October 19, 2015

Dr. Andrew Rawicz
School of Engineering Science
Simon Fraser University
Burnaby, BC V5A 1S6

Re: ENSC 440W Functional Specification for Auto-adjustable Spoiler Control System

Dear Dr. Rawicz:

The enclosed document is a functional specification for an “Auto-adjustable Spoiler Control System”. We intend to design and implement a spoiler control system that makes driving safer, more fuel efficient and more enjoyable. Our design is a cross-disciplinary engineering project which involves aerodynamics, electronics, mechanical system, programming and control theory.

The functional specification is an overview of the functionality of our product throughout different development stages without providing excessive technical details. Our engineers at Veroptimal Solution will also use this document to stay focused on the project development progress and on the implementation of the desired functionality in a safe and reliable manner.

Veroptimal Solutions is composed by four engineering students: Zhengdong Cao, Yueying Li, Tianye Zhou and Tianlin Yang. Their concentrations include an aggregation of systems engineering and electronics engineering. We will be happy to discuss any additional questions or comments you may have regarding the functional specification. Please feel free to contact our CEO Zhendong Cao at zcao@sfu.ca.

Sincerely,

Zhendong Cao
President and CEO
Veroptimal Solutions

Enclosure: Functional Specification for Auto-adjustable Spoiler Control System

Auto-adjustable Spoiler Control System

Functional Specification

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EXECUTIVE SUMMARY

When a car is travelling at high speed, more than 80% of the total drag applied on the vehicle is contributed by air [1]. Also, the rear body of the car is suffering from an aerodynamic lift in range of hundred pounds [2]; this lift of hundred pounds leads to fewer grips of vehicle's back wheels with the ground therefore lowers the vehicle's stability and maneuverability. The drag and lift issues stated above will result in high fuel consumption and less stability of the car while driving at high speed.

Veroptimal Solution is able to solve both the drag and lift issues with the latest product "Auto-adjustable Spoiler Control System", or ASCS. It is an intelligent feedback control system which allows users to control the spoiler. Our product provides a friendly-looking user interface panel which allows the driver having full control of the spoiler: the operation mode of the entire system can be set to either automatic or manual depends on the user. With automatic mode, the ASCS will automatically adjust itself until the vehicle has reached to the optimal aerodynamic state; it can also detect special scenarios such as emergency brake, downhill driving and slippery road conditions, and do its best to serve for the user. With manual, the ASCS will obey the user's command unless the user is intending for dangerous or invalid actions.

This functional specification outlines the functionality and requirements of the overall system as well as for each subsystem of the ASCS including the Front Panel, the Main Controller and the Spoiler System. This document will also serve as the basis for the final design and production as a commercial product.

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List of Figures

List of Glossary

AOA	Angle of Attack
ASCS	Auto-adjustable Spoiler Control System
CSA	Canadian Standards Association
LCD	Liquid Crystal Display
RF	Radio Frequency
N	SI unit of force, Newton
cm	SI unit of length, centimeter
g	SI unit of mass, gram
kg	SI unit of mass, kilogram
V	SI unit of Voltage, volt
W	SI unit of Power, Walt
°C	SI unit of Temperature in Celsius

1 Introduction

The Veroptimal Solution's project Auto-adjustable Spoiler Control System (ASCS) is essentially a feedback control system which is able to either automatically or manually change the elevation and angle of attack (AOA) of the car spoiler. Researches are showing that, when the spoiler elevation is low, or stays very close to the surface of the boot lid, the spoiler can more effectively spoil out the undesirable flows thus to reshape airflow streams around the vehicle; the major benefit would be the decrease of drag or the increase of fuel efficiency. When the spoiler elevation is high, the AOA of the spoiler plays crucial role because the angle determines how much air to be deflected upwards and thus generates downforce at the rear of the vehicle[3], [4], [5]. The functional specifications for the ASCS, as proposed by Veroptimal Solution, will be outlined in this document.

1.1 Scope

This document describes the functionality and requirements that must be met by the proposed ASCS project. This document gives a full description for the ASCS prototype; it will also serve as the basis for the final design and production as a commercial product.

1.2 Intended Audience

This document is intended for use by all engineers of Veroptimal Solution for product development including the project manager, the hardware designers, the mechanical designers, the firmware developers and the test engineers. It will be used as a guideline throughout the development stage of the product. The project manager shall refer to the functional requirements as consistent criteria throughout the developing stages. The test engineers will use this document to test and confirm that the product meets all the requirements specified in this document.

1.3 Classification

The following convention will be used throughout this documentation to denote functional requirements:

[Rn-P]

Where Rn indicates the requirement section and P represents the priority level as denoted by one of the three values:

I The requirement applies to the proof of concept model only

II The requirement applies to both proof of concept model and final product

III The requirement applies to the final product only

2 System Requirements

The requirements of the Auto-adjustable Spoiler Control System (ASCS) are presented below. Specific descriptions and requirements for each subsystem can be found section 3, 4 and 5.

2.1 System Overview

The top level design of the ASCS in proof-of-concept stage can be modelled as shown in Figure 1.

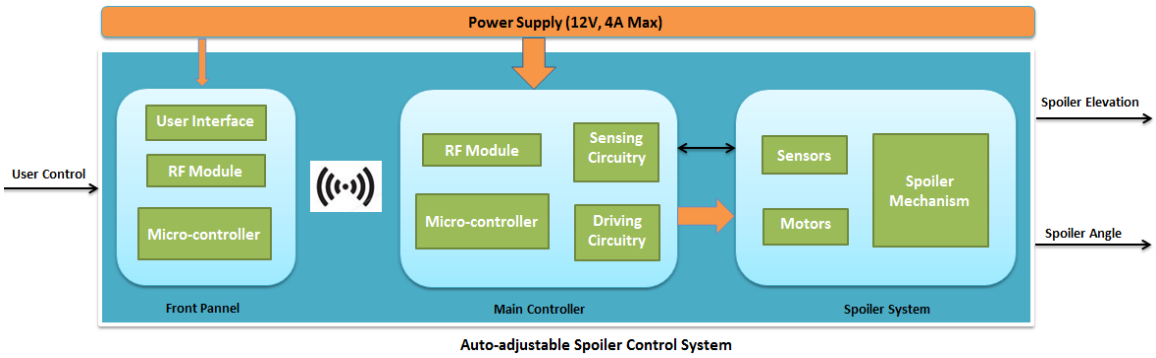

Figure1: High level design of ASCS

The power tree of the system is reflected by the orange arrows. The ASCS is mainly composed by three major sub-systems: Front Panel, Main Controller and Spoiler System (detailed description and functions of each sub-system will be given in section 3, 4 and 5). Generally, users can send commands to the system through the buttons and switches on the Front Panel; the Main Controller will then respond to user's commands by sending control signals to the Spoiler System. The output of the Spoiler System will be the change in elevation and angle of attack (AOA) of the mechanism which ties to the rear spoiler. One emphasis is that a physical spoiler does not belong to the design of the ASCS. The Spoiler System of ASCS is essentially an electrically controlled mechanical system with two "hands" capable to grip an external spoiler, thus the design for compatibility of different spoiler types shall be carefully considered.

By design, the Front Panel will be placed on the right hand side of the driver; the Main Controller will stay inside the rear trunk and the Spoiler System is going to be mounted onto the trunk lid. Theoretically, the downforce generated by a spoiler can go beyond 300N at high speed and this downward force will be applied onto the Spoiler System [6]. Due to time and budget constraints, the Main Controller and Spoiler System in the proof-of-concept stage may only be able to lift against around 200N downforce; the consequence would be that the system stays unmoved while the user still attempts to increase the elevation of the spoiler. Nevertheless, safety is the bottom line of the design. Incapable of handling large downforce should not cause any forms of mechanical failures. With more time and funds provided, the electronics and mechanical system can be further modified for more heavy-duty purposes.

2.2 General Requirements

[R1-II] The device will have automatic, manual and preference modes available to choose
[R2-II] The device shall have an idle state where all adjustable parts are stable and unmovable
[R3-III] The retail price of the device shall be under 400 $CAD
[R4-III] The Spoiler Mechanism of the device shall allow most types of spoilers being able to fit in
[R5-I] The whole device shall fit to sedan cars with trunk lid length longer than 35cm

2.3 Physical Requirements

[R6-I] The length of the device shall not exceed 35cm
[R7-II] The width of the device (without spoiler) shall not exceed 60cm
[R8-I] The height of the device (without spoiler) shall not exceed 30cm
[R9-II] The device weight (including all subsystems) shall not exceed 8kg

2.4 Electrical Requirements

[R10-II] The device shall be powered up using the 12V cigarette plug available in the car
[R11-I] The maximum power consumption of the entire device shall be under 40W
[R12-II] The power consumption during idle state shall be less than 1W
[R13-II] The power loss through wires shall not exceed 3% of the total system power
[R14-II] The power plug of the device shall have over current protection to prevent car battery shorted
[R15-I] Key test points shall be easily accessible for testing and debugging purposes

2.5 Mechanical Requirements

[R16-II] All adjustable components can be moved via the Front Panel when the system is powered
[R17-II] All adjustable components cannot be moved when the system is not powered
[R18-II] All electrical connections on the circuit board shall be connected via soldering

2.6 Environmental Requirements

[R19-II] The system shall be operable at ambient temperatures between -20°C to 50°C, see Appendix 1
[R20-II] The system will be silent when it is in idle state
[R21-II] The electrical hardware contains only lead free components and solder
[R22-II] All components of the system are recyclable

2.7 Engineering Standard

[R23-II] The power connector of the device complies with ISO4165:2001 standard [7]

[R24-I] Wireless communication radio frequency complies with IEEE 521-2002standard [8]

[R25-I] The system shall meet Canadian Standards Association (CSA) electrical standards [9]

[R26-II] All electrical components shall conform to ISO/TC22/SC3 for Electrical and electronic equipment [10]

2.8 Reliability and Durability Requirements

[R27-III] The system functionalities shall be minimally affected by weather (rain, hail, snow and wind)

[R28-II] The system shall be capable to run 4 consecutive hours in automatic mode

[R29-III] The wood and metals exposed in the air shall be coated to prevent rusting

[R30-III] The device shall have a lifetime of minimum 3 years

[R31-III] The maintenance interval shall be at least once every 3 months

2.9 Safety Requirements

[R32-II] The device must not drop off from the car during driving

[R33-II] The components of the device must not drop off from the car during driving

[R34-II] The device shall not block driver's view of the back

[R35-II] The device shall be capable to detect user's wrong command and refuses to execute the task

[R36-II] The device shall not perform any dangerous or aggressive actions even if the software is crashed

[R37-III] The system shall activate cooling system when the system heat sink temperature is above 60°C

[R38-II] The enclosure shall be designed without harmful sharp edges and corners

2.10 Performance Requirements

[R39-II] The system shall respond to user's command within 1 second

[R40-II] The system operation modes shall be mutually exclusive, e.g. when one is selected, the other two will be forced disabled and cause no interference to the selected mode

[R41-III] The system shall display the car battery voltage level to the user during operation

2.11 Usability Requirements

[R42-II] The device shall be self-intuitive for a new user

[R43-II] The average time of installing the device onto car for one user shall be less than 1 hour

[R44-II] The automatic mode shall be completely self-running and causing minimal distraction from the user while driving

[R45-II] The manual mode shall allow user to take control of the system

[R46-II] The preferred mode shall jump directly to user's previous setting of preference

[R47-II] The system shall remember user's previous setting of preference after cycling power

[R48-III] At least 80% of the users shall be satisfactory with the driving experience provided by adding the ASCS system onto their car

2.12 Documentation Requirements

[R49-III] The user document shall include company's contact information, technical support, user manual, and product warranty and customer service

[R50-III] The user manual shall be understandable for general users without knowledge background of mechanics, electronics and coding

[R51-III] The user manual shall be simple to read and including graphs and short text which explain the assembly, installation and operation of the ASCS product step by step

[R52-III] At least 80% of the user shall be able to assemble, install and operate the ASCS product after carefully reading the documentation

3 Front Panel Requirements

This section is complementary to section 2 which illustrates the functionality as well as the requirements of the Front Panel subsystem in more details.

3.1 Subsystem Overview

Front Panel is the only partto be directly controlled by the user as indicated in Figure 2.The user can determine the system operation mode by using the Mode Selection Switch. In automatic mode, the system will be self-running and does not require user to do further control. In preference mode, the system will "ask" the Spoiler Mechanism go directly to the position being set as user's preference; the user's preference will be updated once the Set Preference Button is pressed. In manual mode, user can adjust the elevation and AOA of the spoiler by playing with the Spoiler Height Lever and Spoiler Angle Knob. The RF Module sets up a wireless channel between the Front Panel and Main Controller to allow transmission of the control and feedback signals from the two terminals. The LCD on the Front Panel will regularly updates latest system conditions such as current downforce, AOA and elevation of the spoiler.

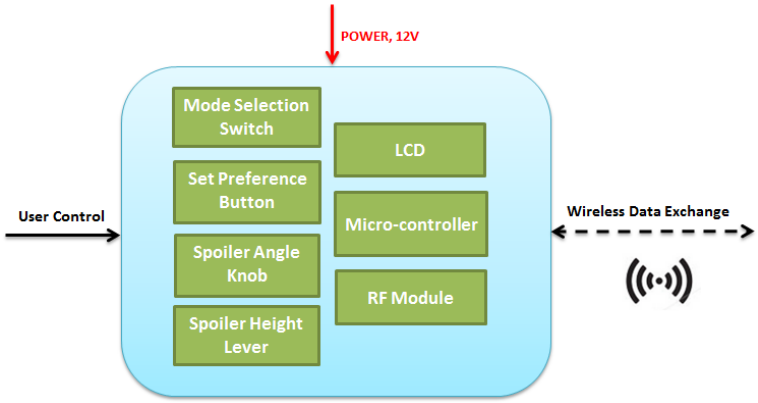

Figure2: Front Panel Block Diagram

The Front Panel prototype in the proof-of-concept stage will be very similar as shown in Figure 3; the dimensions may not be precise but still reflect the geometrical shape and components layout. The prototype in the proof-of-concept stage is good for functional testing however may not be acceptable as a small and easy-portable product. Since it shall be placed besides the driver, its bulky size (as big as iphone6s) may cause disturbance when the driver is trying to use other instruments such as radio/CD, heater/air conditioner or checking the vehicle integrated screen. With more funding and time, the Front Panel will be re-designed as a touch screen device, its whole size will be reduced at least by half and all controls can be operated by touching the screen.

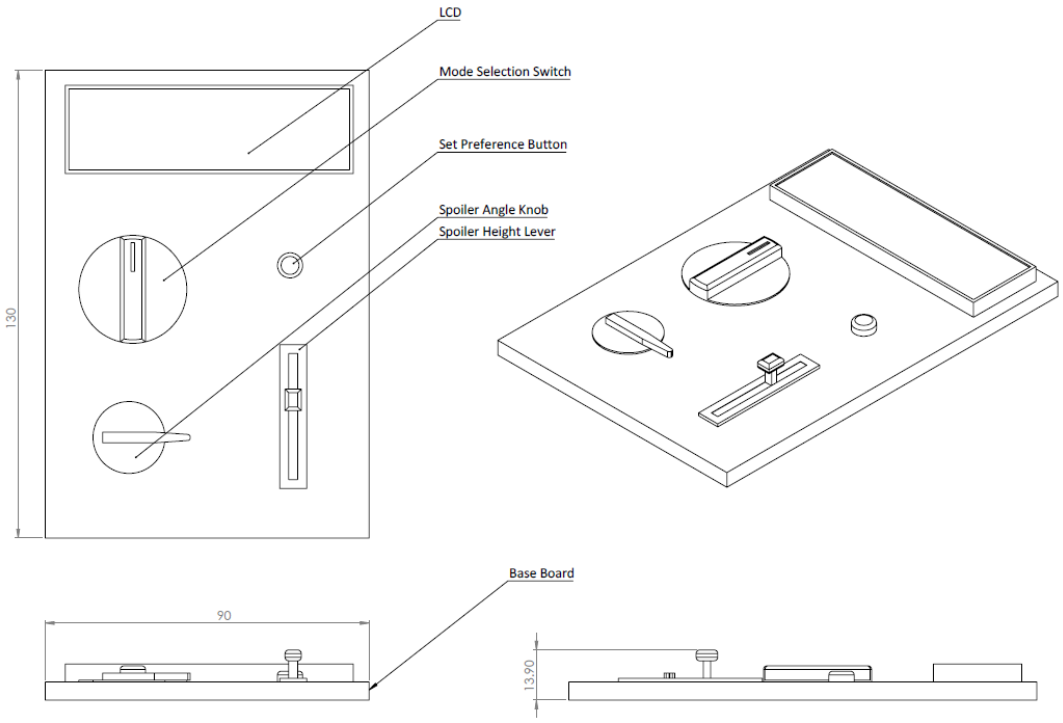

Figure 3: Prototype model of the Front Panel

3.2 General requirements

[R53-I] The Front Panel shall have a control unit, a display unit and RF module

[R54-II] The control unit includes a mode selection switch for Manual, Automatic and Preference modes

[R55-II] The control unit includes a knob to manually adjust the attack angle of the spoiler

[R56-II] The control unit includes a control lever to manually adjust the elevation of the spoiler

[R57-II] The control unit includes a set preference button for user to save to current status as a Preference

[R58-II] The display unit includes a LCD which displays system status such as downforce, elevation and angle of attack of the spoiler

[R59-I] The RF module will be wirelessly exchanging data to the Main Controller

3.3 Physical requirements

[R60-I] The size of the Front Panel shall be small than $30inch^2$ (comparable to a iphone6 plus)

[R61-I] The weight of the Front Panel shall be less than 300g (lighter than iPad mini)

[R62-II] The size of all physical components on the Front Panel control unit shall be appropriate

3.4 Electrical Requirements

[R63-I] The power supply of Front Panel is separate from Main Controller

[R64-II] The input voltage range of Front Panel is 7 to 19V

[R65-I] The Front Panel can be powered via the 12V cigarette plug or dry cell batteries

3.5 Mechanical Requirements

[R66-I] The case of the Front Panel shall be capable to protect hardware board from heavy shaking and medium collision and medium shock

[R67-I] The case of the Front Panel shall be easily attached and stabilized on a surface

3.6 Usability requirements

[R68-III] The Front Panel shall be placed at a location that is easily accessible for driver and not disrupting other functions of the car

[R69-III] Each control unit component will be labeled or marked to indicate its function or purpose

[R70-II] The Front Panel shall be self-intuitive and simple-to-use for new users

[R71-III] The Front Panel shall have a backlight which can be turned on/off when needed

3.7 Performance Requirements

[R72-II] The LCD information update period shall be around 1 second

[R73-I] The RF module shall not cause noticeable interference to other wireless devices on the car

4 Main Controller Requirements

4.1 Main Controller Overview

The Main Controller can be described by the block shown in Figure 4. User's Command will be received by the RF module on the Main Controller to determine the operation mode of the system. GPS Module, Brake Detection Circuit, Force Measuring Circuit as well as Angle Measuring Circuit are able to process Sensor Output Signals sending from the Spoiler System so that the signals can be easily read by the Microcontroller. Based on the information acquired, the Microcontroller will ask Motor Driving Circuit to send control signals to the Spoiler System for further actions; meanwhile, system status will be sent back to the User Interface Panel so that the user can visualize the effects.

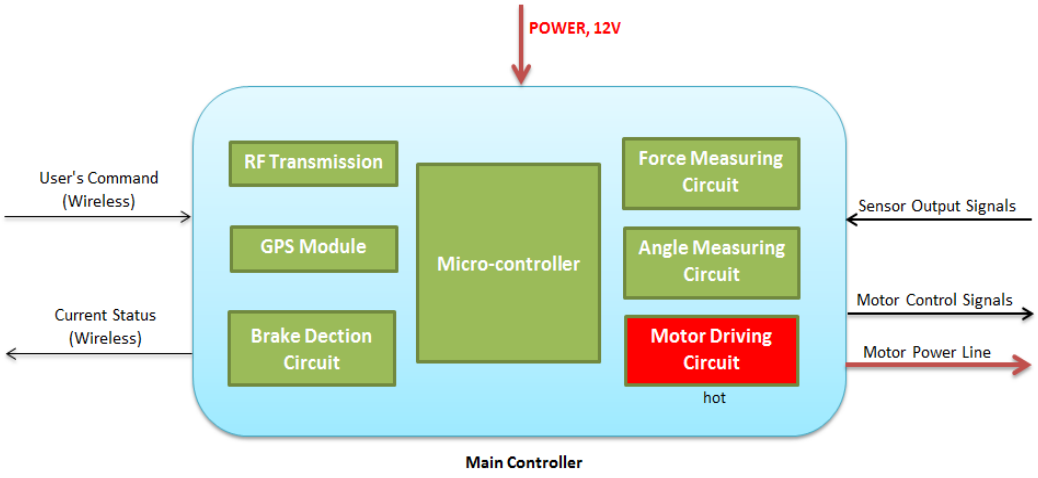

Figure 4: Main Controller Block Diagram

The model of the Main Controller circuit board will be roughly as shown in Figure 5.

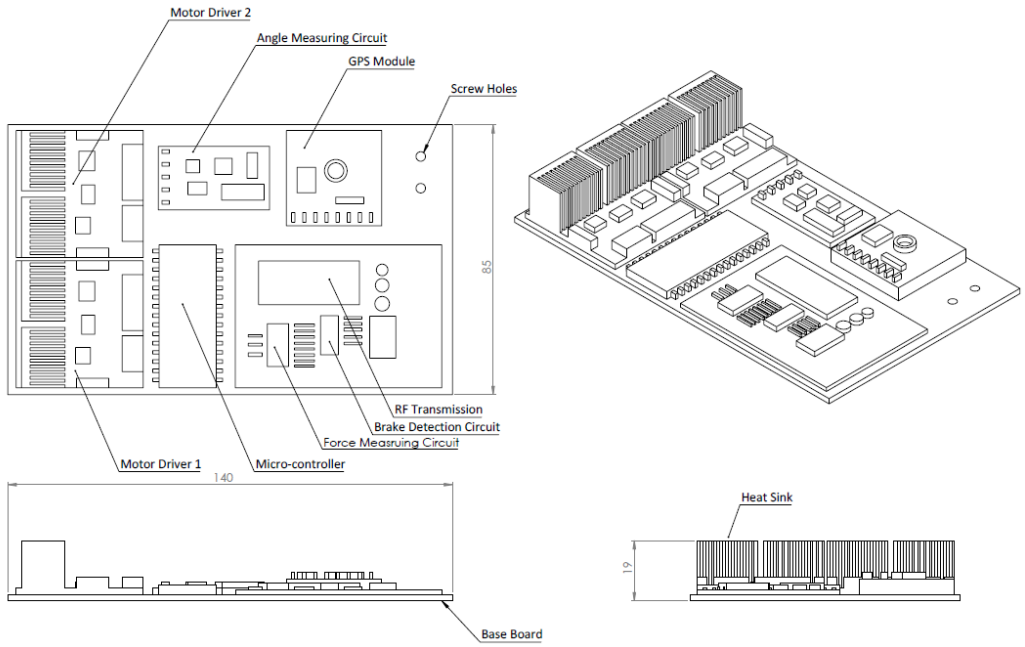

Figure 5: Prototype model of the Main Controller Board

4.2 General Requirements

[R74-II] The Main Controller circuit board shall be protected by a dimension fitted case

[R75-I] The development cost of the Main Controller shall be under 100 $CAD

4.3 Physical Requirements

[R76-III] The edges and corners of the case shall be smooth and unaggressive

[R77-I] The length of the case shall be less than 15cm

[R78-I] The width of the case shall be less than 10cm

[R79-I] The height of the case shall be less than 3cm

[R80-I] The weight of the case including the circuit board shall be less than 300g

4.4 Electrical Requirements

[R81-II] The input voltage range is 6-20V

[R82-II] The voltage drop of the power cable shall be less than 5% of the power source voltage at maximum power operation condition

4.5 Mechanical Requirements

[R83-II] The case of the Main Controller shall be capable to protect hardware board from heavy shaking and light collision

[R84-II] The case of the Main Controller shall be easily assembled and disassembled

4.6 Performance Requirements

[R85-II] Heat sinks will be added for the thermal dissipation of motor driver

[R86-I] In automatic mode, the Brake Detection Circuit shall be capable to detect an emergency brake within 1 millisecond and actuates the “air brake” function immediately

[R87-I] In automatic mode, the system shall be capable to detect uphill and downhill driving and take corresponding actions when necessary

5 Spoiler System

5.1 Subsystem Overview

As previously shown in Section 2 Figure 1, the Spoiler System is a mechanical system that consists of Motors, Sensors and Spoiler Mechanism. Figure 6 explains the function of the Spoiler System in more detail. The Motors are a Linear Actuator and a DC Motor controlled by the Motor Control Signals sent from the Main Controller. The Spoiler Mechanism has two parts: Arm Mechanism and Hand Mechanism. The Arm Mechanism is driven by the Linear Actuator to control the spoiler elevation; the Hand Mechanism is moved by the DC Motor to adjust the spoiler angle. The sensors are able to sense the spoiler elevation and angle, as well as the downforce applied by the spoiler and send back to the Main Controller as feedback signals.

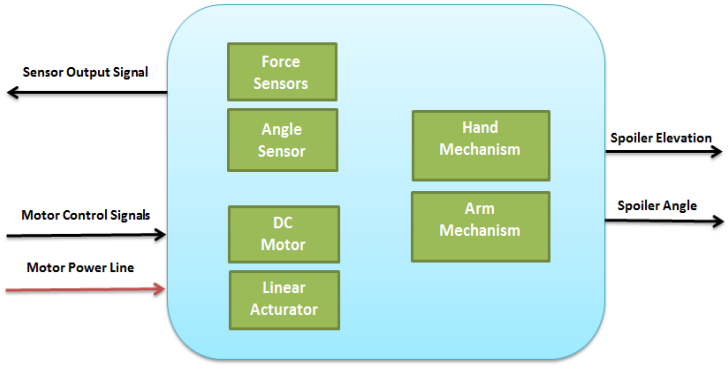

Figure 6: Spoiler System Block Diagram

The model shown in Figure 7 represents the prototype of the Spoiler Mechanism which will be done in the proof-of concept stage. In the final production, some components such as the Installation Base will be different from this prototype. For instance, the Spoiler Mechanism of final product will be mounted onto the car boot lid directly using screws and bolts rather instead of using the Installation Bas since screws and bolts provide more safety and reliability. Besides, the Hand Mechanism design in the final prototype may be slightly different from the one showing in Figure 7 because it requires to confirm that our current mechanism design is capable of firmly fit all types of car wings or spoilers.

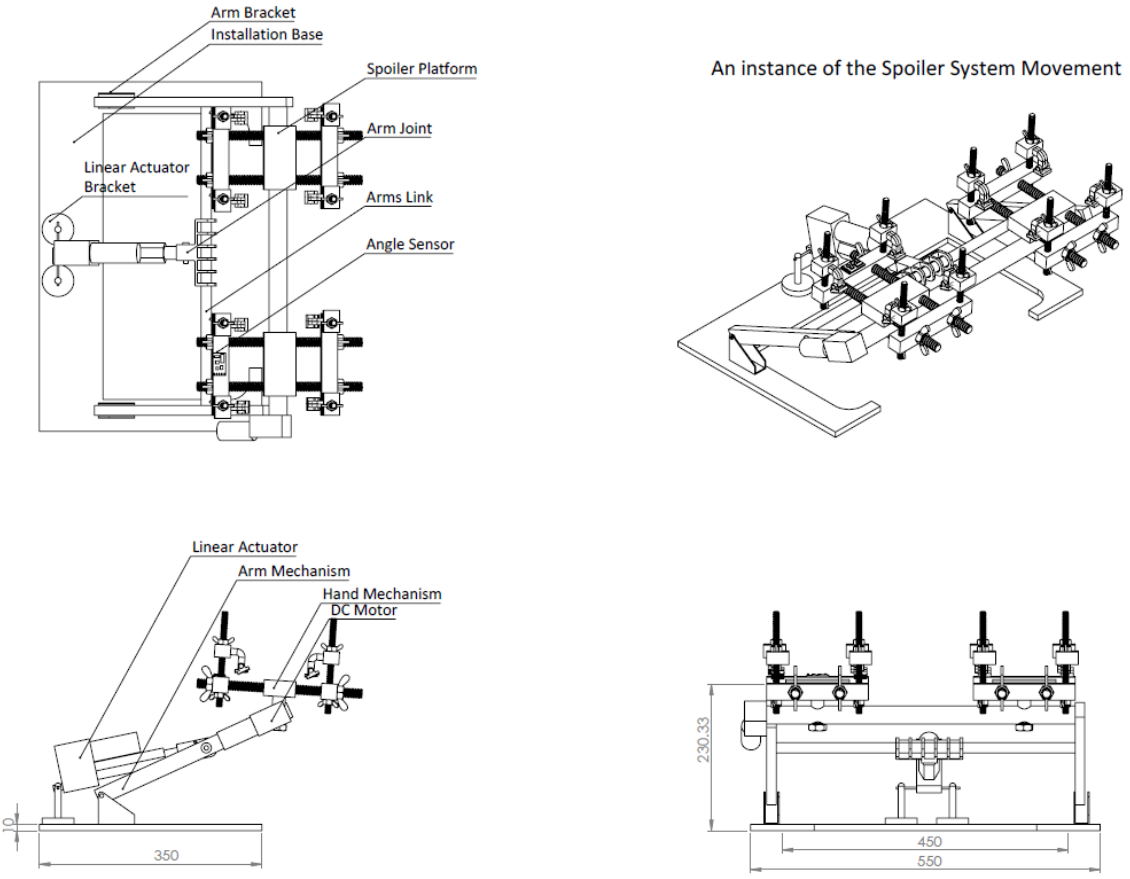

Figure 7: Prototype Mode of Spoiler System

5.2 General Requirements

[R88-II] The Linear Actuator stroke and DC motor shaft will be internally locked when they are not fed by electrical power

[R89-II] The DC Motor and Linear Actuator are powered and controlled by the Main Controller

[R90-II] The movements of the Hand Mechanism can only be directly driven by the DC Motor

[R91-II] The movement of the Arm Mechanism can only be directly driven by the Linear Actuator

5.3 Physical Requirements

[R92-I] The Installation Base length of the Spoiler System shall be within 35cm

[R93-II] The Installation Base width of the Spoiler System shall be within 60cm

[R94-I] The weight of the Spoiler System including the Installation Base shall be less than 7kg

5.4 Electrical Requirements

[R95-I] The maximum electrical power for both the DC Motor and Linear Actuator shall not exceed 40W

[R96-II] The Force Sensors and Angle Sensor draw power from the Motor Power Line

[R97-II] The power loss on the Spoiler System wires shall not exceed 2% of the power delivered from the Main Controller

5.5 Mechanical Requirements

[R98-II] The linkages shall not be bent when the Spoiler System endures 400N load

[R99-II] The Hand Mechanism shall be able to firmly grip most types of car spoilers so that the spoiler can steadily move along with the Hand Mechanism

[R100-III] The Arm Mechanism shall be capable for elevating against 400N downforce

[R101-II] The sensors and wires on the Spoiler System shall be waterproof

5.6 Performance Requirements

[R102-II] The movement speed of the Hand Mechanism can be varied

[R103-I] The lower angle of the Hand Mechanism rotational movement shall be limited within 0 ± 5 degree with respect to the road surface

[R104-I] The upper angle of the Hand Mechanism rotational movement shall be limited within 70 ± 5 degree with respect to the road surface

[R105-II] The movement speed of the Arm Mechanism can be varied

[R106-I] The lowest position where the Arm Mechanism can reach to shall be within 5± 2 cm with respect to the boot lid surface

[R107-I] The highest position where the Arm Mechanism can reach to shall be within 22 ± 3 cm with respect to the boot lid surface

[R108-II] The Angle Sensor shall be able to detect change in angle as small as 1 degree

6 Sustainability and Safety Analysis

The ASCS is intended to be a "Cradle to Cradle" design in which the sustainability and safety become the key factors throughout the design phase. Each part of the ASCS will be designed and verified to serve the purpose of maintaining high resource utilization efficiency and guaranteeing that the ASCS is safe for the users and surrounding environment. Due to that we want to minimum the budget and make the design waste free by taking full advantage of every piece of the design material, a lot of consideration have been taken into recycling the design resources and minimizing the use of the non-recyclables. Regarding the safety of the whole system,since the ASCS involves vehicles driving at high speed, external mounting and significant force generation, we have been investing adequate amount of time on measuring and calculating force, choosing material with high stiffness, and refining the mechanical design based on the safety consideration.

6.1 Sustainability

In order to improve the resource utilization efficiency, we decide to use wood as the primary material to build the mechanical structure of the spoiler system, and upgrade the original system design plan from using multiple linear actuator and motor to single linear actuator and single motor utilization. As one of the benefits of using wood, we are able to make several parts out of one chunk of wood, and reuse the wood that we used for testing and force measurement to make new parts for mechanical model building. In addition, we will provide the spare wood and other components such as screws, circuit board and switches for the need of other groups to make the project building process sustainable. Furthermore, we have been using spare parts and ICs from previous project or disassembled from waste electronic devices.

6.2 Safety

As a vehicle is being driven at very high speed, the position of the car wing makes a huge impact on altering the airflow, forces and more importantly the safety performance. Therefore, limitations will be set on the angle range and height of the car wing, motor turning speed, rising rate of the linear actuator and so on, to make sure that any possible unstable factor is avoided. We are aware of that significant forces will be applied onto the rods of the spoiler system under high speed; hence we decide to make these load-bearing rods using carbon fiber which is the best option in terms of stiffness and weight. What is more, due to the fact that the spoiler system is designed to be mounted onto the car boot lid with substantial amount of force applied onto, there might be a safety vulnerability. As a result, a backup mechanism shall also exist to prevent cascade failures.

7 Conclusion

As a helpful guideline, the functional specification defines the requirements, limitations and capability of the ASCS product, and enables all group members stay focused on the design goals. The two most challenging aspects of the ASCS design are the mechanical design and the safety of the whole system. When it comes to these aspects, numerous design mistakes will be avoided if we keep the function specification in mind throughout the design phase. The prototype development is well in progress; however, it is not easy to meet all requirements since the ASCS design involves a lot of different areas including hardware design, board layout design, firmware programming, wireless communication, mechanical design and power. Although more effort and consideration need to be put into the process of fulfilling the functional specification, we are confident that all functional requirements outlined above applying to the ASCS prototype will be completed before the demonstration date.

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Appendix 1

The operating temperature of the system is determined from Table 1 which gives the workable temperature range of the building components of the system.

		Operating Temperature (°C)	
ITEM	**Components**	**minimum**	**maximum**
1	Arduino Nano	-40	85
2	Force Sensor	-40	60
3	Angle Sensor	-40	125
4	GPS	N/A	N/A
5	LM358 IC	-25	70
6	LM311 IC	-25	70
7	Nrf24l01	-40	85
8	Linear Actuator	-25	65
9	DC Motor	-20	60
10	Car Battery	-20	50
	Overall System	-20	50

Table 1: Operating Temperatures of the Components on ASCS

The datasheet reference listed below are corresponding to the ITEM number in Table 1

1. http://www.atmel.com/Images/7799S.pdf
2. https://cdn.sparkfun.com/datasheets/Sensors/ForceFlex/FLX-A201-A.pdf
3. http://www.61mcu.com/upload/SCA60C-N1000060.pdf
5. https://www.fairchildsemi.com/datasheets/LM/LM258.pdf
6. https://www.fairchildsemi.com/datasheets/LM/LM311.pdf
7.https://www.sparkfun.com/datasheets/Components/SMD/nRF24L01Pluss_Preliminary_Product_Specification_v1_0.pdf
8.http://www.aliexpress.com/item/Electric-Linear-Actuator-motor-with-Potentiometer-feedback-12-or-24vdc-200mm-8-stroke/808766318.html
9.http://www.ebay.com/itm/A58SW31ZY-Turbine-worm-gear-motor-high-torque-robot-with-self-locking-12V-24V-/161252551961
10. http://batteryuniversity.com/learn/article/charging_at_high_and_low_temperatures