February 27, 2009
Mr. Steve Whitmore
School of Engineering Science - Simon Fraser University
Burnaby, British Columbia.
V5A 1S6

Re: ENSC 305/440 Design Specification for the Motion Sensing Remote-Controlled Vehicle

Dear Mr. Whitmore:

Attached is a document describing the design specification for the Motion Sensing Remote-Controlled Vehicle from Ron KittenBruan Technologies Ltd. We are designing and implementing a remote controlled vehicle using natural mapping motion sensing. This project is not only a development of an ordinary toy, but one that has functions such as collision detection, collision avoidance, real-time video process, and semi-autopilot that automatically maneuvers around obstacles.

The design specification provides an initial boundary in the design process of our remote-controlled vehicle prototype development. This document’s purpose is to ensure that the subsequent design and development of our product meets the needs of users and satisfies the proposed functionalities.

If you have any comments or enquiries, please feel free to contact us by email at ensc440-rkb@sfu.ca or by phone at (778)-862-0982.

Best Regards,

Rongen Cheng
Chief Executive Officer
Ron KittenBruan Technologies Ltd.

Enclosure: Design Specification for the Motion Sensing Remote-Controlled Vehicle
Design Specification for CarSim
(Motion Sensing Remote Vehicle)

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Issued Date:  
March 5, 2009

Revision: 1.2
Executive Summary

The design specification for the Motion Sensing Remote Controlled Vehicle provides a set of detail descriptions for the design, development, and implementation of our prototype vehicle. The design specifications are mainly for the prototype version, but because this development may pass onto production, it is also suitable for the production version.

This document illustrates the design of the Motion Sensing Remote Controlled Vehicle and provides justification as to why certain design choices were chosen. The high-level overall system designs, including the mechanical designs, sensor placement, actuator placement, electrical system, and power supply will be provided. Eight sensors are placed on various positions of the vehicle to detect obstacles from different directions for the semi-autopilot and collision functions. Moreover, the designs of the actual remote controlled car, along with its physical/mechanical design and the electric design will be presented. Input and output signal conditions must follow specific design specifications to avoid distortion so that the vehicle functions properly. In the center of this product, there is a microprocessor that acts as the brain of the vehicle. The microprocessor design as well as the hardware/software control designs will be provided in details in this document.

General software program process flow will also be included. Finally, a detailed test plan for the system and its subcomponents is provided at the end of the design specification. During the design process we have become aware of the actual amount of work, which is more than planned, that needs to be done. However, the planned completion date of March 31st, 2009 is not changed.
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Glossary
IR Infra-Red
PWM Pulse Width Modulation
OE Open Embedded
GPIO General Purpose Input Output
ESD Electrostatic Discharge
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO</td>
<td>International Organization for Standardization</td>
</tr>
<tr>
<td>RC</td>
<td>Remote Controlled</td>
</tr>
<tr>
<td>LED</td>
<td>Light-Emitting-Diode</td>
</tr>
<tr>
<td>LCD</td>
<td>Liquid Crystal Display</td>
</tr>
</tbody>
</table>
1 Introduction

CarSim, a motion sensing remote controlled vehicle, is an electrically powered vehicle that adapts a natural mapping control to enhance user usability. This vehicle provides two different operation modes, one of them is the user-controlled mode and the other is the automated mode. In the user-controlled mode, the user can control the car in via natural steering motion from our six-axis motion sensing control. In automated mode, the vehicle will move forward and automatically steer itself around obstacles, with the help of onboard sensor and processor. Accompanied with vehicle controls, a video streaming camera and display will be implemented on the vehicle and on the remote controller respectively. This allows the user to understand and visualize the surroundings of the vehicle, and hence, provide discovery functionality.

1.1 Scope
This design specification describes the design of the CarSim, and explains how the design meets various requirements described in Functional Specification for CarSim (Motion Sensing Remote Vehicle) (1). The design specification, which serves as a proof-of-concept model, includes all requirements specified for CarSim. Since this model may bring to production in future, design requirements are meant to fulfill both functional and environmental requirements. To assist readers to understand our system, a overall system flowchart will be provided in a latter section.

1.2 Intended Audience
The design specification is intended for use by the development team of Ron KittenBruan Technologies Ltd. and by executive officers of ENSC 440. During the development cycles, design engineers shall refer to the listed requirements as primary design goal. Improving product performance and design enhancements will be properly documented and discussed within the development team. When development cycles are complete, test engineers are suggested to use this document as a reference for setting up testing procedures.

2 System Requirements

The high-level systematic behaviours and functionalities of CarSim can be portrayed using the following block diagram (Figure 1).
The steering of the car should be done with the 6-axis controller using the normal steering motion, as like controlling a real automobile. In fact, this is the intended purpose of choosing the 6-axis controller. This control mechanism can be depicted in Figure 2.

To further the exploration aspects of CarSim, a LCD is connected to the 6-axis controller. This LCD and its related component must be able to stream the video image captured by the web camera located on CarSim. The wireless communication between the LCD receiver and the webcam transmitter must not perturb the Bluetooth communication between the controller and CarSim. The power requirements of the LCD components must be manageable and reasonable such that the incorporation of the LCD onto the controller can be achieved with minimal modifications.
3 Overall System Design

This section covers briefly of the designs and layouts of the major components of CarSim. Detail design specifications for each component are in sections to come.

3.1 Mechanical Design
The actual construction and design of the vehicle component of CarSim may vary, as CarSim is based on merely the modification of a remote-controlled car. Therefore, different designs of the vehicle may be applicable for CarSim, as long as it is possible to implement the following modifications or designs to the vehicle:

- Webcam is to be placed securely on the top of the vehicle’s enclosure
- 4 pairs of infrared sensor are to be attached to the four corners of the vehicle without any blockage from the enclosure of the vehicle.
- All circuitries and motors are to be placed securely inside the vehicle.

As for the vehicle we have chosen, we made the following design modification of the vehicle (figure below) in order to achieve the above design specifications:

- We will use mounts and screws to secure the webcam on top of the enclosure.
- To prevent blockage of the sensor, we may put our sensor outside of the enclosure instead of just cutting holes on enclosure or just remove the enclosure, as this will make the outward appearance of CarSim not as appealing.
- Due to the weight of the additional components to the vehicle, we have attached a strong metallic plate to the base of the vehicle in case of the body of the vehicle collapse.

As for the vehicle we have chosen, we made the following design modification of the vehicle (figure 3) in order to achieve the above design specifications:
3.2 High-level System Design
The following figure describes the inputs and outputs relationship of the system along with the subsystems involved.

![Diagram showing inputs and outputs](image)

Figure 4 - System Block Diagram
The switchers described above are basically comparing the input signal with a threshold. Once the input signal is above the signal, the switcher will output a DC ON (high) signal. The signal differentiation was needed to correctly detect an actual collision as opposed to a slight bumped, which in fact is critical when analyzing and processing the signal.

There are two more components of CarSim that are not included in the above figure. They are the PS3 controller and the wireless webcam LCD unit. This is because these two units will be bought without any modification. Therefore, they do not affect our designs.

3.3 Sensor Placement
IR sensors are used to sense the distance between nearby objects and the vehicle. The top view of the car can be thought as a rough rectangular shape, so there are four corners where we place our sensors (see Figure under Mechanical Design section). The sensors have a limited angle of coverage or detection, and the accuracy of detecting different color objects varies. Therefore, there are two sensors at each corner to provide wider coverage. Also, the sensors are chosen to have a range of coverage that allows us to be prepared for the inaccuracies of the sensors.

3.4 Motor Placement
The placement of the actuator follows the most basic structure of a toy car. There are two DC motors: one for the acceleration of the car and one for turning the car. The turning motor is placed at the front of the car between the two front wheels and the acceleration motor is places at the back of the car between the two rear wheels (see Figure under Mechanical Design section).

3.5 Electrical System
The microprocessor has logic voltage of 3.3V. Therefore, the conditioned signals and its related circuits will be running with 3.3V as to avoid errors or the burning of the microprocessor. It is very important for the conditioning circuits to have this property as the input signals and the output signals are all running at different voltages. The voltage specifications for each component are listed in the table below:

<table>
<thead>
<tr>
<th>Signal</th>
<th>Components</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inputs</td>
<td>IR Sensor</td>
<td>5V</td>
</tr>
<tr>
<td></td>
<td>Accelerometer</td>
<td>5V</td>
</tr>
<tr>
<td>Outputs</td>
<td>Motor (acceleration)</td>
<td>9.6V</td>
</tr>
<tr>
<td></td>
<td>Motor (turning)</td>
<td>6.1V</td>
</tr>
</tbody>
</table>

We have used 3.3V (combined with 2A fuse), 5V, and 6.1V regulators with maximum current capability of 1.5A for our circuitries to avoid damaging the microprocessor or other electrical components. We also added 100nF capacitors to each voltage line for ripple filtering.
3.6 Environmental Considerations
The regulators and the fuse are also a preventive feature of the electric component feature of our system. It provides a more safe and user-friendly environment for the user without causing fire hazards or injuries. We also enclosed the circuitries with non-conductive material and with enough paths for heat dissipation. The front and the back of the car have built-in bumpers that have enough elasticity that will at most bounce the car back without breaking the interior components upon collisions. Lastly, we adopted an environmentally friendly power supply approach by using a rechargeable battery pack. Traditional batteries disposal has been a great concern to the environment due to the chemical structure and leakage of the batteries, meanwhile minimizing the cost of the users.

3.7 Power Supply
The following are the power requirements for CarSim:

- 3 A max (sum of current draw on 2 motors, ICs on 3.3 and 5 V voltage line)
- 3.3 V, 5V, 6.1V and 9.6V DC
- Regulated
- Run on portable battery

The maximum current is calculated as the sum of all of the components mentioned in the previous section. The voltage requirements are also explained in the above section. Therefore, we have used a 9.6V battery pack, which meets all the above requirements, to power up all of our components.

4 Remote Control Car
This section will discuss the mechanical and electronic components for designing the remote control car.

4.1 Mechanical Components
The remote controlled car chosen in our project is the New Bright Pro Dirt Buggy, shown in Figure 5. The main reason why this remote controlled car was chosen is that it has enough clearance space inside the vehicle to place our electronic circuitries for the sensors, accelerometers, and servomotors. Another reason to choose this vehicle is that we would like to design the car to have wheels at least 20% of the length of the car, because this will allow the remote controlled vehicle to be driven in rough road conditions and to pass small obstacles without having to maneuver around them. The design of the remote controlled car cover is to reduce air friction when in motion, and to isolate electric and mechanic components from the user. In addition, it shall prevent electrostatic discharge from the user that may damage electronic parts. On the other hand, the design of the chassis is to provide support to the onboard electronics, and to reduce damage of the car and its parts in case of a collision. In order to achieve this, the chassis
shall support at least 3 times its weight.

There are two motors in the car: one for turning and one for accelerating. Both motors are connected to the H-Bridge servomotor board and are controlled by it. More about the H-Bridge circuitry will be described in the next section. The turning motor, which is located in the front end of the chassis, shall be designed to at least be able to turn 30 degrees to each side. The accelerating motor is located near the rear of the car, and it should be able to go forward and backward at the same speed. In addition, the accelerating motor should be powerful enough to push the car to a speed of at least 30 km/h.

To further enhance the security and safety of the remote controlled car, the design of the car should be to have at least 15mm between the front bumper and the wheels, and that the bumpers along with the chassis should be at least 10mm off the ground. The front and rear bumpers should also be wide and long enough to absorb vibrations. The length of the front bumper shall be approximately 43% of the length of the car, and the width should be 19% of the length of the car. For the rear bumper, the length and width should be 25% and 10% of the length of the car respectively.

4.2 Electronic Components

The on board servomotor board with the H-Bridge is shown in Figure 6. This circuitry can only apply a constant DC voltage to the motors, and hence, cannot have variable speeds. This is a very big drawback to our project, therefore, we have chosen to design and build our own H-Bridge, and it is shown in Figure 7. Please note that Figure 7 is only in the development stage and is currently on a breadboard.
The newly designed H-Bridge, which should be placed in the location of the original servomotor board, can now apply various levels of DC voltages to the motors. When the user turns the remote at a small angle, the car will move at a slow speed. As the remote is turned more and more, the speed will continue to increase until the maximum speed is reached.
5 Collision Prevention and Auto Pilot Functions

The input signals, IR sensors and accelerometer, are all analog signals, and they need to be digitalized before the processor can process them. Moreover, the motion controlling signals from the controller needs to be decoded before the processor can process them.

5.1 Infra-Red (IR) sensor signal digitalization
The analog output signal of IR sensor will be digitalized with a comparator. When the IR sensor output signal is over the threshold voltage, meaning the vehicle is moving towards an obstacle, the output of the comparator goes high. Otherwise, the output remains low.

5.2 Accelerometer signal digitalization
The output signal of accelerometer changes when the vehicle hits an obstacle. Thus, a differentiator will be used to detect the changes. In addition, a Schmitt trigger will be used to digitalize the differentiator output. Schmitt trigger have two threshold voltages, and the output will change from high to low when the input is between the threshold voltages.

5.3 Bluetooth™ signal decoding
A Bluetooth™ module with antenna is used to receive the motion-controlled signal from the controller. The motion-controlled signal will be decoded by the module and transmitted to the processor via a serial bus.

6 Output Signal Conditioning Unit

In order to accelerate, turn and light up, the motors and LEDs must receive proper signals from the processor.

6.1 Pulse-Width Modulation (PWM)
The vehicle has two motors, and they require PWM signal to control the turning angle and speed. The turning angle and moving speed are controlled by the duty cycle of the PWM signal. The PWM signal in turn is generated by the motor driver circuit, which has two control signals.

6.2 Motor Drivers
H-bridge is used to drive the motor from the power source. The H-bridge has PWM enable line that can be used as emergency shutdown to prevent damage to the H-bridge. The H-bridge will drive 9.6 V from battery to the moving motor, and 6.1 V from the voltage regulator to the turning motor. Both motors consume a maximum of 1.2 A when moving and turning on high friction surface. Due to high power consumption of the motors, a heat sink is required for each H-bridge and regulator to prevent overheating.

6.3 LED Drivers
The processor will send out signals to turn on the LEDs. BJT current drivers will be used to drive the LEDs due to the output current limitation of the processor.
6.4 Processor signal pull-up network
The logic high voltage of the processor is 3.3 V while the H-bridge enable line requires 5 V. Therefore, a comparator is added at the processor output line to pull the logic high voltage to 5 V as the comparator threshold voltage is set to 3.3 V. This will enable the H-bridge correctly and the H-bridge bias current will be drawn from the 5 V supply instead of the processor.

7 Overview of Microcontroller

We use a microcontroller – Vertex Pro XM4-bt from Gumstix that has a built-in Bluetooth module, which is necessary for the transmission of control signals using the PS3 Six-axis controller via Bluetooth protocol. The chip has a built in Linux kernel which requires a programs to be compiled with a cross-compiler before any C programs can be executed. Linux provides an essential and stable environment during the software development stage of our project. The microcontroller will be used to receive input or/and output control signals from various components (eg: Infrared sensor) and then produce an output according to pre-programmed logic rules.

7.1 Expansion boards
An expansion board is required for convenient power supply, serial ports, USB client, and Bluetooth support. The expansion board is called Console-st and it is mounted on top of the Vertex Pro through a 60-pin connection.

![console-st expansion board](image)

Figure 8 - Gumstix Console-st Expansion Board

7.2 Specifications
Together with an expansion board, the package uses a processor - Marvell PXA270 with XScale that has a speed of 400MHZ, 64MB RAM, and 16MB Flash. USB host signal is useful for data transmission to a secondary storage device as well as manual paring with the PS3 remote controller. An 80-pin and 24-pin connectors allows extra signals to be
transmitted, such as GPIO (General Purpose Input Output). Further details will be discussed in later sections.

### 7.3 Programming and Debugging
Since the micro-controller has a built-in Linux kernel, all the programming will be done under a Linux environment. The newest version of this chipset uses Open Embedded (OE) as its programming specification; therefore, a cross-compiler is required to compile the C codes into programs that are executable by the processor. Programming are done under Linux environment in a host computer and compiled with a cross-compiler. Executable programs will then be transferred to the processor. At the start-up of the processor, the start-up scripts will be modified to execute a series of scripts to initialize the processor. Debugging becomes simple because it is similar to debugging a regular C program. Sufficient hard drive space allows extra drivers and libraries to be loaded to the processor when required.

### 7.4 Signal Processing
The processor will be initialized to the proper mode of operation at start-up, according to the signal sent by the PS3 controller. The processor receives inputs and produces corresponding outputs according to pre-programmed logic rules. Please refer to figure 4 for extra details. CarSim have two different modes of operation, and the first one is the safe mode, which uses infrared sensors to detect obstacles. Collisions can be avoided by sending a signal to the motor. The other mode is the normal mode, and it disables collision detection and enables the accelerometer to sense collisions. A signal is sent to the motor to halt the vehicle for 1 second as well as to the PS3 controller to signal it to vibrate. In any other cases, a straight processing is used by the processor according to the signals received from the PS3 controller via Bluetooth. Please refer to the figure 1 in section 1 for extra details.

### 7.5 General Purpose Input Output (GPIO)
These are the pins located on the 80-pin and 24-pin section of the board. We will be using these pins for hardwired input/output transmission of the signals to/from the processor. Each GPIO pins can be programmed and configured as input or output state. Pin changes in its logic state can be monitored according to predefined rules (rising edge, falling edge, both) in our program. For the above purposes, extra libraries and drivers are required to be installed in the kernel of the processor.

### 7.6 Bluetooth
Manual Bluetooth pairing needs to be done for the first time to pair up the micro-controller with the PS3 controller. After the first manual pairing, the PS3 controller will be able to recognize the address of the micro-controller and connect to it automatically. Signals will be sent to the processor via Bluetooth by the PS3 controller and vice versa. The processor will process the signals and determine the output according to pre-programmed logic rules.
7.7 Motor
Two motors are needed for the remote control car: one for turning and one for accelerating. The turning motor is attached to the front wheels while the accelerating motor is connected with the rear wheels. The motors are controlled by the signal from the processor. The processor takes input signals from the PS3 controller, infrared sensor, and accelerometer to determine the state of the motor.

7.8 LED Driver
The LED driver is driven by the signal from the processor. The processor receives and processes signals from the light sensor and controls the on/off state of the LED.

7.9 IR Sensor
IR sensors are required to detect obstacles around the vehicle. It will only be enabled in safety mode of operation. The IR sensor will go through a pre-designed comparator that will “recognize” the obstacle around the vehicle. A signal will be sent to the processor for processing and determine its output according to various other control signals and mode of operation.

7.10 Accelerometer
The accelerometer is used to detect collisions of the vehicle. The accelerometer will be enabled in the normal mode of operation. The accelerometer will go through a pre-designed differentiator and Schmitt Trigger for collision detection. A signal will be generated by the Schmitt Trigger and sent to the processor for processing. The processor will determine its output according to various other control signals and the mode of operation.

7.11 LCD and Camera
The LCD and Camera is a separate subsystem that requires minimal integration with the rest of the system. The wireless spy camera captures videos and streams it through RF protocol to its receiver. The receiver processes the signal and is connected to a LCD screen via VGA input. The LCD displays the surroundings that are captured by the camera.

8 System Test Plan

The IR sensors, accelerometer, and the motors are tested individually and then the rest will be tested together under both the normal mode and the safety mode. For the IR sensor, we simply test the output signal and observe how it changes when we put an object in front of it. We further test it by altering the angle and the distance between the sensors and the objects. For the accelerometer, we monitor the output signal when we shake it and vary the intensity of the shake. Finally, we directly probe the motors when active, and then directly apply power to motors to confirm our measurements. The rest will be tested as follows:
1. Write test bench for communicating with the microprocessor: the general purpose I/O pins (GPIO), the Bluetooth connection, and the pairing of the PS3 controller.
   a. Write a test bench to alter (in various conditions) the output signal of GPIO pins, and then probe it to see if the output is as expected.
   b. Try using the PS3 controller to detect signal from the microprocessor
   c. Use the PS3 controller to control basic motions of the car.
2. (Normal mode): We will crash our car into some object and see if the controller vibrates.
3. (Safety mode): We will see if the car will stop and roll back if a large object is in front of it, and see whether or not it will run over small objects as intended.

9 Conclusion

The design specification document provides technical design details that are required to implement our project successfully. Hardware details such as microprocessor, motors, IR sensors, LED drivers, and accelerometers have been discussed along with the other software requirements such as programming environment and debugger. Test plans have been included to ensure the proper operations of our system as well as our proposed requirements have been met. All essential topics have been addressed accordingly.
10 References