# Nissan Simulation Conceptual Design

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## I. Introduction

Tennessee Tech currently has a driving simulator using Logitech controllers in the basement of Brown Hall. This simulator was built and designed by a mechanical engineering (ME) capstone team a few years ago. While the simulator was sufficient for providing the university with a generic driving simulation, the electrical and computer engineering (ECE) department has decided to team up with the ME department to further improve this old project. The ECE team is tasked with converting a 2014 Nissan Leaf that resides in Lewis Hall into a real-time accurate driving simulation that uses Nissan hardware as opposed to game controllers. This Nissan Leaf is cut in half, removing the rest of the car behind the driver's seat.

### A. Problem Definition

Team 8 intends to replace the controllers that interface with the simulation to the Nissan Leaf's hardware which includes, but is not limited to the steering wheel, pedals, and shifter. The use of this hardware will still provide real-time and accurate inputs into the simulation to provide the most realistic driving experience possible to its user. To achieve this goal, the car must be powered and tested for the data outputs from the Controller Area Network (CAN) bus, Nissan sensors already inside the vehicle, and external sensors installed by the team. The CAN bus is the highway for all data being communicated between different systems of a vehicle. Thus, the CAN bus contains useful information about steering angles, throttle position, gear position, and brake status. The team will not pull data from the CAN bus because data will not be able to be decrypted, but the team will still capture its outputs. The Nissan sensors and external sensors will be the target for data acquisition. The data extracted from the sensors shall be sent to local microcontrollers to interpret the outputs of the sensors. The local microcontroller data shall then be sent to a master microcontroller that receives the data from each local microcontroller. The master microcontroller will then interpret and communicate data into a personal computer (PC) for use in the driving simulator. The following is the list of shall statements that fully describes the project requirements:

- Shall integrate external systems such that the Nissan Leaf steering wheel, pedal positions, blinker, shifter position, and headlight selection are detected and sent into the simulation.
- The CAN bus data shall be captured in no less than 10 Hz transmission speed.
- Shall integrate an external speedometer such that the simulation data controls the speedometer.
- Shall develop bypass strategy to enable vehicle operation without the back half.
- Shall implement power system that requires flipping a single switch to turn on.
- Shall develop and deploy a testing strategy to identify which original equipment manufacturer (OEM) sensors are functioning and which are not.
- Shall include safety device to protect components from power overloads.

### B. Constraints

The three main constraints of the design are as follows:

1. National Electrical Safety Code (NESC)
2. Accuracy of Data Outputs
3. Unique Implementation of Subsystems

The engineering standard constraining the design of the project is the Institute of Electrical and Electronics Engineers (IEEE) NESC. This safety code lays out all the fundamental precautions to be taken when working with and designing electrical hardware that has inherent hazardous potential [1]. The power system of the design shall include a breaker or fuse box system to prevent overloading components. The fuse system can protect the circuits in the vehicle and the external components from damage or possible failure. To conceal exposed wires, the team shall encase all wires in an insulting material so no direct contact can be made with the user.

Constraint 2 involves the broader impacts of the project. The simulation is to be used to replicate driving a real vehicle as accurately as possible. Any inaccuracies in the simulation can lead to a poor learning experience that can negatively impact a new driver on the road. This can then lead to more accidents and fatalities which opposes the societal goal of the project [2]. To overcome constraint 2, the team shall implement a testing strategy for each subsystem to ensure the output data is accurate compared to a stock Nissan Leaf. Additionally, sensors installed in the vehicle shall have a low margin of error to provide the most accurate data possible.

Constraint 3 is an ethical consideration the project must follow. The team shall not steal or implement any trademarked designs in the project. This includes not replicating the Logitech controllers that already interface with the simulation. Therefore, each subsystem of the design shall be designed only by the team members of the project.

## II. Purpose of Conceptual Design

Designing a complex system is constrained by engineering standards, broader impacts, and ethical concerns. All of these must be accounted for before physical construction of the system can occur so that the project's lifecycle is optimized both economically and timely. For each constraint that is ignored and not incorporated in the design, costly maintenance of the product will be required. Therefore, it is imperative that the team recognizes and accounts for each constraint in the individual subsystems of the design.

To maximize the goals of the customer, all requirements must be met within the boundaries of the constraints. Detailing each requirement must be completed in the conceptual design before construction beings so that the customer is satisfied with the final product. Unfortunately, the project contains some critical unknowns that may inhibit the team's ability to fully deliver the final design. These critical unknowns include wiring schema, CAN bus encryption, and OEM sensor functionality from cutting the vehicle in half. To minimize these risk sources, the team is installing external sensors for most of the subsystems. The sensors being installed can be fully understood by the team through datasheets provided by the manufacturers so that they may be properly implemented.

By planning for the project to be designed around the risks, goals, and constraints associated with it, the team can create a detailed design that utilizes the least number of resources possible. Ultimately, the conceptual design allows the team to layout the steps to complete the final project within an optimal timeline.

## III. Subsystem Design

### A. Power Systems

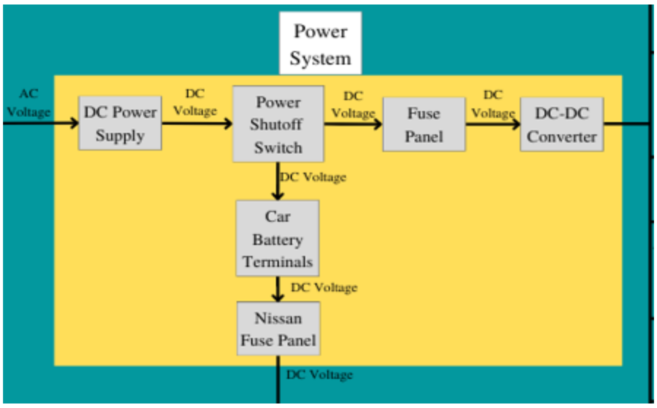


*Figure 1. Block Diagram of the Power Sub-system*

The internal control systems of the car were originally powered by a 12 V dc battery. With the conversion of this car to being an input device for the simulator, the battery will not be recharged from normal car usage and needs to be replaced with a continuous power supply. So, the beginning design of the power system for the car is transferring the 12 V terminals from a battery to a continuous power supply.

For implementation and control of the power system, there will be a cutoff switch installed in series with the power supply output to disconnect all power to the car. This will allow for an accessible point to safely turn the power on and off for the system that does not put the user in danger. The switch will also house a fuse to protect the power supply for any chance of exceeding the rated current due to an inrushing current from when the switch is closed. This instantaneous spike in current to charge the entire system to its initial steady state levels could overload the power supply and damage its internals. So, when implementing a power switch, the design and specifications for it need to be in a manner that will not jeopardize the integrity of the power supply and system [3].

With the power supply being 12 V, it is known that lower voltage will be needed for at least the microcontrollers. Most microcontrollers are powered by 5 V DC, and this proposes the problems of needing either a DC-DC converter or another power supply for 5 V. Due to the cost for another AC-DC power supply being greater than a converter, either a DC-DC buck converter or an operational amplifier will be used for this design rather than another supply. The loads on the converter should mainly be the sensors and microcontrollers. In designing the optimal converter circuit, Spice simulations will be completed to see the maximum loads that could be applied to the converter and what the minimal current requirements are needed and determine if one single converter will be enough.

A problem with a single converter compared to multiple is the receiving voltage at each component of the load. Depending on the length of the line being run, the voltage at each component may drop below the required input level and force the converter to be closer to the component. This concern will be tested analytically with simulations and calculations of the voltage drop for different lengths of wire with respect to the wire size.

To reinforce the safety of every component that will be design and installed, a layer of protection will be added in series with the components in the form of a fuse. The value of each fuse will be based off the required power of the component that it is in series with and the maximum current that can be supported by the wire. Ideally, the sensor or microcontroller that is at the receiving end will be the limiting factor with the wire being large enough to support the current needed. The fuses for each system will be found and then placed into a centralized fuse panel for ease of verifying that all fuses are still functional if there were to be any issues. The National Electrical Code (NEC) states in article 240 what requirements are needed for protection from overcurrent, and this standard will be the largest constraint to the design of the fuse panel and the fuse for each component system [4]. The requirements from NEC's article 240 will be the deciding factor in which the panel will be constructed.

Different from the external system, the Nissan Leaf already has an internal fuse box for all the OEM components. The OEM components are connected to a fuse box between components and the battery terminals. This fuse box was designed for the internal system and should meet safety requirements and constraints. The component restrictions from the manufacturer should not require modification since this fuse box should already be safe and efficient in its design. This provides the safety needed for the OEM systems.

### B. Gear Shifter

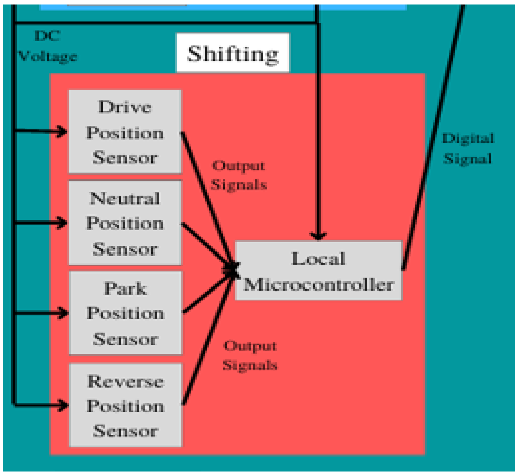


*Figure 2. Block Diagram of the Shifting Sub-system.*

The CAN bus will be used to read the outputs from the gear shifter. These outputs will be collected by a local microcontroller. The local microcontroller will then send the outputs to a master microcontroller. Also, a position sensor for each position will be mounted on the frame around the shifter. These outputs will be collected by a local microcontroller. The local microcontroller will then send the outputs to a master microcontroller. The local microcontroller will read data from all of the sensors, but it will only send one value indicating what gear the position is to the master microcontroller. The sensors will be powered by a 12 V power supply and will be stepped down using an amplifier circuit. This will be used to ensure that the sensor is receiving the appropriate amount of voltage. C code will be created to compensate for the gear shifter’s three second time delay to put the Nissan Leaf in neutral. Without this, the sensor would be reading that the car is in neutral when it could be in park. These two methods will be used for redundancy, so the car’s gear is always matching with what is being stored in the microcontroller. The sensors and CAN bus will operate at 100% accuracy due to the accuracy constraint and the high importance of knowing what gear the car is in due to the negative impacts it could have on the functionality of the car and simulation.

If the signal being sent to the microcontroller is not accurate when compared with the actual gear of the car, it could cause the accelerator pedal to not work properly due to the car being in park even though the sensors read that it is in drive. To measure the accuracy of the sensors and CAN bus, the team will continuously check to see if the signal being sent to the microcontroller matches what gear the car is in. The team will go through many trials of testing to ensure that there is zero error in accuracy. To verify that the sensors are receiving the appropriate amount of power, a multimeter will be used to measure the power being sent to the sensor. This will be checked until the sensors are consistently receiving the appropriate amount of power.

### C. Steering Wheel

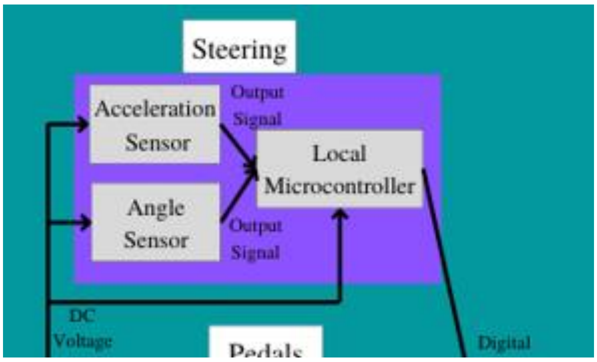


*Figure 3. Block Diagram of the Steering Wheel Sub-system.*

The steering wheel subsystem in the block diagram is a system to measure the angle and the rate of rotation inside the steering wheel. Also, inside the subsystem, the sensor shall communicate with the local microcontroller and store the information. The local microcontroller shall send the stored information to the master microcontroller.

Since the steering wheel is unique for many different vehicles, this will create a constraint for the subsystem. For the Nissan leaf, the input range constraint arises due to the steering wheel having 2⅔ rotations from the limitation of the left and right (980 degrees). Since this restriction of 2⅔ rotations of the steering wheel exists, the sensor shall measure within that range. The rate of the steering wheel, however, shall assist in improving angle measurement. There is a small constraint when it comes to identifying a sensor that is not too sensitive to movement, which could lead to high error rates.

The precision of the encoding of the output comes from "shall be in the range 2⅔ ". Given 2⅔ rotation, the user is able to rotate the steering wheel with 0 to -480 degrees representing the position from the center to the right limit (clockwise) and 0 to 480 degrees representing the position from the center to the left limit (counterclockwise).

An output angle shall be created and sent to the local microcontroller. It is critical to note that the rate of steering wheel rotation shall send a general idea about what the driver is doing with the steering wheel to the microcontroller. Both sensors shall transmit information to the local microcontroller that results in a realistic steering experience. An example of this will be when the user turns a positive 45 degrees on the left and moves to steer fast. The first sensor shall detect the speed and give an idea to the local microcontroller before the user turns the steering wheel completely. Also, the second sensor will send how much the steering wheel rotated.

The purpose of unit tests and integrated test units is to ensure constraints are met analytically before using them. The unit test will check that the rotation is positioned correctly and send verification to a display that is ready to use. However, the integrated test unit will detect if the sensor is working efficiently and send a confirmation to display each sensor's working. When establishing the integrated test unit and unit test, an oscilloscope or multimeter shall check whether the sensor is producing any signals.

### D. Accelerator and Brake Pedals

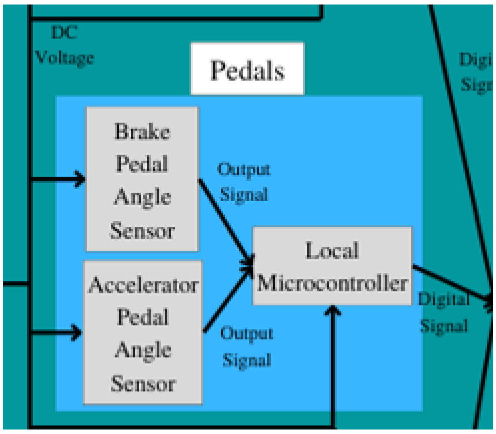


*Figure 4. Block Diagram of the Accelerator and Brake Pedals.*

The purpose of this subsystem is to gather data of the position of the pedals and send it to the master microcontroller to be implemented into the simulation. This subsystem is made up of the atomic pieces of the accelerator angle sensor, the brake angle sensor, and the local microcontroller their outputs feed into. The inputs of the sensors come from the power system and the OEM pedals. This subsystem outputs data to a local microcontroller from each sensor. These signals are then processed in the local microcontroller and sent to the master microcontroller. The brake pedal and the accelerator atomic systems will be implemented identically on the hardware aspect. To differentiate the output signals of the pedals, the microcontroller subsystem will send the data to the simulation and store it in the appropriate parameter within the physics engine that controls the brake pressure and acceleration of the vehicle respectively.

The subsystem is constrained by Constraint 1 and Constraint 2. It must be compliant with Constraint 1 because the user could negatively affect the system if the wires and the sensors are not secured safely. In the event a wire is not properly secured or protruding from the pedal, the user could interrupt the signal by damaging the hardware below their feet. Constraint 2 must be followed to get accurate information of the pedal angle for the simulation to be realistic. Discrepancies between the true pedal angles and the measured pedal angles from the sensors could provide a fallacious learning experience to the user. Inaccuracies of this kind are not to be tolerated from a civil standpoint. To verify these constraints, the team will use a multimeter to verify if the current levels are within a safe range of values as well as verifying the voltage output has a direct relation to the angle of the pedals

### E. *Microcontroller Network*

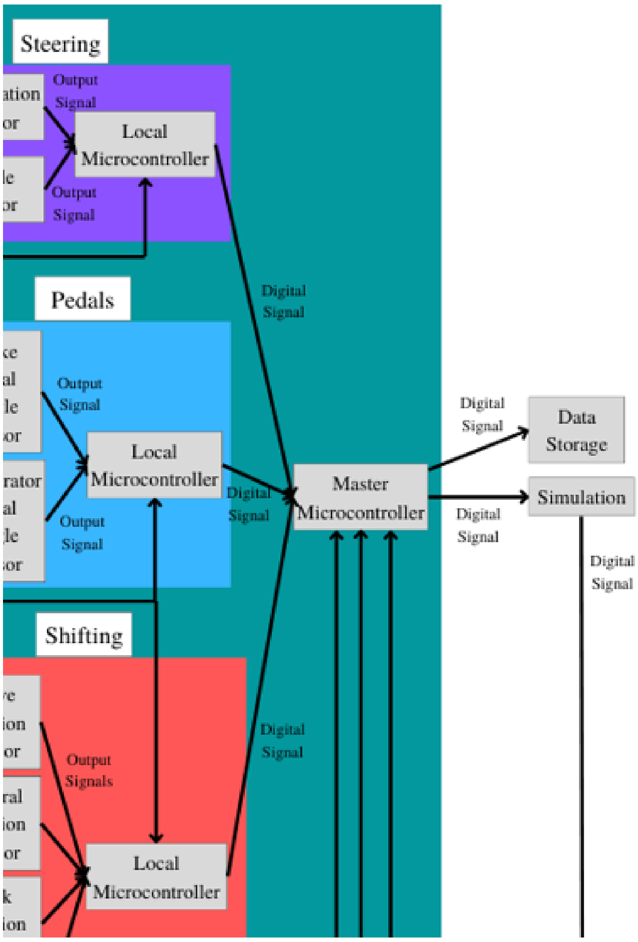


*Figure 5. Block Diagram of the Microcontroller Network.*

The microcontrollers will be categorized by local and master such that local refers to the microcontrollers that interface directly with the atomic subsystems, and master refers to the microcontroller that interfaces with each of the local microcontrollers in the system. The local microcontrollers (LMCU) will be reading the sensor outputs for the following atomic subsystems: steering wheel, shifter, and pedals. For the speedometer system, a LMCU will receive data from the simulation on the PC and write to the speed sensor. This allows the dashboard of the Nissan Leaf to display the simulated vehicle speed. To maintain time efficiency, algorithms for each LMCU will be written in C/C++ alongside any integrated development environments (IDE) that accompany the product. The design of using multiple LMCUs instead of a single microcontroller for the entire system, is to reduce noise during data transmission. Noise can occur with multiple wires sending and receiving data simultaneously within a small area. By spreading out the LMCUs, noise can be reduced, and the data will be less likely to be altered during transmission.

The master microcontroller (MMCU) serves as the data hub for each output of the LMCUs as well as the device for capturing CAN bus outputs. The CAN bus will be connected directly from the Nisan Leaf to the MMCU, and its outputs will be sent to the PC for storage. To meet the requirement of capturing CAN bus data, the MMCU must be fast enough to process the data in less than 10 Hz. This includes selecting a microcontroller with a fast enough clock frequency and writing algorithms that are time efficient. To verify the time efficiency of the code, the team will calculate the time complexity of the algorithms written on the MMCU.

### F. *Speedometer System*

The speedometer system will be implemented using the OEM speed sensors on the wheels of the vehicle. Because the car is not in motion during the simulation, the signal will be spoofed based on the data in the simulation's physics engine. This way, the speedometer will match the graphical simulation on the monitor and will not have to depend on actual motion of the wheels. By spoofing the signal on the original sensor in the vehicle, the speed will be displayed on the vehicle's digital gauge cluster, which allows the team to avoid installing an external non-OEM speed gauge. To successfully introduce the signal from the simulation into the speed sensor, the team will have to identify the wiring scheme of the sensor through data sheets and testing. The signal from the simulation will be sent into a local microcontroller to be processed before it is sent to the speed sensor of the vehicle. Due to the accuracy constraint, this system will involve heavy testing to ensure the speedometer is as accurate as possible.

### G. *Signal Lights/Blinkers*

The signal lights or blinkers are functional with the current condition of the car and a 12 V power supply. The simulation does not currently have an input for the blinkers, so the goal is to record the output from the OEM blinker into a Simulink format. This will allow for integration of the blinkers into the simulator at a later date.

Blinker lights are only in an on or off state on each side allowing for a wiretap to detect if the voltage is high or low. This retrieval of data will be fed into a microcontroller and needs to be duplicated for each side of the car. This will require two bits of information, one for each side of the car, to be stored.

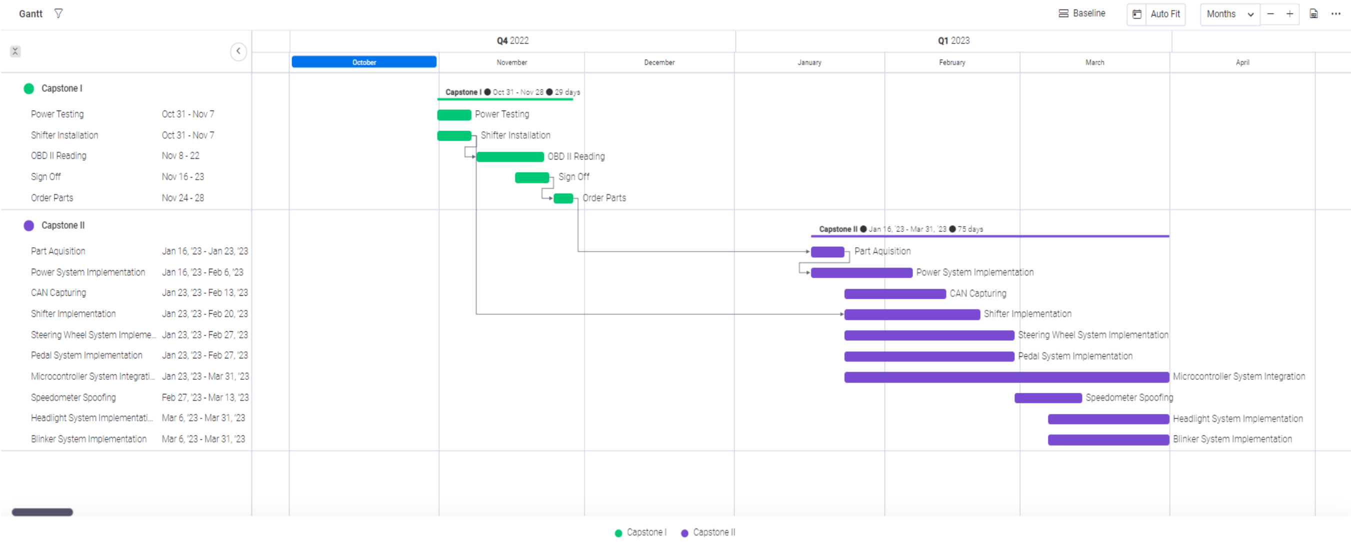


*Figure 6. Gantt Chart of the Project*

### *H. Headlights*

The headlights on the car are functional in the current condition of the car. As well as the blinker lights, there is not currently an input for the state of the headlights in the simulation. With this, two wire taps can be installed to detect which lights are on and the results be saved for later use. In the Nissan Leaf, the lights are composed of bright and dim light settings. The lights can be in one of three potential states: off, on and bright, or on and dim. The lights on both sides of the car have the same output, so the system can be designed for one side of the car.

To detect the output of the headlights state, two signals will need to be retrieved to detect the output from the car. This can be completed by tapping into the wires on both the bright and dim lights. Both signals can be interpreted as a high or low value since they only need to be either on or off. This signal can be fed directly into a microcontroller to then store the output.

### *I. Testing Process*

Each subsystem of the project will undergo testing to verify its functionality in the overall system. Although no two subsystems can be tested identically, the general process for each is described in the figure below.

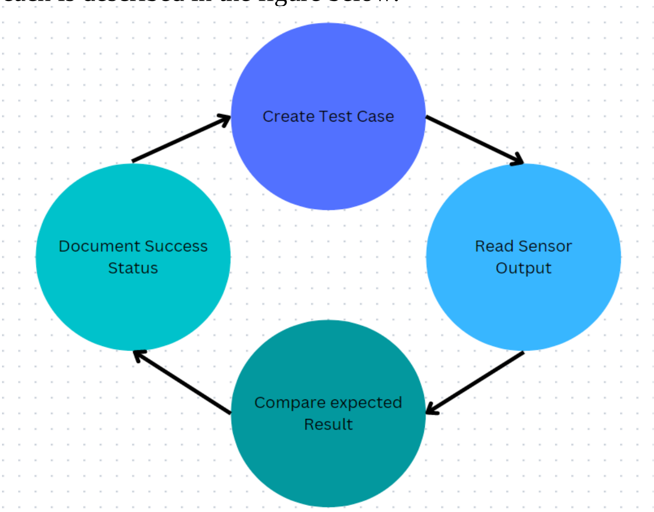


*Figure 7. Testing Process Diagram*

The process will begin by creating various test cases for each sensor. These test cases will be created by the lead designer of each subsystem. Then, sensor outputs will be read in the LMCUs given a certain test case. Once read, the output will be compared to the expected result. Expected results will be both analytically calculated and experimentally observed. The status of the data verification will then be recorded in a document alongside the corresponding test case. If the expected results match the sensor output, then the testing can move on to the next test case. However, if the expected results fail to match the sensor output, changes must be made to the subsystem until the results match.

## IV. Timeline

The order of which the tasks are completed is critical to the success of the project. The power system is the first system that must be implemented so that each of the other subsystems can function. Brett Harden is responsible for the design and implementation of the power system. Upon powering the vehicle and its surrounding components, the shifter system becomes the top priority subsystem. Without the proper installation of the shifter system, the vehicle diagnostics cannot be read from OBD II, and debugging cannot occur. Therefore, it is imperative that the shifter is installed quickly and accurately to allow the rest of the team to implement their subsystems as soon as possible. This subsystem will be directly managed and designed by Ethan Powers. After the shifter subsystem is properly installed, the steering wheel, pedals, microcontrollers, blinkers, speedometer, and headlight systems can begin implementation.

Due to being the fundamental components of driving, the steering wheel and pedals will become the next top priorities of the whole system. The steering wheel subsystem is led by Gerardo Mateo and the pedal subsystem is led by Chase Colotta. During the implementation of each of these systems, the microcontroller network will begin integration. The network will begin by installing LMCUs to each subsystem that is ready to begin testing and data collection. Upon completing the installation of the LMCUs for each subsystem, the outputs will feed into the MMCU. Michael

Mollica is responsible for the design and implementation of the microcontroller network. Algorithms that are to be written to the microcontrollers can begin development earlier as they do not fully depend on the completion of the other subsystems. Additionally, the MMCU can begin CAN data collection before interfacing with any of the LMCUs because the CAN bus will function as soon as the power system and debugging are complete. The lower priority subsystems include the headlights, blinker, and speedometer. This is due to their inherent nature of being less important to the driving of a vehicle as compared to the other higher priority subsystems. The speedometer subsystem is the next highest priority and will be designed by Michael Mollica and Ethan Powers. The blinker and headlight subsystems can begin implementation concurrently with the speedometer subsystem as they share no dependencies. These subsystems will be designed by Brett Harden and Chase Colotta respectively.

Each subsystem will be tested following the process described in Fig. 7. Testing shall immediately occur upon completion of a subsystem so that proper functionality can be identified quickly and before the subsystem interfaces with any other part of the whole system. This will allow the team to prevent confusion and propagating errors within the system.

## References


[1] "2017 National Electrical Safety Code(R) (NESC(R))," in 2017 National Electrical Safety Code(R) (NESC(R)) , vol., no., pp.1-405, 1 Aug. 2016, doi: 10.1109/IEEESTD.2016.7526279. (accessed Sep. 23, 2022).J. Clerk Maxwell, A Treatise on Electricity and Magnetism, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68–73.

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[3] "StackPath," *www.electronicdesign.com*. https://www.electronicdesign.com/technologies/analog/article/21807286/choosing-the-right-switch-know-your-ac-from-your-dc (accessed Oct. 30, 2022).

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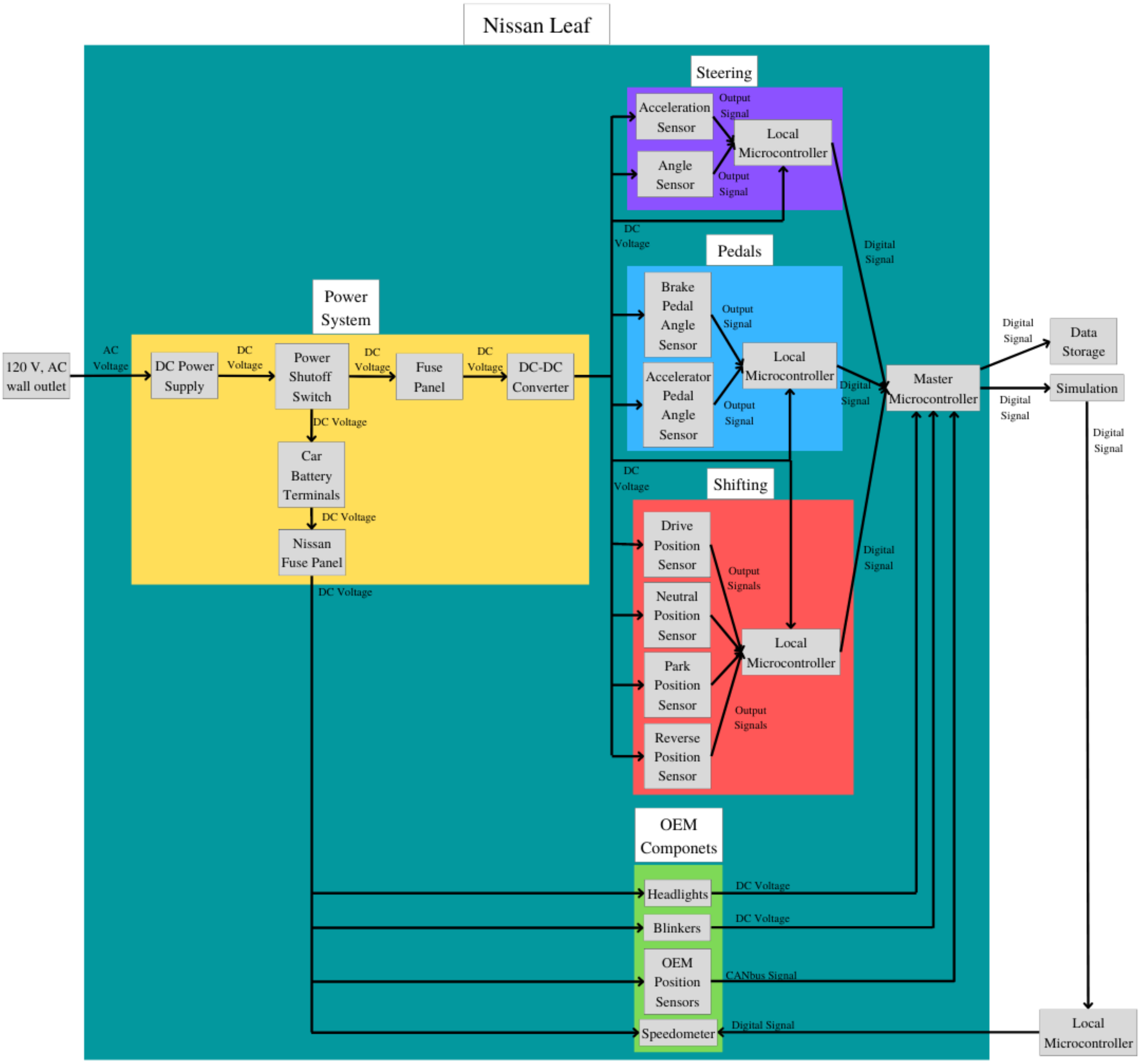


*Figure 8. Complete Block Diagram*