efficiency, resilience, and unparalleled performance in the most challenging environments.

4.1.3 Mechanical Standards

Mechanical standards play a crucial role in ensuring safety, interoperability, and efficiency across various industries that involve mechanical engineering. These standards are established guidelines or specifications that define the design, construction, testing, and performance requirements for mechanical components, systems, and processes. They are developed and maintained by organizations such as the American Society of Mechanical Engineers (ASME), International Organization for Standardization (ISO), and others, often in collaboration with industry experts, engineers, researchers, and regulatory bodies.The importance of mechanical standards cannot be overstated, and here are several reasons why they are essential:

1. **Safety:** One of the primary objectives of mechanical standards is to ensure the safety of products, equipment, and processes. By adhering to established standards, manufacturers can design and produce mechanical components and systems that meet minimum safety requirements. This helps prevent accidents, injuries, and fatalities in various industries, including manufacturing, construction, transportation, and energy.

2. **Interoperability:** Mechanical standards facilitate interoperability by ensuring compatibility and interchangeability between different components, equipment, and systems. This is particularly critical in industries where various parts need to work together seamlessly, such as in automotive manufacturing or machinery production. Standardized dimensions, tolerances, and interfaces enable easier integration and assembly of mechanical parts from different manufacturers.

3. **Quality Assurance:** Compliance with mechanical standards helps ensure the quality and reliability of products and processes. Standards outline specific criteria for materials,

manufacturing processes, testing procedures, and performance characteristics, providing manufacturers with clear guidelines to follow. Adhering to these standards can lead to improved product quality, reduced defects, and enhanced customer satisfaction.

4. **Regulatory Compliance:** Many industries are subject to regulatory requirements and legal obligations related to product safety, environmental protection, and public health. Mechanical standards often serve as a basis for regulatory frameworks and compliance assessments. Companies that fail to meet applicable standards may face penalties, fines, or legal liabilities, highlighting the importance of adherence to established norms.

5. **Innovation and Efficiency:** While standards provide a baseline for safety and quality, they also drive innovation and efficiency by promoting best practices and technological advancements. Engineers and designers use standards as reference points for developing new solutions, optimizing processes, and improving performance. Standardization can streamline design and manufacturing processes, reduce costs, and accelerate time-to-market for innovative products and technologies.

6. **Global Trade and Market Access:** In an increasingly interconnected world, adherence to international mechanical standards is essential for global trade and market access. Harmonized standards facilitate cross-border commerce by ensuring that products meet consistent requirements and regulations across different countries and regions. This simplifies regulatory compliance, reduces trade barriers, and fosters economic growth and competitiveness.

Ensuring the Rock 'N' Rover's toughness, reliability, and effectiveness relies heavily on strict mechanical standards. Before diving into the nitty-gritty of mechanical engineering, it's crucial to establish clear rules for choosing parts, making components, and putting them together. This careful approach guarantees that every part of the vehicle can handle its job without breaking down. By using tough, long-lasting materials known for their strength and resistance to rust, we strengthen the vehicle's structure, making it less likely to wear out too soon. We also pay close attention to how moving parts fit together, making sure they run smoothly and don't wear down quickly due to rubbing against each other. Following these precise standards not only improves the Rock 'N' Rover's performance and lifespan but also shows our commitment to creating a top-notch product in mechanical engineering.

4.1.4 Software Development Standards

Software development standards are paramount in product development, serving as the backbone of quality, reliability, and security in the realm of software engineering. These standards encompass a comprehensive set of guidelines, best practices, and methodologies that govern the design, coding, testing, deployment, and maintenance of software systems. Adhering to established software development standards ensures consistency, efficiency, and transparency throughout the development lifecycle. By following standardized processes and practices, developers can mitigate the risk of errors, bugs, and vulnerabilities, thereby enhancing the overall quality and performance of the software product. Moreover, compliance with software development standards fosters interoperability and compatibility, facilitating seamless integration with other software systems and platforms. Beyond technical considerations, adherence to software development standards also contributes to regulatory compliance, risk management, and customer satisfaction. In essence, software development standards not only ensure the reliability and functionality of software products but also uphold industry best practices, bolster market competitiveness, and instill confidence among users and stakeholders.

1. **Interoperability:** One of the most significant advantages of adhering to software standards is the promotion of interoperability. By following established standards, different software components can communicate and work seamlessly with each other, regardless of their origin or the platforms they run on. This interoperability fosters integration, allowing disparate systems to function together harmoniously. For instance, adherence to web standards ensures that applications are accessible across different browsers and devices, enhancing the user experience.

2. **Compatibility:** Software standards ensure compatibility across different versions of software and hardware. This is particularly crucial in environments where various vendors provide products or services. For example, adherence to standards such as HTML, CSS, and JavaScript ensures that web applications function correctly across different web browsers and operating systems. Similarly, adherence to file format standards ensures that documents can be exchanged and opened across various software applications without loss of fidelity or functionality.

3. **Ease of Development:** Standards provide developers with clear guidelines and best practices, streamlining the development process. Developers can leverage existing standards and frameworks to build upon established solutions rather than reinventing the wheel. This not only accelerates development but also improves the quality and reliability of software products. Moreover, adherence to standards facilitates collaboration among developers by establishing a common language and set of conventions.

4. **Quality Assurance:** Software standards often include guidelines for testing and quality assurance. By adhering to these standards, developers can ensure that their software undergoes rigorous testing to identify and rectify defects early in the development lifecycle. This results in higher quality software products that are more reliable and resilient to failures, ultimately leading to increased customer satisfaction and trust.

5. **Future-proofing:** Standards provide a level of future-proofing by ensuring that software remains relevant and compatible with evolving technologies and industry trends. As technology advances, standards evolve to accommodate new requirements and innovations, thereby safeguarding investments in software development. Additionally, adherence to standards reduces the risk of vendor lock-in, allowing organizations to switch between different software solutions without encountering significant compatibility issues.

6. **Regulatory Compliance:** In many industries, compliance with regulatory requirements is mandatory. Software standards often align with regulatory frameworks and industry-specific guidelines, ensuring that software products meet legal and security requirements. Adhering to these standards not only mitigates the risk of non-compliance

but also instills confidence among stakeholders regarding the security and integrity of the software.

Software reliability serves as a linchpin for the seamless operation and mission success of the Rock ‘N’ Rover project, where precision and dependability are non-negotiable. Prior to initiating software development endeavors, it is imperative to establish a robust framework of stringent standards to govern every facet of the process. This comprehensive approach encompasses not only code quality and maintainability but also extends to encompassing scalability, performance optimization, and security considerations. By meticulously adhering to industry best practices, such as adhering to coding standards and utilizing design patterns, developers can ensure the production of clean, efficient, and maintainable code. Additionally, the implementation of robust error handling and logging mechanisms serves as a proactive measure to identify and address issues promptly, minimizing disruptions to operations and facilitating rapid troubleshooting. Regular updates and maintenance activities further bolster the reliability and security of the vehicle's software systems, ensuring that it remains resilient in the face of evolving threats and operational demands. Through these concerted efforts, we affirm our commitment to delivering a software ecosystem characterized by stability, security, and unwavering performance, thereby advancing the objectives of the Rock ‘N’ Rover project with confidence and reliability.

4.1.5 Communication Standards

Communication standards play a crucial role in product development across various industries, ensuring compatibility, interoperability, and seamless integration between different components, systems, and devices. These standards serve as guidelines or protocols that dictate how data is transmitted, interpreted, and received between different entities, enabling effective communication and collaboration within complex ecosystems. Here's why communication standards are essential in product development:

1. **Interoperability:** In today's interconnected world, products often need to communicate with each other, regardless of their origin or manufacturer. Communication standards ensure that devices and systems from different vendors can work together seamlessly. For example, USB, HDMI, and Bluetooth are widely adopted standards that allow devices from different manufacturers to connect and communicate without compatibility issues.

2. **Efficiency:** Standardized communication protocols streamline the development process by providing clear guidelines and specifications. Developers don't need to reinvent the wheel every time they want two devices to communicate; they can simply follow existing standards. This saves time and resources, accelerating product development cycles and reducing time to market.

3. **Cost Reduction:** Developing proprietary communication protocols can be costly and time-consuming. By leveraging existing standards, companies can significantly reduce development costs and focus their resources on creating unique features and functionalities that add value to their products.

4. **Scalability:** As products evolve and new features are added, communication standards provide a scalable framework that accommodates growth and expansion. Standards like TCP/IP for networking or MQTT for IoT (Internet of Things) enable products to scale efficiently without requiring major architectural changes.

5. **Compatibility:** Consumers expect products to work together seamlessly, regardless of the brand or model. Communication standards ensure compatibility between different generations of products and facilitate backward and forward compatibility. For example, smartphones with different operating systems can communicate with each other via standard protocols like SMS, MMS, or Bluetooth.

6. **Reliability:** Established communication standards have undergone rigorous testing and validation, ensuring reliability and robustness in various scenarios. This reliability is crucial, especially in mission-critical applications such as industrial automation, healthcare, and transportation systems.

7. **Global Adoption:** Communication standards that are widely adopted across industries and regions provide a common language for developers, manufacturers, and users worldwide. This global adoption fosters innovation, interoperability, and collaboration on a large scale.

8. **Regulatory Compliance:** In many industries, adherence to specific communication standards is mandated by regulatory bodies to ensure safety, security, and compliance with industry regulations. For example, medical devices must adhere to standards such as DICOM (Digital Imaging and Communications in Medicine) to ensure interoperability and data security in healthcare environments.

In addition to facilitating communication between products, communication standards also play a vital role in enabling collaboration and coordination among engineers during the product development process. Here's how communication standards support developer collaboration:

1. **Shared Protocols and Interfaces:** Communication standards provide developers with common protocols and interfaces for exchanging information, sharing data, and collaborating on projects. Whether it's through APIs (Application Programming Interfaces), messaging formats like JSON or XML, or version control systems like Git, standardized communication methods ensure that developers can work together effectively regardless of their geographic location or organizational boundaries.

2. **Consistent Communication Patterns:** Standardized communication patterns help establish common ground among developers, ensuring clarity, consistency, and understanding throughout the development lifecycle. By following established conventions and protocols, developers can communicate more efficiently, reducing misunderstandings and enhancing productivity.

3. **Cross-Platform Compatibility:** In a diverse development environment where teams may use different tools, programming languages, and technologies, communication standards

provide a common framework for interoperability. For instance, standards like RESTful APIs enable developers to build applications that can communicate seamlessly across different platforms, devices, and programming languages.

4. **Integration with Development Tools:** Many development tools and platforms support communication standards, allowing developers to integrate various software components and streamline collaboration workflows. For example, project management tools like Jira or communication platforms like Slack often provide integrations with version control systems and issue tracking systems, enabling seamless communication and collaboration among development teams.

5. **Real-Time Collaboration:** Communication standards facilitate real-time collaboration among developers, enabling instant messaging, video conferencing, screen sharing, and collaborative editing of code and documents. Platforms like Microsoft Teams, Google Workspace, and GitHub provide features that support real-time communication and collaboration, fostering teamwork and innovation.

6. **Documentation and Knowledge Sharing:** Communication standards often come with documentation and best practices that help developers understand how to interact with each other and with external systems effectively. This documentation serves as a valuable resource for knowledge sharing, onboarding new team members, and maintaining consistency in development processes.

7. **Community Engagement and Support:** Many communication standards have vibrant communities of developers who actively contribute to their development, support, and improvement. Engaging with these communities provides developers with opportunities to learn, share experiences, and collaborate on enhancing communication standards to meet evolving needs and challenges.

Effective communication standards are vital for ensuring the smooth integration of the Rock ‘N’ Rover with external devices and systems, guaranteeing its proper functioning and compatibility. To achieve this, thorough attention must be given to establishing comprehensive guidelines before proceeding with the implementation of communication systems. These standards encompass various aspects beyond just selecting protocols and transmission methods. By adopting industry-standard wireless communication protocols like Bluetooth and Wi-Fi, we establish a solid foundation for connectivity. Moreover, these communication standards extend beyond device-to-device communication and also encompass communication between engineers involved in the Rock ‘N’ Rover project. Through shared protocols and interfaces, developers can collaborate seamlessly, regardless of their geographic location or organizational boundaries. Consistent communication patterns ensure clarity and understanding throughout the development process, reducing misunderstandings and enhancing productivity. Additionally, incorporating encryption and authentication mechanisms helps protect the integrity and confidentiality of data exchanged among team members, creating a secure environment for collaboration. Real-time collaboration tools such as instant messaging and video conferencing further facilitate communication and coordination among engineers, enabling efficient problem-solving and decision-making. Finally, ensuring compatibility with a wide range of development tools and platforms enhances workflow efficiency and promotes integration among different software components. By adhering to these meticulously crafted communication standards, the Rock ‘N’ Rover project not only facilitates seamless integration with external devices but also upholds reliability, security, and adaptability, essential for its success.

4.1.6 Quality Assurance Standards

Quality assurance (QA) standards are crucial in product development to ensure that products meet predefined quality criteria and standards throughout their lifecycle. These standards encompass various processes, procedures, and guidelines aimed at maintaining consistency, reliability, and customer satisfaction. Here's an overview of quality assurance standards in product development and their importance:

1. Establishing Quality Metrics:

- Define Standards: QA standards establish benchmarks and metrics for product quality. These standards specify criteria such as performance, reliability, usability, and safety.
- Setting Objectives: They help set clear objectives for product quality, allowing teams to focus efforts on meeting or exceeding these objectives.

2. Process Improvement:

- Continuous Improvement: QA standards promote a culture of continuous improvement by identifying areas for enhancement in processes, methodologies, and tools.
- Root Cause Analysis: When defects or issues arise, QA standards facilitate thorough root cause analysis, enabling teams to address underlying problems and prevent recurrence.

3. Risk Management:

- Identifying Risks: QA standards help identify potential risks early in the product development lifecycle, allowing proactive mitigation strategies to be implemented.
- Mitigation Strategies: By implementing robust QA processes, organizations can minimize the likelihood of defects, errors, or failures, thus reducing risks associated with product development.

4. Compliance and Regulation:

- Ensuring Compliance: QA standards ensure that products adhere to relevant industry regulations, standards, and compliance requirements, mitigating legal and regulatory risks.
- Certification: Compliance with QA standards may be necessary for obtaining certifications or approvals essential for market acceptance or regulatory compliance.

5. Customer Satisfaction:

- Meeting Expectations: QA standards help deliver products that meet or exceed customer expectations in terms of quality, functionality, and reliability.
- Building Trust: Consistently high-quality products enhance customer trust and loyalty, leading to positive brand reputation and increased competitiveness.

6. Cost Efficiency:

- Preventing Rework: Implementing QA standards helps detect and rectify defects early in the development process, reducing the need for costly rework or corrective actions later.
- Optimizing Resources: By streamlining processes and focusing efforts on quality, organizations can optimize resource utilization and minimize wastage.

7. Stakeholder Confidence:
- Assurance: QA standards provide stakeholders, including customers, investors, and partners, with assurance that products are developed and delivered with a high level of quality and reliability.
- Transparency: Transparent adherence to QA standards fosters trust and confidence among stakeholders, demonstrating a commitment to delivering value and meeting expectations.

Quality assurance is fundamental to the development process of the Rock ‘N’ Rover, integrated seamlessly at every step of its creation. Before testing even begins, our team invests significant effort into establishing thorough standards, drawing from industry best practices and innovative approaches. These standards serve as precise blueprints, ensuring comprehensive validation of every aspect of the vehicle's functionality and performance. Our testing procedures are designed to scrutinize each component carefully, from the strength of its chassis to the efficiency of its control systems, leaving no aspect unchecked in our pursuit of excellence. Additionally, detailed documentation of test results and the maintenance of a comprehensive quality assurance log demonstrate our unwavering commitment to accountability and transparency. Through this attention to detail and our relentless pursuit of perfection, we continuously enhance the Rock ‘N’ Rover, pushing the boundaries of innovation and setting new benchmarks in automotive engineering.

4.1.7 Documentation Standards

Documentation standards for product development are essential guidelines and protocols that dictate how information about a product is recorded, organized, and maintained throughout its lifecycle. These standards encompass various types of documents, including requirements specifications, design documents, test plans, user manuals, and release notes. They ensure consistency, clarity, and completeness in the documentation, enabling effective communication among stakeholders and facilitating efficient product development processes. The importance of documentation standards in product development cannot be overstated, and here's why:

1. **Clarity and Understanding:** Clear and well-organized documentation helps teams understand the product's requirements, design, and functionality. It serves as a reference point for developers, designers, testers, and other stakeholders, reducing misunderstandings and ambiguities.

2. **Consistency and Standardization:** Documentation standards establish uniform formats, templates, and terminology for all project documentation. This consistency fosters better collaboration, streamlines processes, and makes it easier for team members to locate and use relevant information.

3. **Traceability and Accountability:** Proper documentation allows for tracing requirements throughout the development process. By maintaining a clear trail of decisions, changes,

and dependencies, documentation standards help ensure accountability and enable effective change management.

4. **Risk Management:** Comprehensive documentation mitigates risks associated with product development by providing a comprehensive overview of project scope, goals, constraints, and dependencies. It helps identify potential issues early in the development cycle, allowing teams to address them proactively.

5. **Onboarding and Knowledge Transfer:** Well-documented projects facilitate the onboarding of new team members by providing them with a structured overview of the product and its development history. Additionally, thorough documentation aids in knowledge transfer between team members, ensuring that institutional knowledge is preserved and shared effectively.

6. **Regulatory Compliance and Audits:** In regulated industries, adherence to documentation standards is often a legal requirement. Documentation serves as evidence of compliance with regulatory standards and provides the necessary documentation for audits and inspections.

7. **Customer Support and Training:** User manuals, guides, and other customer-facing documentation are crucial for helping users understand how to use the product effectively. Clear and comprehensive documentation enhances the customer experience, reduces support requests, and minimizes user frustration.

8. **Continuity and Maintenance:** As products evolve and undergo updates, well-maintained documentation ensures continuity by documenting changes, bug fixes, and new features. This continuity is vital for future maintenance, troubleshooting, and further development efforts.

Documentation plays a crucial role in fostering transparency and collaboration throughout the development of the Rock ‘N’ Rover. To effectively leverage documentation as a tool for enhancing project outcomes, it is imperative to define clear standards before initiating the documentation process. These standards serve as guiding principles for creating and maintaining various types of documentation, such as design specifications, schematics, software code, and test reports. By adhering to these standards and regularly updating documentation to reflect the project's progress and any modifications, we ensure that every team member remains well-informed and capable of making meaningful contributions to the project's success. Thorough and up-to-date documentation serves as a comprehensive reference point, facilitating efficient communication, decision-making, and problem-solving throughout the development lifecycle.

4.2 Design Constraints

Design constraints are the boundaries within which designers operate when creating a product, system, or solution. These constraints encompass a wide array of factors that influence the design process, ranging from technical limitations to user needs and market requirements.

Understanding and effectively navigating these constraints are crucial for producing successful designs that meet the intended objectives and satisfy stakeholders.

Technical constraints are often among the most tangible and immediately apparent limitations designers face. These constraints may include factors such as available materials, manufacturing processes, technological capabilities, and performance requirements. For example, a product designed for mass production may need to adhere to specific dimensions or material properties to ensure cost-effectiveness and feasibility within the manufacturing process. Similarly, technological limitations may dictate the functionality or compatibility of a digital product within existing hardware or software ecosystems.

Beyond technical considerations, designers must also contend with constraints related to user needs and preferences. User-centric design requires a deep understanding of the target audience, including their demographics, behaviors, and pain points. Designers must balance competing user requirements and preferences, ensuring that the final product is intuitive, accessible, and enjoyable to use. Accessibility considerations, for instance, may impose constraints related to font sizes, color contrast, or input methods to accommodate users with disabilities or diverse needs.

Market constraints further shape the design process by reflecting broader economic, cultural, and competitive dynamics. Designers must account for market trends, consumer expectations, and regulatory requirements to ensure their designs remain relevant and compliant. Competitive analysis can reveal opportunities and constraints inherent in the competitive landscape, guiding designers in differentiating their offerings and delivering unique value propositions.

Additionally, economic constraints such as budgetary limitations or resource availability may influence design decisions, requiring designers to innovate within constrained parameters.
In navigating these multifaceted constraints, designers must adopt a creative and adaptable mindset, viewing limitations not as impediments but as opportunities for innovation and problem-solving. Iterative design processes, prototyping, and interdisciplinary collaboration can help identify and address constraints early in the design cycle, reducing the risk of costly revisions or project delays later on. By embracing constraints as integral components of the design process, designers can leverage them to drive creativity, foster empathy, and ultimately deliver solutions that resonate with users and stakeholders alike.

Design constraints for the Rock ‘N’ Rover:

1. **Technical Constraints:**
    - <u>Size and Dimension:</u> The body of the car must adhere to specific dimensions, with a minimum width of 3 inches and a minimum length of 5 inches to accommodate all integrated components effectively.
    - <u>Battery Life:</u> The car must be powered by a battery capable of sustaining operation for at least 1 hour to ensure prolonged use and enjoyment.
    - <u>Mobility:</u> The design must allow the car to move forwards, backwards, and turn left and right smoothly and efficiently to enable versatile navigation.

- Cost: The total cost of the car must not exceed $800 to align with budgetary constraints, equivalent to $200 per team member, ensuring affordability and feasibility.

2. **User Needs and Preferences:**
    - Visibility: The headlights must be visible from a distance of at least 3 feet to enhance visibility in low-light conditions, addressing user safety concerns.
    - Ease of Use: The controller and app interface must be intuitive and user-friendly, allowing seamless switching between manual and remote control modes to cater to users of varying technical proficiencies.

3. **Market Constraints:**
    - Competitive Pricing: The cost of the Rock ‘N’ Rover must be competitive within the market to attract potential buyers and ensure commercial viability.
    - Performance: The car must meet or exceed industry standards for remote-controlled cars in terms of performance, functionality, and features to remain competitive and appealing to consumers.

4. **Advanced Features:**
    - Obstacle Detection: Integration of ultrasonic sensors for obstacle detection to ensure safe navigation and collision avoidance, enhancing user experience and safety.
    - Entertainment Features: Incorporation of a speaker for interactive experiences and music playback controlled via the companion app, providing entertainment value to users.
    - Camera System: Integration of a camera system with Bluetooth connectivity to provide users with a visual perspective through the app, enabling immersive control and navigation experiences.

5. **Manufacturing Constraints:**
    - Assembly and Manufacturing Processes: The design must consider ease of assembly and manufacturing processes to streamline production and minimize costs, ensuring scalability and efficiency in manufacturing.

By adhering to these design constraints, the Rock ‘N’ Rover can effectively meet user needs, technological requirements, and market demands, ensuring its success as a cutting-edge remote-controlled car in the competitive landscape of RC vehicles.

5. Project Design Details

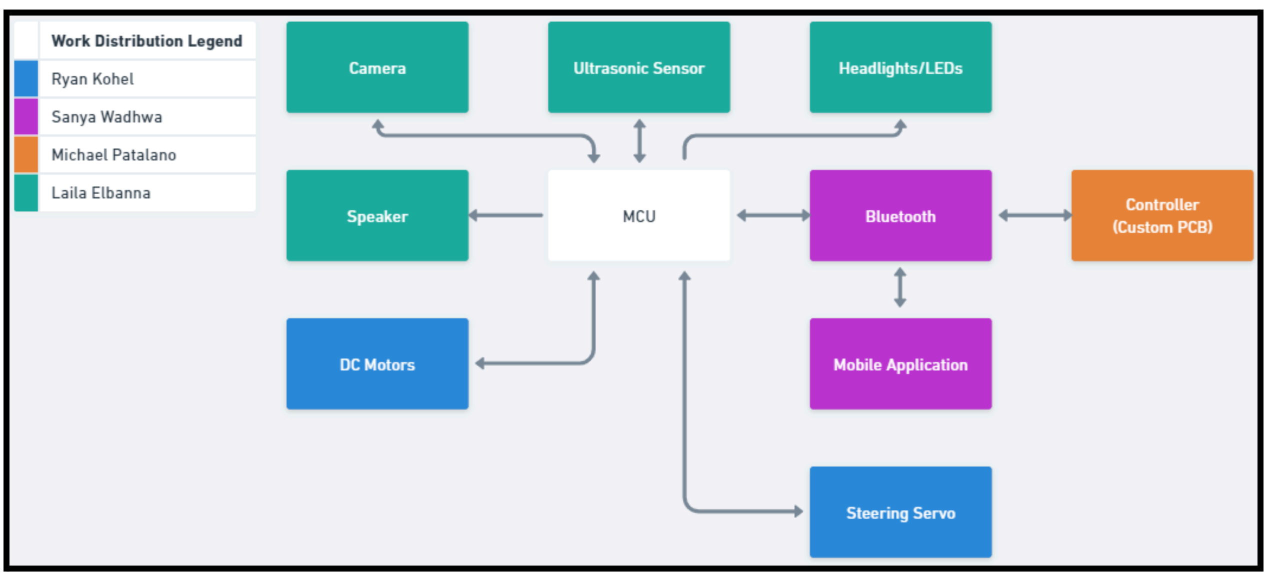
In this section, we will discuss the design of the project.

5.1 Initial Project Diagrams

For our project, hardware diagrams and software diagrams were created initially to provide a very general, brief overview of how our project would work. Also, the initial diagrams would show the work distribution between the different members of our group. The initial hardware and software diagrams are provided in the sections below.

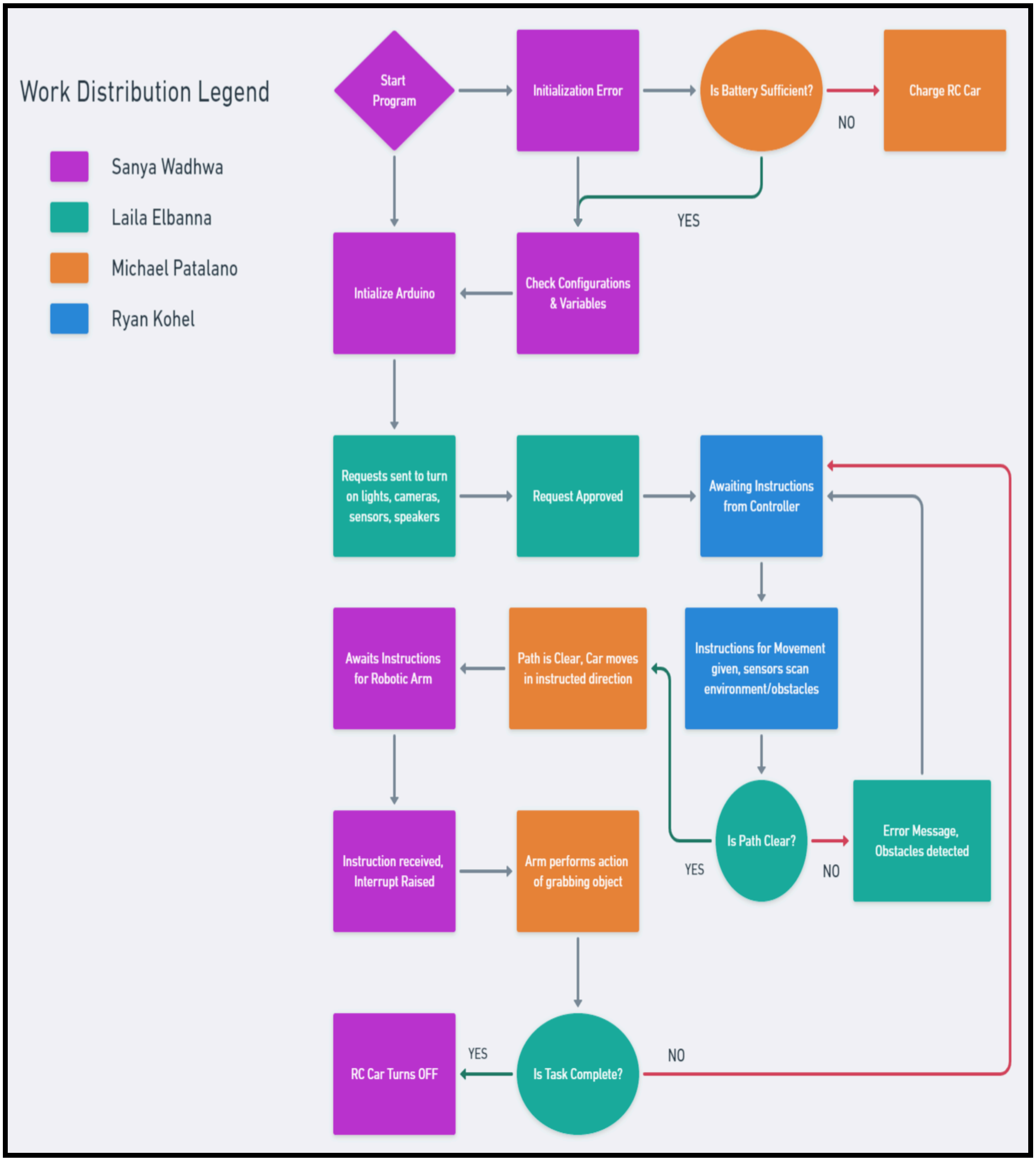
5.1.1 Initial Hardware Diagrams

This initial hardware diagram below provides a general overview of the different components of the project and how they are connected to one another. The microcontroller is connected physically to 6 different components: a camera, an ultrasonic sensor, headlights, a speaker, DC motors, and a steering servo. The camera will be used to have a POV in front of the remote control car. The ultrasonic sensor will be used to detect if the remote control car comes close to an object. The speaker will be used to produce a beep if the remote control car comes too close to an object. The DC motor will move the remote control car forwards and backwards and the steering servo will be used to turn the remote control car left and right. Initially, we were going to connect the mobile application and the controller via Bluetooth, however, we decided to connect the application via Wifi and connect the controller via a infrared transmitter and receiver. So, we will have an application that will be connected to the microcontroller via Wifi, and the application can be used to drive the remote control car and view the video from the camera. We will also be creating a custom PCB for our controller to control the remote control car. The controller will include an infrared transmitter that will send information to an infrared receiver on the car to control the car remotely.

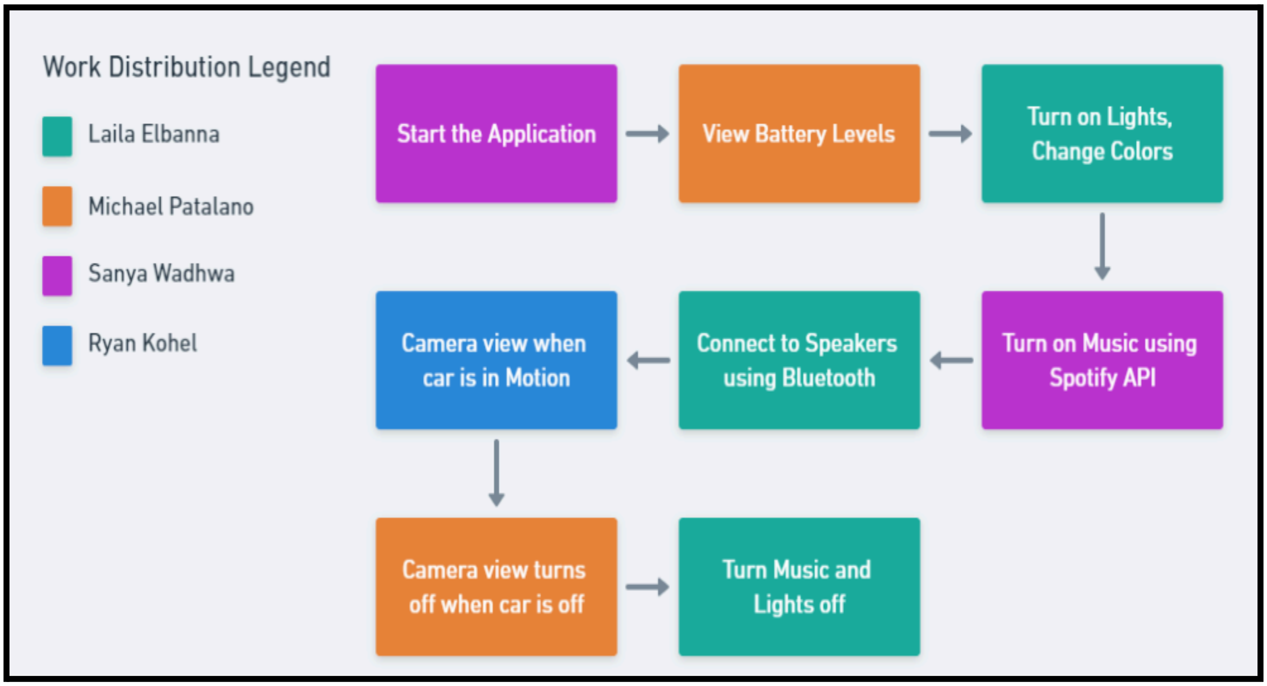


5.1.2 Initial Software Diagrams

The software diagram below illustrates the communication between the Arduino and the controller, detailing the program's execution and functionality. It encompasses the initialization of the Arduino, reading sensor data for environmental awareness, configuring motors and the robotic arm, and receiving user inputs from the controller. The program then assesses sensor data for potential obstacles or targets, determines desired rover movements and robotic arm positions, and executes corresponding commands. Following this, it halts the motors and the arm, culminating in the termination of the program.



The application software diagram below provides a comprehensive overview for various functions of the RC car. It intricately outlines the process of turning lights on and off, allowing for dynamic color changes, and even incorporating music playback through Spotify, enhancing the user experience for entertainment purposes. Additionally, the diagram showcases the functionality of navigation, utilizing the camera view to provide a visual perspective during operation. Beyond that, it introduces a monitoring system for tracking the battery levels of the car, ensuring users are informed about the power status for optimal control and efficient operation of the robotic car. In essence, this application software diagram serves as a visual guide, offering a clear depiction of the diverse and multifunctional capabilities.

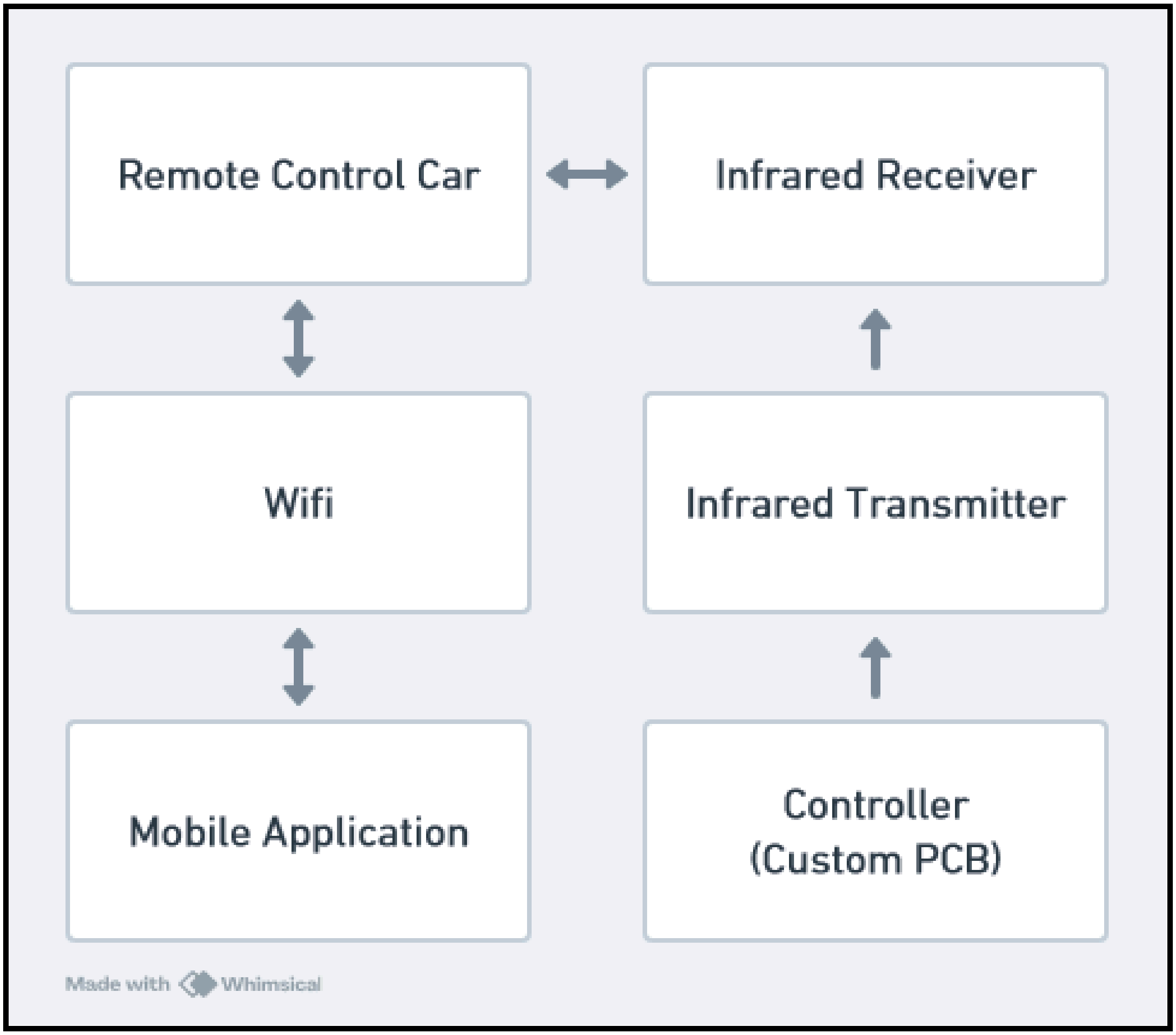


5.2 Hardware Diagrams

In this section, we will show the hardware diagrams that were created after the initial hardware diagrams were created. The hardware diagrams shown are the main block diagram and the block diagrams for the two subsystems: the remote control car and the controller.

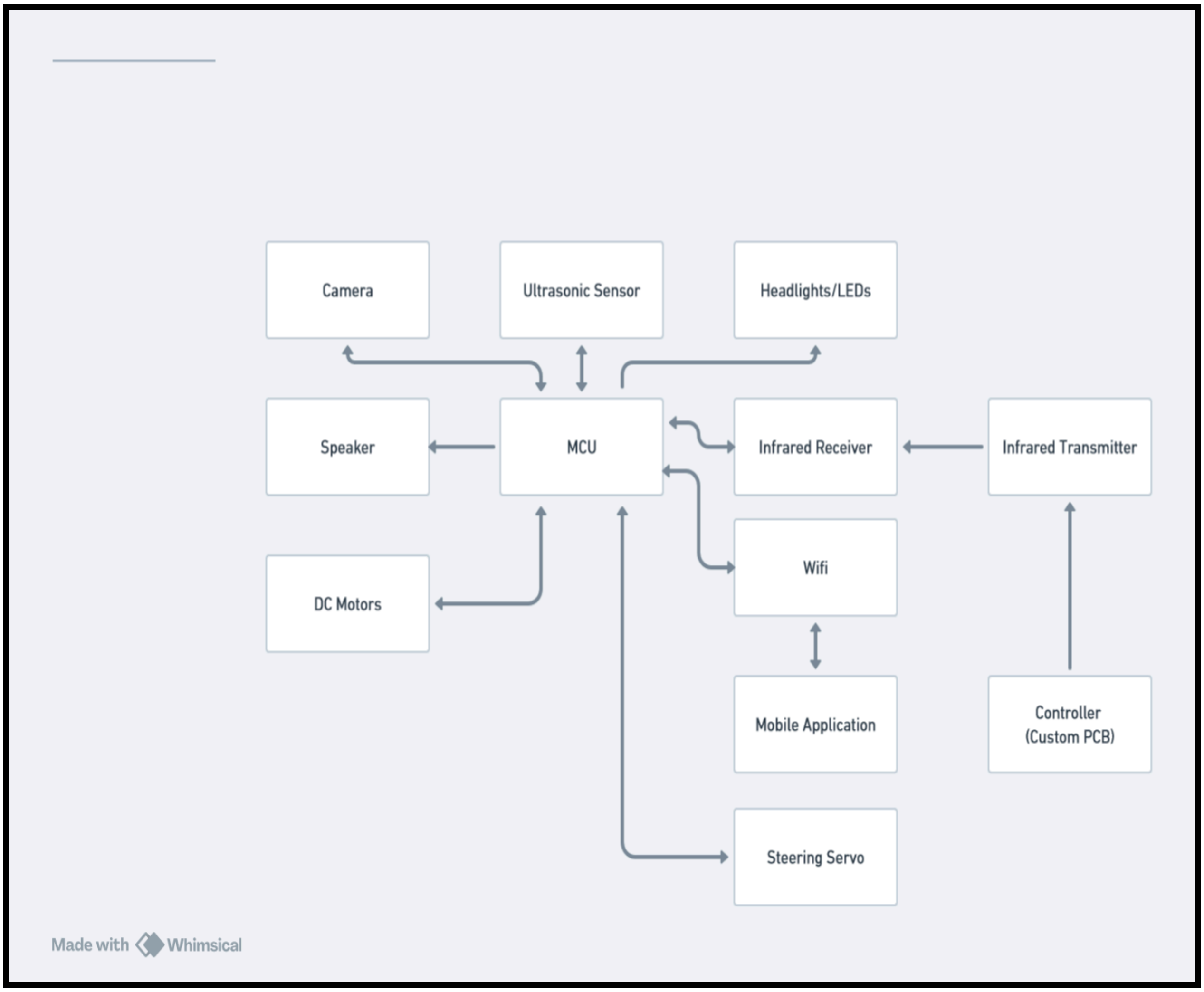
5.2.1 Main Block Diagram

The main block diagram shows how the three main components of our project are connected to each other. The three main components of our project are: the mobile application, the remote control car, and the controller. The controller is connected to the remote control car via an infrared transmitter and receiver. The controller will communicate to the remote control car via the infrared transmitter and the infrared receiver on the remote control car will receive the communication. The mobile application will connect to the remote control car via a Wifi interface.



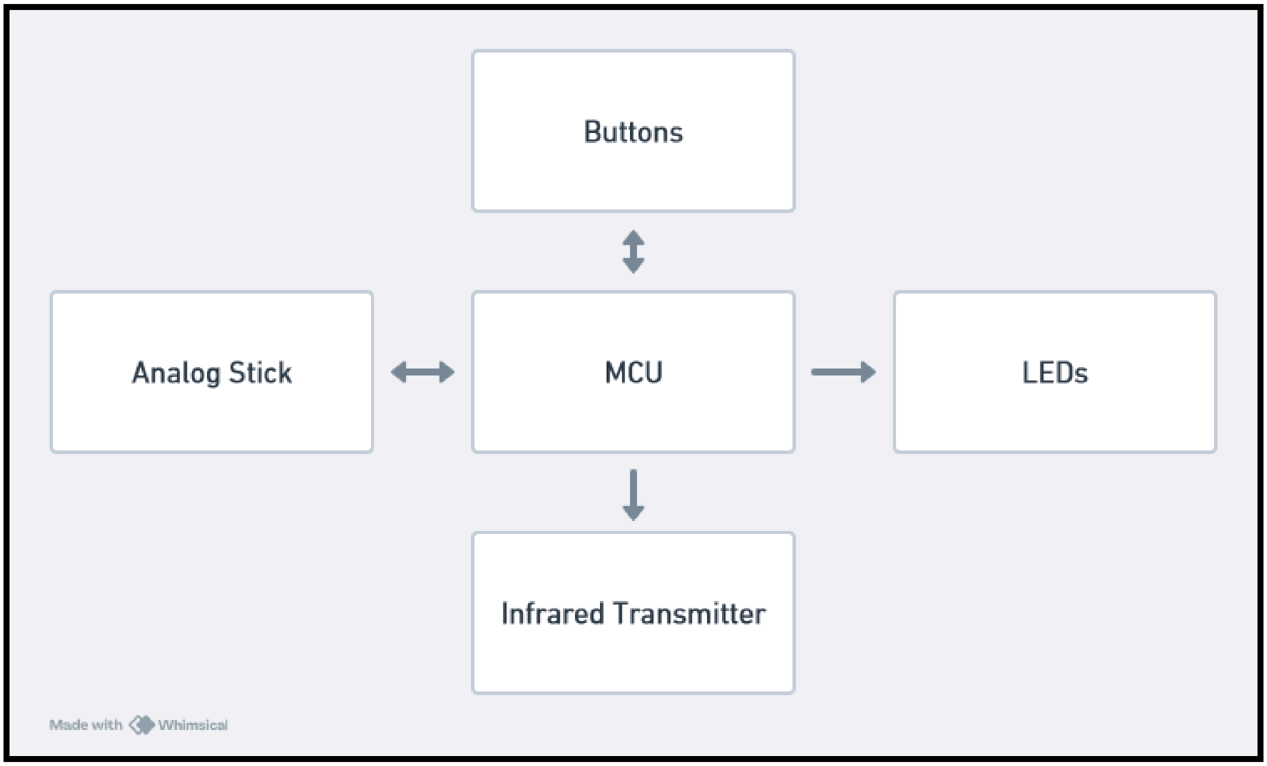
5.2.2 Remote Control Car Block Diagram

The hardware diagram for the remote control car is shown below. This hardware diagram was derived from the initial hardware diagram. Initially, we were going to connect the mobile application and the controller to the remote control car via Bluetooth. However, it was decided to connect the mobile application to the remote control car via Wifi and it was decided to connect the controller to the remote control car via an infrared transmitter and receiver. The remote control car will feature a steering servo, DC motors, a speaker, a camera, an ultrasonic sensor, and headlights. The steering servo will be used to steer the car left and right. The DC motors will move the car forwards and backwards. The camera can be used to view a POV from the car via the mobile application. The ultrasonic sensor will detect if the car gets too close to an object and the speaker will produce a beep if the ultrasonic sensor detects that the car gets too close to an object.



5.2.3 Controller Block Diagram

The hardware diagram for the controller for the remote control car is shown below. The controller will be using a custom PCB design that will feature buttons, an analog stick, LEDs, and an infrared transmitter. The buttons will be used to toggle different features of the remote control car. The buttons will be able to toggle the headlights and the ultrasonic sensor on the remote control car. The analog stick will be used to control the movement of the remote control car. The infrared transmitter will communicate to the receiver on the remote control car in order to control it. And of course, all of these peripherals will be connected to a microcontroller.



6. Project Construction

7. Project Testing Plan

8. Administrative Content

In this section, we will discuss planned milestones and a planned schedule for completing the project. We will also discuss the planned budget for our project.

8.1 Project Milestones/Schedule

	Senior Design I
Week	**Description and Due Dates**
1-2	Develop a detailed project plan
3-4	Research and Benchmarking
5	Begin the design process for the robotic machine components
6	Create initial prototypes

7-8	Conduct initial tests to validate design concepts
9-10	Present progress to advisors and adjust design plans
11-14	Finalize detailed designs for each module and select specific components, sensors, and materials for construction
15	Assemble a basic prototype to test the integration of key components
16	Perform initial functionality tests

Senior Design I:

Week 1-2: Develop a Detailed Project Plan

During the first two weeks, the focus is on laying down the groundwork for the entire project. This involves creating a detailed project plan that outlines the scope, objectives, milestones, and tasks to be completed. An extensive project plan will be used as a roadmap for the team, ensuring everyone is aligned on the project's direction and responsibilities. It should include timelines, resource allocations, risk assessments, and communication protocols. By dedicating sufficient time to planning upfront, our team can mitigate potential risks and set a strong foundation for the project's success.

Week 3-4: Research and Benchmarking

Research and benchmarking are essential steps for gathering information and understanding the landscape of the project. This phase involves conducting literature reviews, studying relevant technologies, and analyzing existing solutions or products in the market. By benchmarking against competitors or similar projects, our team can identify best practices, challenges, and opportunities. This information will inform the design process and help our team make informed decisions throughout the project lifecycle.

Week 5: Begin the Design Process for Robotic Machine Components

With a solid understanding of the project requirements and the findings from research and benchmarking, our team can now begin the design process. This involves brainstorming, conceptualizing, and sketching out ideas for the robotic machine components. The focus should be on translating requirements into feasible design concepts while considering factors such as functionality, manufacturability, and scalability. Collaboration and communication among team members are crucial during this phase to ensure diverse perspectives are considered, leading to innovative designs.

Week 6: Create Initial Prototypes

Creating initial prototypes allows our team to materialize our design concepts and test them in a tangible form. Prototyping helps identify potential design flaws, technical challenges, and areas for improvement early in the development process. These prototypes don't need to be perfect but should be functional enough to validate key design decisions. Our team should be prepared to iterate on our prototypes based on feedback from testing and evaluation.

Week 7-8: Conduct Initial Tests to Validate Design Concepts

During weeks 7-8, our team conducts initial tests to validate the design concepts and functionalities of the prototypes. This involves setting up test scenarios, performing experiments, and collecting data to assess the performance and reliability of the designs. The focus should be on identifying any discrepancies between expected and observed results and addressing them through iterative design improvements. Documenting test procedures and outcomes is essential for tracking progress and informing future iterations.

Week 9-10: Present Progress to Advisors and Adjust Design Plans

Presenting progress to advisors provides an opportunity for external feedback and validation of the project's direction. Our team should prepare a comprehensive progress report or presentation that highlights achievements, challenges, and proposed solutions. Advisors may offer valuable insights, suggestions, or critiques that can help refine the design plans and address any concerns. We should be prepared to approach these meetings with an open mind and be receptive to constructive feedback, as it can ultimately lead to a stronger project outcome.

Week 11-14: Finalize Detailed Designs and Select Components

During this phase, our team finalizes detailed designs for each module of the robotic machine and selects specific components, sensors, and materials for construction. This involves refining the design documentation, creating detailed drawings or schematics, and specifying the required parts and materials. Attention to detail is crucial to ensure the compatibility, functionality, and performance of the selected components. Our team should also consider factors such as cost, availability, and lead time when making decisions.

Week 15: Assemble a Basic Prototype for Integration Testing

Assembling a basic prototype allows our team to test the integration of key components and subsystems. This involves physically putting together the individual modules or components according to the finalized designs. Integration testing helps identify any compatibility issues, wiring errors, or mechanical constraints that may arise during assembly. Our team should conduct thorough testing to ensure proper functionality and alignment with project requirements.

Week 16: Perform Initial Functionality Tests

In the final week, our team performs initial functionality tests on the assembled prototype to evaluate its performance and validate its functionality. This involves executing test cases, measuring key performance metrics, and assessing the overall reliability of the prototype. Any inconsistencies or deficiencies identified during testing should be documented and addressed through iterative design improvements. By completing functionality tests, our team can gain confidence in the prototype's capabilities and readiness for further development or refinement.

Overall, each week of the project plan plays a necessary role in progressing through the various stages of design, development, and testing. Effective collaboration, communication, and attention to detail are key factors for achieving success in senior design projects. By following the outlined timeline and diligently executing each phase of the plan, our team can maximize our chances of delivering a high-quality robotic machine that meets the specified requirements and objectives.

	Senior Design II
Week	**Description and Due Dates**
1	Address any issues identified
2	Continue refining prototype
3	Begin integrating different modules for comprehensive system test
4-5	User interface and mobile app development
6	Implement customizable settings based on user feedback
7	Conduct extensive system testing to ensure all components work
8-10	Optimize software algorithms for enhanced performance, finalize assembly of the robotic machine, conduct testing
11-12	Prepare a comprehensive final presentation and documentation and submit and present the final project documentation

Senior Design 2:

Week 1: Address any Issues Identified

During the first week, our team focuses on addressing any issues or challenges identified from the previous phase. This may involve troubleshooting technical issues, resolving design flaws, or incorporating feedback from advisors or initial testing. Quickly addressing these issues ensures that the project remains on track and sets a solid foundation for further development.

Week 2: Continue Refining Prototype

In week 2, our team continues refining the prototype based on the insights gained from addressing identified issues. This may involve making iterative design improvements, optimizing functionality, or enhancing user experience. The goal is to enhance the prototype towards meeting the project's objectives and user requirements.

Week 3: Begin Integrating Different Modules for Comprehensive System Test

Week 3 marks the beginning of integrating different modules of the robotic system for comprehensive testing. This involves assembling various components and subsystems to create a unified system. Our team conducts initial system tests to evaluate the interaction between different modules and ensure seamless integration. Any integration issues or compatibility issues are addressed quickly to ensure smooth progress.

Week 4-5: User Interface and Mobile App Development

During weeks 4-5, our team focuses on developing the user interface and mobile application for controlling the robotic machine. This involves designing intuitive user interfaces, implementing features, and ensuring compatibility across different devices and platforms. User feedback is solicited and incorporated into the development process to enhance usability and functionality.

Week 6: Implement Customizable Settings Based on User Feedback

In week 6, our team implements customizable settings based on user feedback gathered during the UI and mobile app development phase. This may involve incorporating user preferences, adjustable parameters, or personalized features to enhance the user experience. Iterative testing and refinement ensure that the customizable settings meet user expectations and contribute to overall satisfaction.

Week 7: Conduct Extensive System Testing

Week 7 is dedicated to conducting extensive system testing to ensure that all components and functionalities of the robotic machine work as intended. This involves executing predefined test cases, stress testing, and evaluating performance under various conditions. Comprehensive testing helps identify and address any remaining issues or deficiencies before finalizing the project.

Week 8-10: Optimize Software Algorithms, Finalize Assembly, and Conduct Testing

During weeks 8-10, our team focuses on optimizing software algorithms for enhanced performance, finalizing the assembly of the robotic machine, and conducting thorough testing. This involves refining algorithms for efficiency, reliability, and accuracy, completing the assembly of mechanical and electronic components, and performing integration testing. The goal is to ensure that the robotic machine operates smoothly and meets all project requirements.

Week 11-12: Prepare Comprehensive Final Presentation and Documentation

In the final weeks of the project, our team prepares a comprehensive final presentation and documentation. This involves summarizing key findings, achievements, and lessons learned throughout the project. Our team creates professional documentation, including technical reports, user manuals, and assembly instructions. The final presentation showcases the project's accomplishments and highlights its significance, innovation, and potential impact.

By following the outlined plan and executing each week's tasks, our team can successfully complete Senior Design II and deliver a high-quality robotic system that meets user needs and project objectives.

8.2 Budget Breakdown

While we currently lack a designated project sponsor, the funding for this endeavor will be collectively contributed by our group members. We have set a budget ceiling of $800, equating to $200 per person. Although we possess certain testing components such as Arduinos, wires, breadboards, servos, and various sensors, the acquisition of additional project items will necessitate some expenditure.

Component	Cost
Wood (for the car body and arm)	$40
ESP8266 (MCU to control the car)	$15
DC Motors	$20
4 Wheels	$15
Battery	$25
Breadboards, wires, small servos (build a small arm to test code, and then larger one with more powerful servos), ultrasonic sensor, PS4 controller (to drive the car)	Free
Front and rear view cameras (ESP32-CAM Wireless)	$14
PLA filament	$100

Cost Breakdown of Required Components:

Wood (for the car body): $40

Wood serves as the primary material for constructing the car body of the robotic system. The cost accounts for purchasing quality wood materials suitable for the project's requirements.

ESP8266 (MCU to control the car): $15

The ESP8266 microcontroller unit (MCU) plays a crucial role in controlling the car's functions and communication. Its affordability makes it a suitable choice for this project.

DC Motors: $20

DC motors are essential components for powering the movement of the robotic car. The cost covers the acquisition of reliable motors capable of providing sufficient torque and speed for the project's mobility requirements.

4 Wheels: $15

Wheels are fundamental for enabling the mobility of the robotic car. The cost includes purchasing four durable wheels suitable for various terrains and conditions.

Battery: $25

A reliable power source is essential for powering the robotic system. The cost includes purchasing a suitable battery pack capable of providing sufficient voltage and capacity to support the system's operation.

Front and rear view cameras (ESP32-CAM Wireless): $14

Cameras are integral for providing vision capabilities to the robotic system. The cost accounts for acquiring front and rear view wireless cameras (ESP32-CAM) for real-time video streaming and navigation.

PLA Filament: $100

PLA filament is a 3D printing material used for fabricating various components and prototypes. The cost covers a significant portion of the budget, reflecting the importance of 3D printing in the project's development process.

Additional Considerations:

- While some testing components such as Arduinos, wires, breadboards, small servos, ultrasonic sensors, and a PS4 controller are available for use at no additional cost, the acquisition of specialized components and materials requires extra spending.

- The project's budget allocation must be managed wisely to ensure optimal utilization of resources and adherence to the budget ceiling. Prioritizing essential components and seeking cost-effective alternatives can help maximize the project's value within the available budget.

- Regular budget tracking and monitoring are essential throughout the project's lifecycle to identify any overspending. Adjustments may be necessary to reallocate resources or find additional funding if required.

By conducting a thorough budget analysis and carefully planning the purchasing of required components, the project can effectively manage its finances and ensure the successful execution of the robotic system development within the specified budget constraints.

9. Conclusion

As we approach the conclusion of our in-depth exploration into the Rock 'N' Rover project's development journey, it's become increasingly evident that our achievements in engineering extend far beyond basic technical skills. They are a combination of careful planning, smooth adherence to standards, and a commitment to perfection. Throughout this path of innovation and discovery, the industry standards have paved our path, steering us towards safety, reliability, and innovation. Our journey will be marked by countless moments of collaboration, problem-solving, and creativity. As we get towards the final creation of our invention, we're filled with a sense of pride and accomplishment, knowing that we'll overcome challenges and push boundaries to create something truly remarkable. This experience also feels like the beginning of a new phase filled with even more opportunities for growth, learning, and impact. We're excited to see where this journey takes us next, confident that our foundation of teamwork, dedication, and passion will continue to guide us towards greater heights of innovation and excellence.

From the project's establishment, safety has remained our prominent concern. Through the implementation of robust safety protocols, comprehensive risk assessments, and the establishment of emergency backup plans, we have underscored our undeniable dedication to preserving life, property, and the environment. This proactive stance toward safety not only diminishes potential risks but also instills a profound sense of confidence in the integrity and success of the project. Additionally, regular safety checks and ongoing training sessions ensure that everyone involved is well-prepared to handle any unforeseen challenges that may arise. By prioritizing safety at every stage of the project, we create a secure environment where innovation can thrive and all team members can work effectively towards our common goal.

In the field of electrical engineering, we take seriously the responsibility to follow industry-approved standards and conduct thorough testing with unwavering determination. By sticking to established best practices and testing our creations rigorously, we aim to create a vehicle that not only works reliably but also proves to be durable and adaptable. Every part of the Rock 'N' Rover's design has been carefully thought out to handle exploration, overcoming challenges with consistent confidence and effectiveness.

When it comes to software development, our main focus is on ensuring quality. We do this by using proven methods, encouraging compatibility, and putting a lot of effort into quality assurance. Our goal is to create software that is stable, secure, and performs well. By writing precise and efficient code, we ensure that the Rock 'N' Rover runs smoothly in any situation, demonstrating excellence in software engineering.

Effective communication has served as the essence coursing through our collaborative efforts. By establishing clear guidelines for information exchange and collaboration, we have created an environment of transparency, accountability, and innovation. Our shared protocols and interfaces have provided a comfortable ground in which creativity and efficiency can flourish, propelling us toward the height of our collective aspirations.

Moreover, our unwavering dedication to quality assurance and careful documentation standards will have laid the basis where every aspect of the project rests. Through persistent documentation and accurate testing, we will have ensured that every component of the project adheres to the highest standards of excellence, enhancing reliability, customer satisfaction, and streamlining the development process.

As we take a look into the future, The Rock 'N' Rover project is ready to make a big impact in the world of remote-controlled vehicles. We've got a strong foundation based on following the rules, doing things well, and aiming high. This sets us up to explore new ideas and inspire future engineers and innovators. As we keep pushing the limits of what we can do, our project will not only make waves in robotics but also open doors for more discoveries. By sticking to our values and encouraging creativity and curiosity, we're set to shape the future of remote-controlled vehicles and make a lasting mark on the industry.

In conclusion, the Rock 'N' Rover project shows how working together, staying determined, and being passionate can really make a difference in achieving engineering greatness. As we move forward, we're filled with excitement and hope because we know that there are so many opportunities for new ideas, discoveries, and making things better. We're ready to dive into this next phase, knowing that it's full of potential for innovation, uncovering new things, and making big changes.

10. Appendices

10.1 Appendix A - References

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