Automotive Wheel Alignment Sensor System

Design Review

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1 Introduction

1.1 Statement of Purpose

The project’s goal is to design a system that can identify when a car is out of alignment with a high level of accuracy. This effectively helps car owners to keep their cars’ performance regularly maintained and, in turn, drives overall efficiency up. The efficiency of automobiles is a very prevalent topic in today’s society. With the push for green technology and the constant need to optimize every existing system, a system that can identify when a car is out of alignment is necessary. Vehicles out of alignment experience reduced performance; by being out of alignment, a vehicle can experience up to ten percent lower fuel efficiency. In addition, the wear on the tire tread is a resource cost, since rubber is a finite resource and also leaves a carbon footprint.

In the initial design when the project was proposed, we thought of placing the sensor on a part of the wheel and powering it via the car battery; however, the current design entails creating custom wheel caps, which are typically used in cars with alloy wheels as to cover the wheel hub. Each wheel cap will then contain sensing equipment, powered by a lithium-ion battery.

1.2 Objectives

Goals
- Create a system that can detect static alignment issues.
- Create a system that can measure dynamic fluctuations in alignment.

Functions and Features
- Simulated infotainment system to view collected alignment data.
- Can prompt user when car is out of alignment by a significant enough margin.
2 Design

2.1 Block Diagram

Figure 1: Device Hardware Block Diagram
Figure 2: System Hardware Block Diagram

Figure 3: Control Flow
2.2 Block Descriptions

2.2.1 Power Supply

This module will supply the voltage to the entire system. It consists of a 3.8V Li-Poly battery that will be regulated by a linear regulator to step the voltage down to a 3.3V stable value. Power will only be supplied to the sensors when a ping is issued by the microcontroller to take measurements.

<table>
<thead>
<tr>
<th>Device</th>
<th>Power Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATmega328</td>
<td>Voltage: 3.3V to 5V</td>
</tr>
<tr>
<td>LSM303DLHC</td>
<td>Voltage: -.3 to 4.8V</td>
</tr>
<tr>
<td></td>
<td>Typ: 3.0V</td>
</tr>
<tr>
<td>L3GD20H</td>
<td>Voltage: 2.2V to 3.6V</td>
</tr>
<tr>
<td>CC2540</td>
<td>Voltage: -.3 to 3.9V</td>
</tr>
<tr>
<td></td>
<td>Typ: 3.0V</td>
</tr>
<tr>
<td>150mA Low-Noise LDO Regulator</td>
<td>Voltage: 2.5 to 16V</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Device</th>
<th>Voltage</th>
<th>Current</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATmega328</td>
<td>3.3V</td>
<td>.2 mA</td>
<td>.66 mW</td>
</tr>
<tr>
<td>LSM303DLHC</td>
<td>3V</td>
<td>110 uA</td>
<td>.330 mW</td>
</tr>
<tr>
<td>L3GD20H</td>
<td>2.2V</td>
<td>5 mA</td>
<td>11 mW</td>
</tr>
<tr>
<td>CC2540</td>
<td>3V</td>
<td>6.7 mA</td>
<td>20.1 mW</td>
</tr>
<tr>
<td>Total Power</td>
<td></td>
<td></td>
<td>22.06 mW/h</td>
</tr>
</tbody>
</table>

3.8V Li-Poly battery at 1200 mAh results in 4560 mWh. 206.7 Hours.
2.2.2 Microcontroller ATMEGA328/P

The microcontroller will poll its GPIO pins for accelerometer and gyroscope data that is incoming from the sensors. In addition it will also act as a switch to turn on the sensors when measurements are required or leave them in lower power mode when not in use. The data will then be transmitted to the bluetooth transmitter to be sent to the mobile device.
2.2.3 Bluetooth Transceiver CC2540

This module will communicate with the microcontroller by using the MCU’s Tx/Rx pins. The wheel data will then be transmitted to a mobile device by ensuring that all four nodes are able to connect to the device.
2.2.4 Camber Sensors

Each sensor will consist of a 3-axis accelerometer to measure the angle of inclination of the wheel in order to provide data about when the car is static and when the car is in motion. By differencing the acceleration of the tire and the acceleration of the wheel hub, the camber can be calculated. A resulting difference of near zero will correspond to an aligned camber. Each sensor will be connected to a transmitter.
Figure 7: Camber angles, measured in degrees.

Figure 8: LSM303DLHC Accelerometer/Magnetometer
2.2.5 Caster Sensors

Each sensor will consist of a 3-axis accelerometer to measure the orientation of each individual strut. By comparing the orientation of the accelerometer to the orientation of a chassis-mounted accelerometer, caster can be determined. Each sensor will be connected to a transmitter.

![Caster angle diagram]

Figure 9: Caster angle, measured in degrees.

2.2.6 Toe Sensors

Each sensor will consist of a 3-axis accelerometer that will measure the angle at which the tires point inwards towards the frame of the car. By comparing the orientation of the accelerometers to the orientation of a chassis-mounted accelerometer, static toe can be determined. When the car is in motion, the sensors will work by calculating the difference between wheel and chassis acceleration. Each sensor will be connected to a transmitter.
Figure 10: Toe angles, measured in degrees.
Figure 11: U501 Gyroscope
Figure 12: Full Device Circuit
## 3 Requirements and Verification

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Verification</th>
<th>Points</th>
</tr>
</thead>
</table>
| **Power Supply Units**  
1) Central Unit:  
Transforms car battery or alternator voltage (12V-14.5V) to +5V±5% | 1) Verification process for Item 1:  
a) Connect input voltage leads of power supply unit to a bench DC power supply unit.  
b) Connect output voltage leads to a multimeter and set it up to measure DC voltage.  
c) Increase bench DC power supply unit voltage from 12V to 14V, using increments of .1V. For each increment, verify that the multimeter reading is within the +5V±5% tolerance. | 1) 5 |
| 2) Sensor Unit: Turns on when pinged by microcontroller. | 2) Verification process for Item 2:  
a) Probe power supply output voltage leads with a handheld multimeter to verify that the output voltage is 0±10μV.  
b) Turn car accessory power on.  
c) Start software.  
d) Probe power supply output voltage leads with a handheld multimeter to verify that the output voltage is 3.3V±5%. | 2) 5 |
| 3) Sensor Unit: Steps down Li-Poly battery voltage from 3.8V±5% to 3.3V±5%. | 3) Verification process for Item 3:  
a) Turn car accessory power on.  
b) Start software.  
c) Probe Li-Poly battery leads with a handheld multimeter to verify that the battery voltage is 3.8V±5%.  
d) Probe power supply output voltage leads with a handheld multimeter to verify that the output voltage is 3.3V±5%. | 3) 5 |
| **Microcontroller**  
1) Executes alignment system software. | 1) Verification process for Item 1:  
a) Turn car accessory power on.  
b) Start software.  
c) Check software log files to verify | 1) 15 |

Danek & Kousari  
September 12th
<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Verification Process</th>
<th>Criticality</th>
</tr>
</thead>
</table>
| 2)     | Properly communicates with all other modules.                               | 2) Verification process for Item 2:  
(a) Turn car accessory power on.  
(b) Start software.  
(c) Check software log files to verify that software runs without critical errors. | 2) 15       |
| Bluetooth Communication Module | 1) Central receiving antenna receives sensor data from all transmitting antennas up to 10 feet away. | 1) Verification process for Item 1:  
(a) Place sensor transmitting antennas 10 feet away from central receiving antenna.  
(b) Turn car accessory power on.  
(c) Start software.  
(d) Check software log files to verify that software runs without communication errors. | 1) 10       |
| Sensors | 1) Sensors measure camber within ±1° of actual value.                        | 1) Verification process for Item 1:  
(a) Turn car accessory power on.  
(b) Start software.  
(c) Note camber values listed in software.  
(d) Measure camber values manually or at an alignment shop.  
(e) Compare software and measured values to verify requirement has been met. | 1) 15       |
|        | 2) Sensors measure caster within ±1° of actual value.                       | 2) Verification process for Item 2:  
(a) Turn car accessory power on.  
(b) Start software.  
(c) Note caster values listed in software.  
(d) Measure caster values manually or at an alignment shop.  
(e) Compare software and measured values to verify requirement has been met. | 2) 15       |
|        | 3) Sensors measure toe within ±1° of actual value.                          | 3) Verification process for Item 3:  
(a) Turn car accessory power on. | 3) 15       |
<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
</table>
| value. | b) Start software.  
c) Note toe values listed in software.  
d) Measure toe values manually or at an alignment shop.  
e) Compare software and measured values to verify requirement has been met. |
4 Tolerance Analysis

The most important block of the design is the camber sensors. In order to have a robust system, the sensors must be able to withstand 260g of force. This calculation allows for 1% of error tolerance in calculations an extraneous forces acting upon the car. It must also be noted that 6g of random force acting upon the car is a tremendous amount of force and in addition the margins chosen for the calculation were on the generous side. This is calculated by defining the sensor to be placed .5 inches away from the center of a 16 inch wheel and for the car to be traveling at 90 mph. This calculation is as follows:

\[
\text{.5 in} = .0127 \text{ m} \\
90 \text{ mph} = 40.23 \text{ m/s} \\
16 \text{ in} = .4064 \\
\text{Circumference} = \pi (.4064) = 1.28 \text{ m} \\
\text{Angular Velocity} = \frac{40.23 \text{ m/s}}{1.27 \text{ m}} = 31.51 \text{ rad/s} \\
\text{Force on Sensor} = \frac{2\pi(31.51)^2(0.0127)}{9.8} = 8.085\text{g}
\]

The accelerometer can measure forces greater +/- 16g which means that the mems devices can withstand accelerations that a car undergoes during travel. This calculation does not have to do with measuring accurately under those conditions however being able to survive in those conditions without stresses affecting the system permanently.

Let’s assume that there exists two Vector quantities \(V_1<x,y,z>\) and \(V_2<x,y,z>\). Where the components are forces exerted on the chip by either gravity or magnetism. \(V_1\) becomes the stable system reference value.

For this explanation assume the car is on a completely flat surface.

Toe only affects the xy plane of the coordinate system, any change in magnetic readings will be able to be registered on the magnetometer. Camber will only affect the xz plane, the \(\text{tangent}(x/z)\) will result in the angle distance from true center.

For non completely flat surfaces the same method works, however with the reference value present the difference between \(V_2.\text{tan}()\) and \(V_1.\text{tan}()\) is the true camber angle.

The sensor has an accuracy of .001 g per axis and a noise density of .00063 g at 10 Hz. If the camber is off by .1 degree the percent error is as follows.

\[
9.81\sin(.5) = .0856 +/- .00981 \\
1 - (.0856 - .00981)/.0856 = 11.4\% \text{ error}
\]
5 Cost and Schedule

5.1 Cost Analysis

5.1.1 Labor

<table>
<thead>
<tr>
<th>Name</th>
<th>Hourly Wage</th>
<th>Hours Worked</th>
<th>Subtotal</th>
<th>2.5 X Subtotal</th>
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</thead>
<tbody>
<tr>
<td>Isaac Kousari</td>
<td>$31.85</td>
<td>250</td>
<td>$7962.50</td>
<td>$19,906.25</td>
</tr>
<tr>
<td>Michael Danek</td>
<td>$31.85</td>
<td>250</td>
<td>$7962.50</td>
<td>19,906.25</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>500</td>
<td>$15,925.00</td>
<td><strong>$39,812.50</strong></td>
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5.1.2 Parts

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATmega328</td>
<td>5</td>
<td>$6.80</td>
</tr>
<tr>
<td>LSM303DLHC</td>
<td>5</td>
<td>$5.30</td>
</tr>
<tr>
<td>L3GD20H</td>
<td>5</td>
<td>$5.70</td>
</tr>
<tr>
<td>CC2540</td>
<td>5</td>
<td>$30.45</td>
</tr>
<tr>
<td>MIC5205</td>
<td>5</td>
<td>$15.68</td>
</tr>
<tr>
<td>Crystal Oscillator</td>
<td>5</td>
<td>$0.80</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>$64.73</strong></td>
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</tbody>
</table>

5.1.3 Grand Total

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Labor</td>
<td>$39,812.50</td>
</tr>
<tr>
<td>Parts</td>
<td>$64.73</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$39,877.23</strong></td>
</tr>
</tbody>
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## 5.2 Schedule

<table>
<thead>
<tr>
<th>Week</th>
<th>Task</th>
<th>Delegate</th>
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</thead>
<tbody>
<tr>
<td>9/19</td>
<td>Finalize Design Requirements</td>
<td>Isaac Kousari</td>
</tr>
<tr>
<td></td>
<td>Finalize Design Requirements</td>
<td>Michael Danek</td>
</tr>
<tr>
<td>9/26</td>
<td>Sensor placement and angle optimization</td>
<td>Isaac Kousari</td>
</tr>
<tr>
<td></td>
<td>RF antenna communications and optimization</td>
<td>Michael Danek</td>
</tr>
<tr>
<td>10/3</td>
<td>Design sensor network for each block</td>
<td>Isaac Kousari</td>
</tr>
<tr>
<td></td>
<td>Design Power Regulator for 12VDC to 5VDC conversion</td>
<td>Michael Danek</td>
</tr>
<tr>
<td>10/10</td>
<td>Create diagnostic software for running background systems</td>
<td>Isaac Kousari</td>
</tr>
<tr>
<td></td>
<td>Signal Processing analysis and ADC/DAC programming</td>
<td>Michael Danek</td>
</tr>
<tr>
<td>10/17</td>
<td>Initial implementation and testing</td>
<td>Isaac Kousari</td>
</tr>
<tr>
<td></td>
<td>Initial implementation and testing</td>
<td>Michael Danek</td>
</tr>
<tr>
<td>10/24</td>
<td>System redesign if necessary/ physics modeling &amp; programming</td>
<td>Isaac Kousari</td>
</tr>
<tr>
<td></td>
<td>System redesign if necessary/ finalize Tx/Rx design</td>
<td>Michael Danek</td>
</tr>
<tr>
<td>10/31</td>
<td>Preliminary Assembling and Testing</td>
<td>Isaac Kousari</td>
</tr>
<tr>
<td></td>
<td>Preliminary Assembling and Testing</td>
<td>Michael Danek</td>
</tr>
<tr>
<td>11/7</td>
<td>Port software to Android</td>
<td>Isaac Kousari</td>
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<tr>
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<td>Data Statistics and Normalization</td>
<td>Michael Danek</td>
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<tr>
<td>11/14</td>
<td>Testing and Debugging</td>
<td>Isaac Kousari</td>
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<td></td>
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<tr>
<td>11/21</td>
<td>Optimization and Finalization</td>
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<td>Optimization and Finalization</td>
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<tr>
<td>11/28</td>
<td>Final Demonstration</td>
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<tr>
<td></td>
<td>Final Demonstration</td>
<td>Michael Danek</td>
</tr>
<tr>
<td>12/5</td>
<td>Final Presentation</td>
<td>Both</td>
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</table>
6 Safety Issues

All devices involved in the system use low amperage. The most important issues involving safety in this project is handling static hazards in addition to the operating conditions of batteries. Batteries should be kept in dry cool areas that have no liquids nearby. Batteries should not be overcharged and always handled with care. When discharging a voltage, it must be ensured that it is in the operating region as defined by the datasheet. The load should not draw more current from the battery than is defined by the datasheet as the max load. The battery should not be shorted or used in reverse polarity. Another aspect to battery safety comes into play when testing our system on an automobile. All system components to be connected to the car battery should be connected while the car battery is disconnected.

7 Ethical Issues

[1] Our design is consistent with the IEEE code of ethics.

\{1\} to accept responsibility in making decisions consistent with the safety, health, and welfare of the public, and to disclose promptly factors that might endanger the public or the environment;

Our design will not interfere with the operations of the vehicle and any information gathered from our system only aids in the maintenance of said vehicle to protect the driver and occupants.

\{3\} to be honest and realistic in stating claims or estimates based on available data;

Our design is simple in that all technology has been available and operates in the necessary margins for accurate data. In addition, no forgeries in analysis or estimations will be given.

\{5\} to improve the understanding of technology; its appropriate application, and potential consequences;

We designed our system such that it would not interfere with the operating conditions with the system that it measures. The technology that we are using for this application is used for similar concepts but none directly for this application.

\{7\} to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others;

We seek only to complete our work diligently and present ourselves in a professional manner, citing others where credit is due.
to assist colleagues and co-workers in their professional development and to support them in following this code of ethics.

As following with the guidelines and mission statement of the university, we strive to accomplish an inclusive environment, pushing for the success of the project and the individual team members.

Citations