

# Automated Parking Space Locator: RSM

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## Abstract

The purpose of this project is to develop a Robotic Stall Monitor (RSM). This product will monitor parking spaces within an enclosed parking structure and wirelessly transmit data to a system where parking attendants may inform clients of available spaces. The project will focus on implementing a system travelling on an overhead track hosting numerous sensors capable of indicating if a stall is occupied. This project is funded by and done in collaboration with Federal APD.

## Introduction

In the parking industry there are numerous methods for monitoring parking lots and garages. The simplest technique is to count cars as they enter and light a “Full” sign when the lot reaches capacity. More complex systems exist that can determine exactly which spots are available [1]. This information is then relayed to the customer, allowing them to find spaces efficiently and reduce congestion.

Unfortunately, many of these technologies require extensive wiring throughout a parking garage since most sensors can only monitor one or two spots. These systems can be unattractive because of high-costs and the existence of several potential points of failure. Costs tend to be high because each spot requires at least one sensor and then each sensor needs to be hard-wired into the network [2]. Other technologies include using imaging software and an existing security camera system. The disadvantage lies with complicated software and the high-cost of installing that advanced security camera system software. Another huge disadvantage to these types of systems are the resources required in terms of technicians and construction personnel and the difficulty of installation. These camera based and sensor based systems require the installation of the cameras themselves and running the wiring for those cameras, or sensors, which can be very cumbersome. The solution is to set up a system that requires only one mobile set of sensors that is installed in one step. The proposed design will not require an electrician, as is the case in many other installs, but only the mounting of physical hardware to the ceiling of the structure.

The intent of this project is to implement a novel design of a Robotic Stall Monitor (RSM) system that was proposed by John Rambow of Federal APD. APD stands for “Automated Parking Devices”, and they are the largest US manufacturer of parking access and revenue control systems. This project will be a collaboration between CMU College of Science and Technology and Federal APD. The proposed system intends to combine several existing technologies onto a mobile platform which reduces the points of failure and can be installed with little help of highly specialized technicians, but utilize more general labor practices.

An internal computer will be utilized to control the RSM’s functions and collect, store, and transmit data. The RSM will utilize an overhead rail system and DC motor for forward motion along a predetermined path. Along the path, a barcode scanner and ultrasonic sensor will scan the parking spaces. From the gathered scan data, the number and location of empty spaces

can be computed. The figure below will explain contains a concept map of how the proposed system will operate.

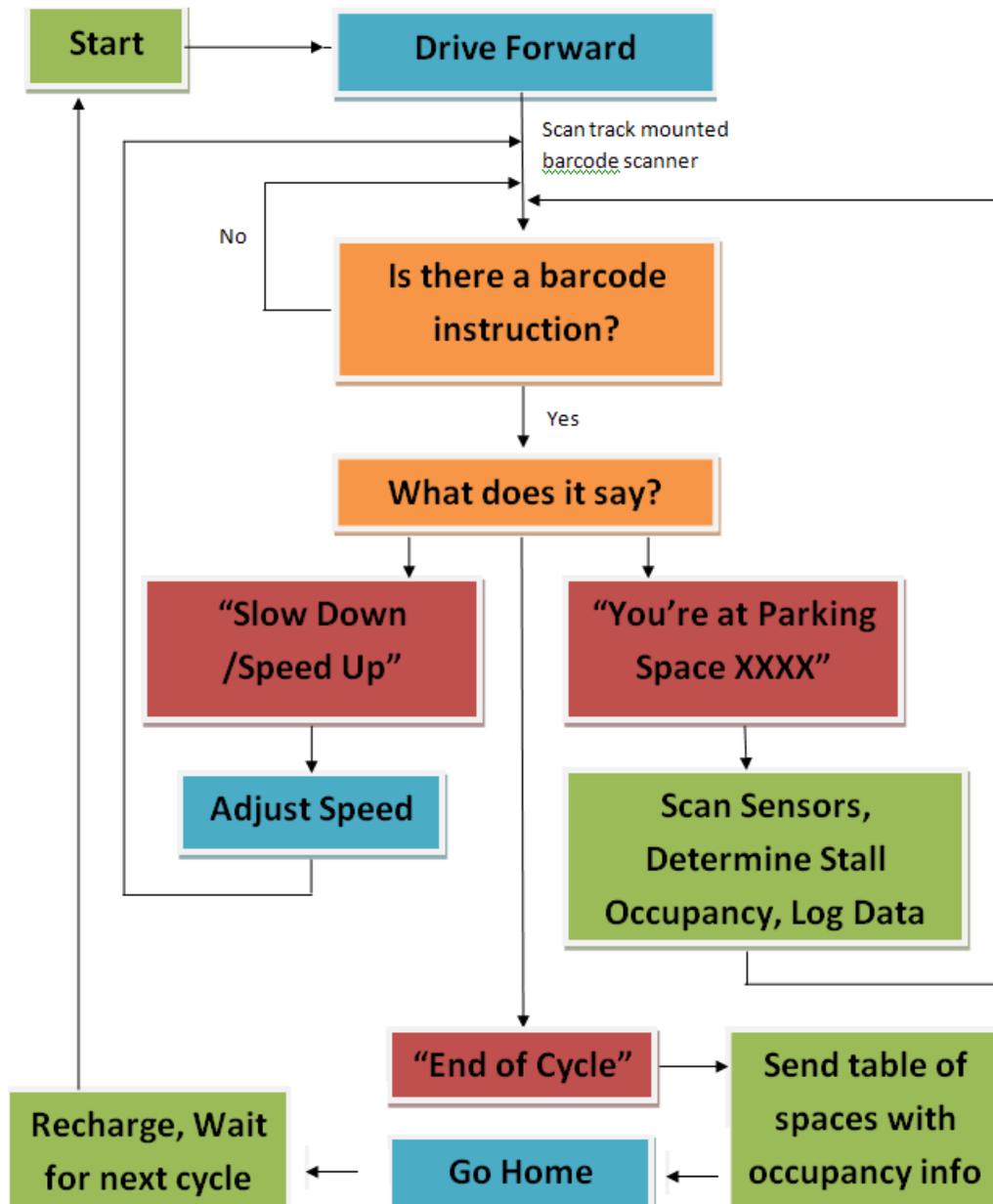


Figure 1: Concept map of RSM operation.

The objective of the system is to provide a low-cost RSM solution to enclosed parking structures to better analyze use and provide valuable information to the parking garage owners and their customers. The system will be able to travel up a grade, or incline, within a parking structure. The system will be able to indicate whether a space is occupied or not using an ultrasonic sensor and barcode scanner. These sensors will enable the system to locate an individual space through use of barcode scanning and designate if that space is occupied. The RSM will be battery powered and rechargeable. The prototype will be demonstrated on a custom built, small-scale, mock parking structure in the Engineering and Technology building at CMU.

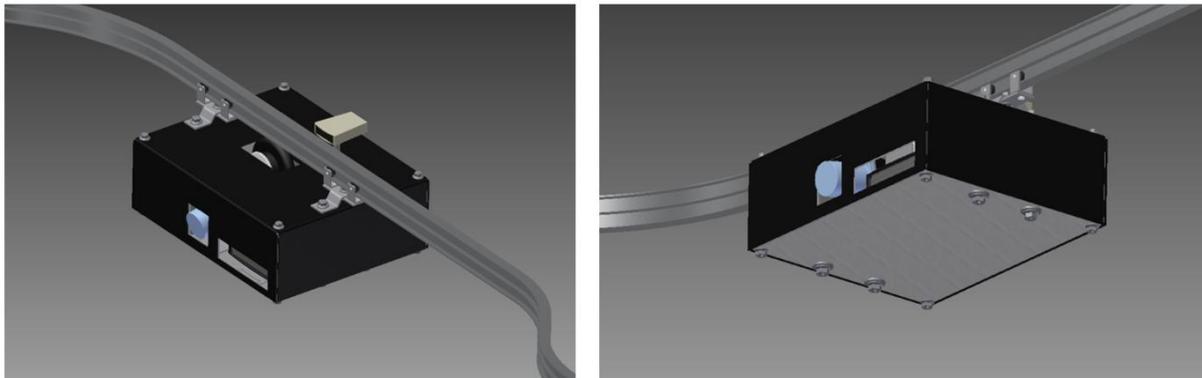


Figure 1: Simulated RSM constructed and Mounted on Rail

### Specifications

The design specifications are defined by the customer (Federal APD). The customer requires the RSM to:

- Scan for empty parking stalls from an overhead track
- Update a database containing information on spaces within parking structure
- Wirelessly transmit data to potential customers indicating location of vacant spaces
- Allow for user to define cycling periods of the RSM
- Achieve low-cost installation with minimal maintenance

The system should encompass all of these needs so that an owner of this system can pinpoint individual spaces and provide that information to its customers parking in that structure. The solution is to combine ultrasonic scanning technology with a barcode scanner to indicate location and availability of space. A barcode scanner will scan for a barcode at each space; the software for optical recognition comes with the scanner. By mounting the scanner on a mobile platform, the number of scanners in the system can be reduced and the need for a large array of sensors eliminated. Additionally, the unit will be self-powered by a rechargeable battery and the rail will not carry any power to the device. Data will be transferred to and from the robot via a Wi-Fi connection, further eliminating the need for wiring. The end result is a system that is easy and cheap to install, and doesn't require hundreds or thousands of sensors.

### Design Considerations

More detailed design considerations include the following:

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- Designing or choosing the overhead rail system that will comprise the track of the RSM
  - This system must be capable of supporting the RSM (roughly 30 pounds)
  - The design must accommodate and allow for removal and maintenance
  - The overhead rail must allow the RSM to travel forward and backward
  - The track must be low-cost and easy to install, requiring general labor rather than more specialized trades people
- Choosing a motor that will drive the RSM around the track
  - The motor must accept a DC source from a portable battery pack
  - The torque provided by the motor should be great enough to drive the RSM up a grade, minimum 3.0 lb-in
- Designing the package that will contain all relevant components of the RSM
  - The package will contain the motor and drive system
  - Ultrasonic sensor and barcode scanner
  - Single Board Computer
  - Rechargeable batteries

## **Benchmarking**

Current parking space monitoring technologies can be split into two categories: sensor based and vision based. Sensor based systems use a strong-arm approach by monitoring each stall independently, with a larger system to monitor space occupancy. The vision based systems employ an array of cameras to gather data, which is then analyzed by complicated computer software to determine parking space occupancy.

Visual Soft Incorporated is one company that offers a sensor based system. Their system employs laser sensors to determine whether or not a parking stall is occupied [3]. Siemens also offers a sensor-based system called “SIPARK” but instead uses ultrasonic sensors [4]. However, regardless of the occupancy detection methodology, the disadvantage of either system is the same – each sensor requires power and data lines to be run to each individual space. As a result, this type of sensor based system is expensive and difficult to install and significantly increases the possible points of failure. One implementation done by UCLA circumvented the wiring and installation issues by using wireless sensors; however, it was incapable of monitoring individual parking spaces and could only provide basic zonal information based on traffic patterns between zones [5]. Another system developed at the Chinese Academy of Sciences uses a wireless network to transmit data from their stall monitoring sensors but still requires that a power conduit be run to each individual space [6].

There currently exists no commercial vision-based system on the market. However, Catherine Wah of the University of California led a development project for this type of system. It required the utilization of pairs of cameras in order to generate a 3D reconstruction of the parking lot environment, and in turn to determine the occupancy of a parking space [7]. The software developed to achieve this is rather complex and better suits an open environment where camera pairs could be mounted to monitor large areas. As a result of the limited line-of-sight and cramped quarters in a parking garage, such a vision-based system would suffer many of the same drawbacks of modern-day sensor-based system since so many camera pairs and corresponding wiring would need to be installed [8].

The system proposed in this project circumvents the issues mentioned above by employing a mobile platform for the sensors and transmitting the data wirelessly. Also, it is able to avoid line-of-sight issues that plague multiple camera systems, which helps cut costs. The concept proposed will only use a few sensors, a camera, and have the ability to traverse an overhead track customized to suit the structure and capture all relevant data. This system will use a wireless connection to transfer the data to users of the system, both customer and owners. This system will provide a low-cost option to parking stall monitoring in enclosed parking structures.

### Target Values and Metrics

The prototype will be tested on a small circular track, so the target speed will be limited to around 3-5 mph, for safety, for small scale testing. Ideally, once the system is installed in a parking structure the top speed should be approximately 20 mph. Knowing the limits on the speed and the rotational limits on the motor's RPMs, the team was able to mix and match various sprocket teeth counts and place those values into an excel spread sheet to calculate how each particular combination would affect the speed. A motor sprocket with 5 teeth and a wheel sprocket with 30 teeth, yielding a ratio of 1:6, will achieve a speed within the target range at 1500 RPMs, see Table 1 below.

Table 1: Gear and Speed Considerations

RSM Speed Based on Motor RPM and Wheel Diameter		
Diameter (in)	5.5	Max Speed
Circumference (in)	17.27	Desired: 4mph
# of Teeth (Motor)	5	Gear Ratio:
# of Teeth (Wheel)	30	0.1667
RPM Motor	RPM Wheel	Speed (mph)
1000	166.67	2.73
1100	183.33	3.00
1200	200.00	3.27
1300	216.67	3.54
1400	233.33	3.82
1500	250.00	4.09

Motors that would provide enough power and torque were mostly available in either 24 or 48V. This limited the team in the selection of batteries, which have common voltages of 6 and 12V, for sealed lead acid batteries. Since sealed lead acid batteries were going to be used for their ability to supply the required power (see more below in Battery Calculations), the team was limited to 24V for the motor, due to weight constraints. It was calculated that two 12 Volt, 8.5 Amp-Hour batteries, connected in series for the required 24V, would be sufficient for the RSM prototype both in supplied power and run time. The blue region in the table below shows the battery life that we can expect from these batteries given the operating current of the Single Board Computer (SBC) and the DC motor.

Table 2: Battery calculations.

<u>Current (A)</u>	<u>Power (W)</u>	<u>Battery Life</u>			
		<u>Hours</u>	<u>Minutes</u>		
1	24	8.50	510.0	<b><u>Battery Specs</u></b>	
2	48	4.25	255.0		<b>Voltage:</b>
3	72	2.83	170.0	<b>Capacity (Ah) :</b>	8.5
4	96	2.13	127.5		
5	120	1.70	102.0	<b><u>Operating Current</u></b>	
6	144	1.42	85.0	SBC	5 A
7	168	1.21	72.9		1-5
8	192	1.06	63.8	Motor	A
9	216	0.94	56.7		
10	240	0.85	51.0		

Finally, the team created a weight tally for all components in the design, see Table 3 below. This was an enormous help in selecting the SBC, Batteries, and Motor for the prototype so that we could achieve the 30lb weight goal. This goal was determined by the casters that hang the RSM from the overhead track, and because a heavier package would be more difficult to remove for maintenance.

Table 3: Weight Tally

<b>Weight Tally:</b>			
<b>Component</b>	<b>Weight (lbs)</b>	<b>Quantity</b>	<b>Weight (lbs)</b>
Batteries	6.91	2	13.82
SBC	7.7	1	7.7
Case	1	2	2
Motor	3.15	1	3.15
Ultrasonic	2	1	2
Bar Code Scanner	1	1	1
		<b>Total</b>	<b>29.67</b>

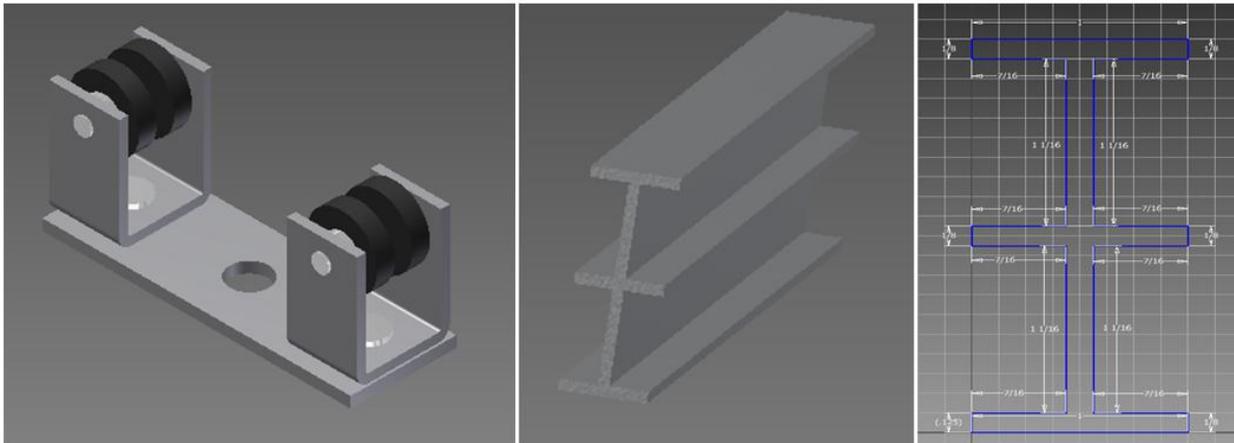


Figure 2: Caster and I-Beam Rail

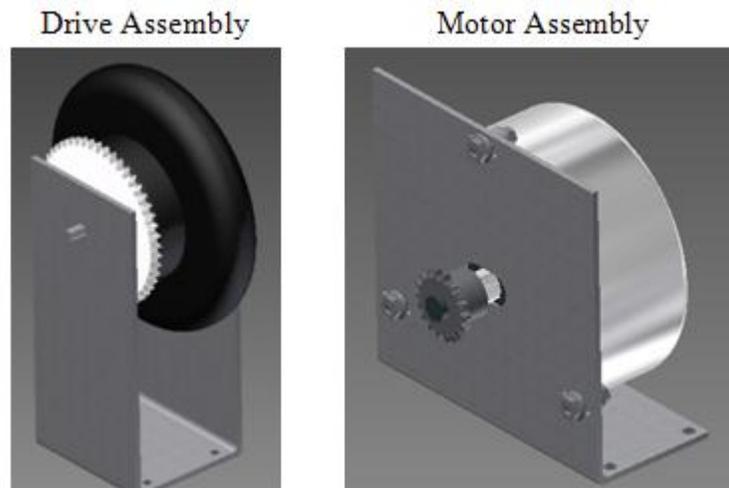
There were two main rail options considered: enclosed rail and double I-beam rail. The enclosed rail is advantageous because it has a lower profile and maintains the RSM clearance with traffic in the parking structure.

However, the enclosed rail required the robot drive wheels to be located within the enclosed rail and would involve designing and building a drive system that ultimately would be very small and would require small parts and tight tolerances. A belt drive would be required to drive the wheels within the enclosed track. The belt would have to also be narrow enough to fit between the gaps in the rail but strong enough to withstand the tension placed on it from the motor to the drive wheel. There was also the consideration of how to suspend the robot from the internal drive system and have everything fit between the gaps and have the required strength to support the weight and torque.

Using the I-beam rail, on the other hand, allows for a much simpler design which utilizes a direct drive system. The drive wheel is connected directly to the motor and makes direct contact to the bottom of the rail. This design concept allows for more flexibility and simplicity in the design. Using this rail also allows for the use of standard carriers from the rail supplier to support the robot.

### Motor Selection

Motor selection was also an integral part of the concept. The motor had to provide enough torque to propel the robot but be small enough to fit with the overall concept. Brushed motors are relatively simple to control but require more maintenance in the long run. Brushless motors, on the other hand, are more complicated to control but require less maintenance and offer more torque at lower RPMs [9].



### Case

The case/enclosure will contain all of the components and there were two main thoughts on this; one used L-shaped aluminum brackets to create a rectangular frame. Plastic, or some other material, would then be attached to the frame. Additional aluminum brackets/supports could be used internally to attach all the various components or the components could be attached directly to the material used to enclose the robot frame. A second case concept was to use sheet aluminum. The aluminum would be cut and folded to create a box like structure. Two of these structures would be used and would slide over each other and be secured by pins.

The case would be made from two pieces of aluminum sheet; each will be cut and folded to essentially form a box without a top. One box is to be marginally smaller than the other so that it can fit inside the other. The two boxes will then be clamped together using four nuts and bolts located in each of the four corners of the case. The next consideration to make was the size requirement. This consideration is based upon the contents of the case. As a result, each of the main components of the design (batteries, SBC, camera, ultrasonic sensor, motor controller, and the mechanical drive system) were rendered in CAD according to the respective manufacturer specifications and dimensions. These components were then virtually arranged to understand the necessary size requirements. The determination was that a minimum internal set of dimensions of [466mm long x 366mm wide x 166mm tall] would be required. This estimate allowed for sufficient clearance between the components themselves (both as a convenience and a precaution in the event that an alternative larger part need be substituted later on) but provides for zero distance between the components and the case wall. As a result, the final internal case dimension was selected to be: [506mm long x 406mm wide x 166mm tall]. This provided ample space for adjustments/changes in components as well as space for the drive system. At this point, the bottom case was rendered in CAD since all of the other components rest on it. Then, the top case was rendered to be slightly larger based on the external dimensions of the bottom case. This allowed the top case to fit perfectly over the top of the bottom case.

Next, a method of attaching the two cases together needed to be developed. As a result, the components were virtually installed into the case to determine where bolts could be put through the case. It turned out that there was sufficient space to place four bolts clear through the case at each corner. Holes were cut at these four positions to allow for bolts to be placed. In reality, these holes will be drilled through the material prior to bending the aluminum sheets. The bolts selected were ISO4162 M12 x 120mm. The large diameter of the bolt is excessive in terms of clamping force, but is necessary in order to obtain the 120mm length in a standard bolt. However, an advantage to such a large bolt is that it also has a larger flange area which will distribute the clamping force on the case over a slightly wider case thereby reducing the likelihood of deforming the case.

Several windows then needed to be cut from the case. The first of these accommodates the view for the camera and ultrasonic sensor. The second was made in the top of the case, directly above where the drive system will be installed. This enables the drive wheel to protrude from the top of the case and make contact with the rail. These windows could be cut prior to bending the case but could also be done after to allow for greater flexibility/adjustability.

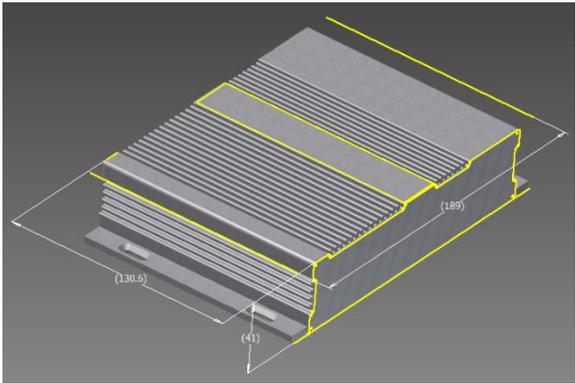
Custom brackets are required to mount the motor and the drive wheel into the case. These two brackets will also be made from the same 1/8" thick aluminum plate that the case is to be constructed of and will be bent accordingly. The motor bracket will be a simple L-shaped bracket featuring three 1/2" elongated mounting holes (based on the motor's mounting holes) to allow for chain tension adjustments and ease of installing and uninstalling the drive chain. The drive bracket is a simple U-shaped bracket with two holes at the top to accommodate the drive axle.

The ultrasonic sensor also requires a custom bracket which will be made from 1/8" aluminum sheet. This bracket is a simple L-shaped bracket that can be bent to accommodate the required angle needed to target vehicles in adjacent parking spaces based on the ceiling height and aisle width of a parking structure.

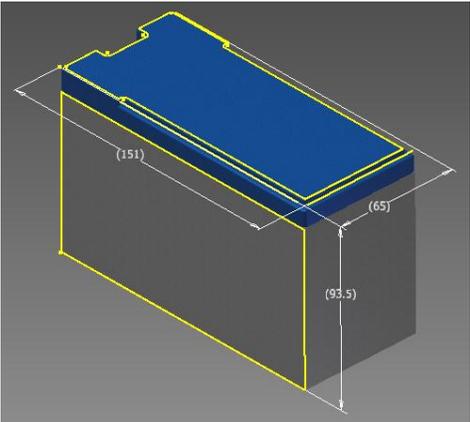
The final modification required of the case was to devise a method by which to attach it to the I-beam rail system. The selected rail was the Automatic Devices Company (ADC) 1400 Series double I-beam rail. A segment of the rail was also rendered in CAD for development purposes. Additionally, the team selected the ADC 4251 Carrier / Caster system since it had a sufficient weight capacity to fit the needs of the system (when used in tandem). This component was also rendered in CAD; however, it was slightly modified by eliminating an unnecessary bracket. In place of this bracket, the team utilized an ISO4251 M14 x 130mm bolt per bracket. The two holes for these bolts had to be placed centered (longitudinally) between the front and rear of the case. By placing the casters at the front and rear of the case, it reduces the likelihood of the casters binding when it proceeds through a corner. Centering the casters ensures that the case will hang level due to the arrangement and weight distribution of the internal components.



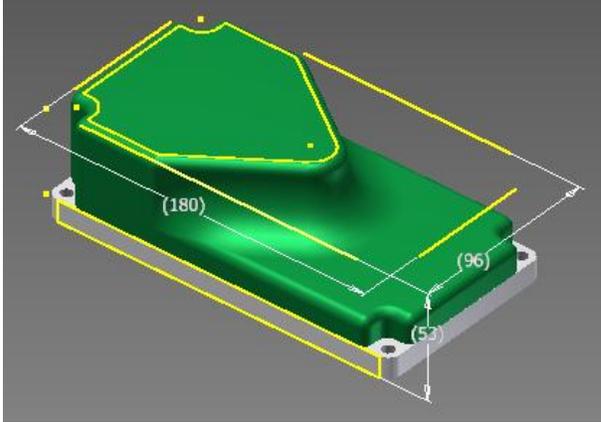
### Single-Board Computer



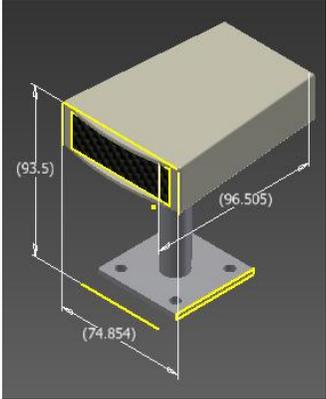
### Battery



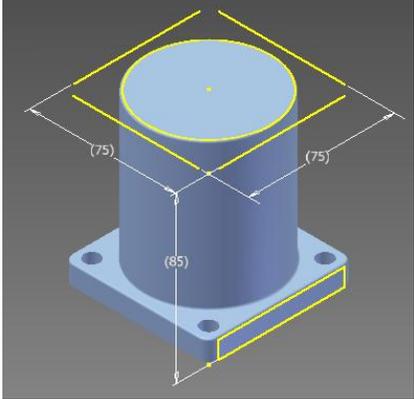
### Motor Controller



### Barcode Scanner

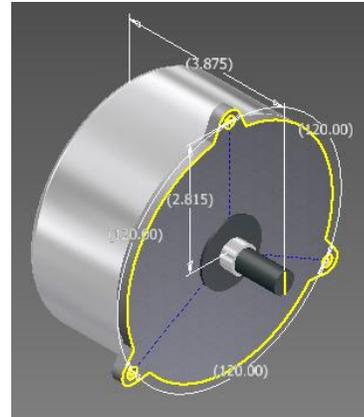
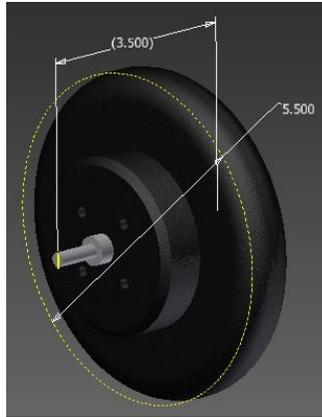


### Ultrasonic Sensor



### Drive Wheel

### Motor



## Conclusion

In summary, the proposed system design for the Automated Parking Space Locator: RSM addresses the need for an effective and relatively inexpensive stall monitoring system. Not only does it address these concerns, but the appropriate research was conducted to benchmark against other similar technologies. The findings show that the team's approach is not currently employed in the marketplace. Other techniques, multiple cameras per lane or individual sensors per stall, are explored but are found to be high-cost and complex. Our design tackles robotic stall monitoring in a novel way that will improve the cost-effectiveness of such systems in the parking industry. The overhead track system featuring a battery power supply, single board computer, camera, ultrasonic sensor, barcode scanner, and wireless module provides a simple, effective technique which will prove marketable for Federal APD. The track itself was chosen carefully to be compatible with supporting the weight of the unit itself and to allow for a drive system to propel the product. The system addresses technical concerns including climbing a typical parking garage grade, avoiding collisions with vehicles, targeting stalls correctly by angle, and compiling all of the information gathered from the sensors to transmit to a parking attendant wirelessly. This concept's packaging will be fabricated using sheet metal designs appropriately constructed to allow for housing of electrical components and appropriate mounting of various sensors. By building this prototype the team gained experience in automation and software development, and hopefully see this product enter the market place through a working relationship with Federal APD.

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