High Level Design

Trailer Towing Assistance System

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Introduction

In this project we seek to design and construct a trailer monitoring system that will provide the operator with useful safety related information about the trailer and its surroundings.

Problem Statement

The purpose of this system is to mitigate a number of safety risks associated with towing a trailer as well as to provide some convenient features for the operator. First, when a vehicle is towing a trailer its blind spots are significantly increased. As a result, normal driving maneuvers, such as changing lanes, become much more difficult and risky. Secondly, any situation that requires the operator to back up can prove hazardous because the operator has a large blind spot directly behind the trailer. If these blind spots could be eliminated or reduced, the safety risks associated with towing a trailer would also be reduced.

Other safety concerns when towing a trailer include the status of the trailer door as well as the temperature inside and outside of the trailer. For obvious reasons, it is important that an operator does not drive away with the trailer doors open. The temperature inside the trailer would be useful when carrying cargo, such as crayons or candle wax, which could be damaged by extreme temperatures. An outdoor temperature measurement would allow the driver to adjust for icy conditions.

Finally, a trailer operator does not currently have an indicator to show if the trailer brake lights and turn signals are working properly. Checking for burnt out bulbs must be done manually. Our goal is to minimize these safety risks by providing more information to the driver.

Proposed Solution

To help reduce the risk associated with these blind spots we propose to build a unified system of sensors to provide the operator with information about potentially hazardous conditions. The sensors will provide information to help mitigate the risks discussed in the Problem Description above. The system will check the trailer's blind spots for the presence of other vehicles, monitor the status of the trailer doors, measure inside and outside temperatures, monitor the brake & blinker lights, and help avoid collisions when backing up. In essence the system is a unified set of sensors which we will integrate together.

The operator of the trailer will receive this information via a wireless console kept in the cab of the towing vehicle. This console must not only display information, but must at times get the driver's attention to alert him of unsafe conditions. Additionally, it may be convenient to provide the operator with the option to turn certain features on or off using this wireless console.

System Description and Block Diagram

The entire system will consist of two main units along with multiple external sensors. The first main unit will reside on the trailer, and will interface with all of the sensors placed on the trailer. This unit will gather the information from the sensors and then wirelessly transmit this data to the second main unit, the driver's display.

The driver's display will reside inside the cab of the towing vehicle. It will be the device through which the operator interfaces with the system. Not only will the driver's display passively relay information, but it must at times actively get the operator's attention and alert him of dangerous conditions. The driver will also be able to change certain settings and turn certain features on and off using this display.

Figure 1: Block Diagram
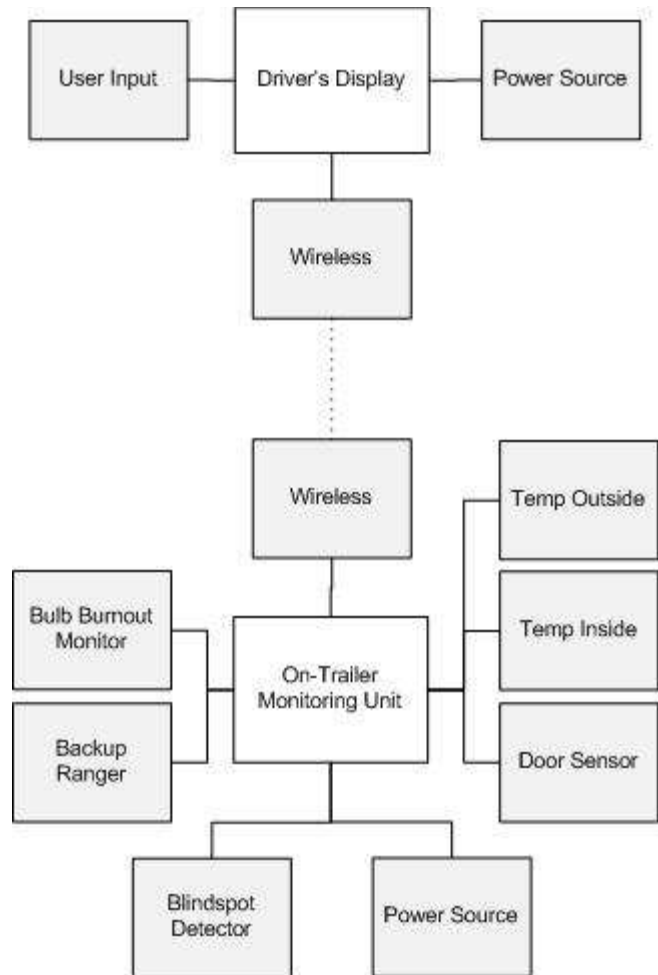
System Requirements

Overall System

- Clear, safe, intuitive relay of information to driver
- Appropriate alerts and alarms when necessary
- Easily operated and interfaced with
- Functions in all weather conditions
- Continuous operation
- Specific Features
    - Detect and indicate when car/truck/motorcycle is adjacent to trailer, and on which side
    - Detect and indicate temperature inside trailer
    - Detect and indicate temperature outside trailer
    - Detect and indicate status of trailer door (open/closed)
    - Assist in backing up trailer by providing backup ranging
    - Detect and indicate when (and which) brake/blinker lights are on

Subsystem Requirements

Driver's Display

- Must display all sensor information
- Must receive user inputs
- Must alert driver of alarmed states when necessary
    - Audible and/or visual
- Wirelessly Communicate with On-trailer unit
    - Two-way communication, send and receive information
- Display information clearly
    - In sunlight
    - At night
- Interface with Driver easily and safely
    - Large buttons, text, indicators
- Sufficiently powered for continuous use

On-Trailer Monitoring Unit

The on-trailer monitoring unit will function as the control center for the system.

- Must connect to all the required sensors
- Must be able to handle short power losses (bad connection from truck to trailer)
- Must include 'industry standard' connections for both the trailer and the truck
- Must contain short range wireless communication
- Allow for plug and play connections for all peripherals
- Have a master on/off switch accessible to user
- Operate in all weather conditions (Excluding hurricanes, white-out conditions, etc.)
- Have a sufficient sampling rate to keep user up to date in real time
- Easily installed
- Fail-safe mode; trailer operates normally despite unit failure
- Provide accurate information to the display unit

Wireless Communications

- Reliable communication between on- trailer system and display up to 30 feet
- Reliable communication in all weather conditions
- Sufficiently low power to prevent RF pollution or interference with surrounding devices
- Low power to extend life of power source
- Low data rate to minimize system cost and complexity; high data rate not needed
- Signal must be able to penetrate through body of trailer and truck
- Relatively easy implementation of technology and software
- Transceiver chips must be sufficiently affordable to fit in budget
- Transceiver chip must fit size constraints of system

Blind Spot Detection

- Ambient sunlight (or headlights) should not affect functionality.
- Extreme temperatures should not affect operation.
- The device should withstand rain and snow.
- The sensor's range should be at least 15ft. The width of a highway lane is 12ft.[1]
- The apparatus should be directional; it should not detect objects that are located behind or in front of the trailer.
- The sensor must return correct readings even if the trailer is moving at fast speeds (80 mph max.)
- A sufficient number of sensors should be placed such that the entire blind spot region is covered.
    - The number of required sensors will depend on the trailer's length, as well as on the smallest vehicle that should be detected.
    - The maximum trailer length supported by our design will be 15 ft, and the smallest detectable vehicle should be a motorcycle (about 5 ft long). Therefore, a minimum of three sensors will be required for each side.
- Interface with microcontroller should be simple.
- Software implementation should be simple.
- The color/nature of the detected vehicles should not affect accuracy.
- The material of the trailer should not affect operation.
- Accuracy is not paramount; the system must simply decide whether the lanes are empty or not.
- Low power
- Low cost

Backup Ranging

- Operable over a useful distance: 4-6 ft
- Accurate to ±3 in
- Durable
    - Withstand normal driving conditions
    - Withstand effects of weather
- Operable in all weather conditions (excluding white-outs, hurricanes, etc.)
- Color or reflective nature of the object behind trailer should not affect distance measurement
- User can turn off when not in use
- The sensor should easily interface with the microcontroller
- Inexpensive
- Easy to install
- Low Power

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[1] Average highway width is 12 ft: http://www.fhwa.dot.gov/ohim/hs01/hm33.htm

Brake/Blinker Light Burn-out Detection

- Detect when a brake light or turn signal bulb has burned out or failed
    - Measure current to bulbs, approximately 2-3A
- Give the operator information about which light is not on

Inside Temperature Monitoring

- Operational over range of -10°F to 110°F
- Accurate to ±3°F within above range
- Sample at least once every 5 minutes
- User can set a 'safe temp range'; alarm sounds if temperature goes outside the set range
- Low power
- Low cost

Outside Temperature Monitoring

- Operational over range of -10°F to 110°F
- Accurate to ±3°F within above range
- Sample at least once every 5 minutes
- Turn on 'icy roads' icon when below 35°F
- Low power
- Low cost

Door Monitoring

- Operational over range of -10°F to 110°F
- Sample at least once every 2 seconds
- Door Open alarm
    - User can turn feature on/off
- Robust – not going to break after repeated slamming of door
- Reliable – gives accurate door open/closed information
    - 'Door open' event occurs when doors are completely misaligned
    - 'Door open' event DOES NOT occur when door is jostled, vibrated during travel
- Low power
- Low cost

Future Enhancement Requirements

Since our system is aimed at providing the driver with relevant safety information, there are some features that could be added to future revisions of the device which are beyond the current scope of our project.

Load Balance Sensing

In any closed trailer the ability to detect a shift in the load would provide the operator with valuable information. This information would be useful both while towing the load and during the loading/unloading process. While towing a trailer, a shift in the load could affect the behavior of the trailer and cause it to become unsafe. During the loading process this improvement could help the operator load the trailer evenly. Finally, being able to detect a shift in the load could warn the operator in the event that the load has shifted and is resting against the door of the trailer.

Complete Wireless Coupling

Being able to simply attach the trailer to the hitch and drive away without worrying about connecting any wires would simplify things for the operator. Ideally this revision to our system would allow the trailer system to sense the truck and power up and would then power down when the truck is detached from the trailer.

High Level Design Decisions

Driver's Display

The driver's display must wirelessly communicate with the on-trailer unit and display the current status of all the sensors in an easily-readable and intuitive fashion. In addition, the display unit must accept user input. A proposed layout of this display unit is below:
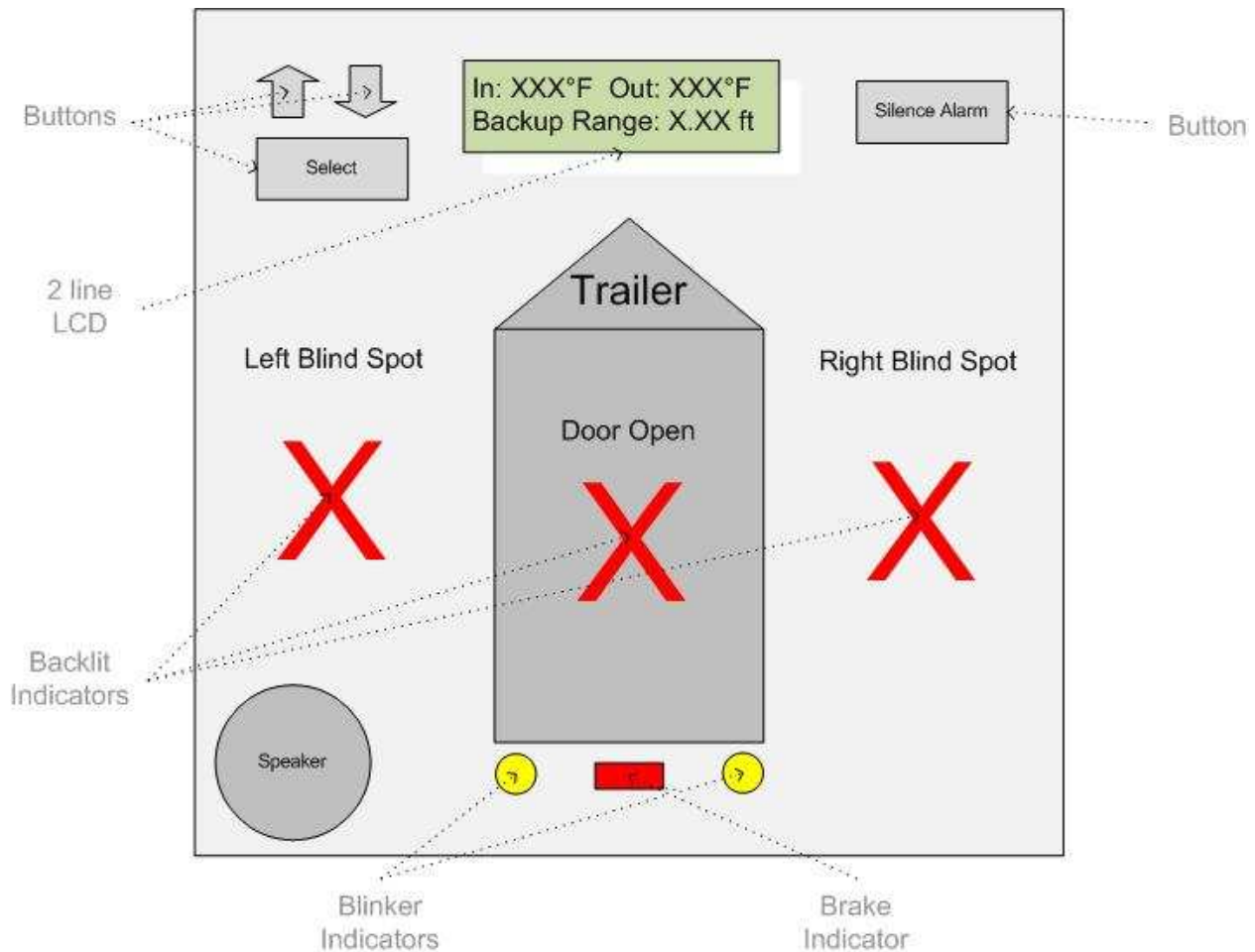
This proposed design for the driver's display unit uses an LCD to display the backup range and temperatures. This LCD must be backlit so it can be read at night, and must be sufficiently large to see clearly. The blind spot detection, door open status, brake light and blinker indicators will all be displayed with appropriately positioned LED's in the above trailer diagram. This should allow for an intuitive understanding of each light. The buttons in the top left of the display will allow the user to cycle through options and select settings. The only user-input required at this time would be for setting the 'safe temperature range' for the inside temperature monitor. The 'silence alarm' button in the top right of the console would be used to turn off any audible alarms.

The brains of this console will be a microcontroller. We are leaning towards using the same PIC as used in class because it has sufficient I/O and the ability to easily interface with a 2 line LCD. The

wireless technology in this device is discussed in the wireless communications section below. This console will be powered from the cigarette adapter in the cab of the towing vehicle.

On-Trailer Monitoring Unit

The on-trailer monitoring unit must interface with all sensors, make sense of their outputs, and send logical information to the display unit. It is up to the on-trailer monitoring unit to make decisions based upon the outputs of the sensors. For example, if the trailer door is open, it is up to the on-trailer unit to detect that and send a command to the display to turn on the appropriate LED.

The brains of the on-trailer monitoring unit will be a microcontroller. We are leaning towards using the same PIC as used in class as this microcontroller should have more than enough I/O and processing power for our needs.

Wireless Communications

The wireless interface will be used for communication between the on-trailer unit and the driver's display. We considered a few different technologies for the interface, including Bluetooth, Wibree, Ultra-wideband (UWB) and ZigBee. The technology that best fits our requirements is ZigBee, for a number of reasons. It is designed to fit low data rate applications, which ostensibly extends the life of any power source. In fact, the technology was developed with low power consumption requirements in mind. The technology is also simpler to implement than some of the other wireless standards that were considered due to less software requirements. In fact, all of the other technologies had some particular outstanding disadvantage, such as power consumption and software complexity for Bluetooth, limited availability for Wibree, and unneeded data rate overhead for UWB. ZigBee appears to be the best solution for our display interface at this time.

Requirement	Bluetooth	WiBree	ZigBee	UWB
Reliable @ ~30 feet	6	6	10	10
Low interference w/other devices	5	5	8	10
Low power	5	10	8	8
Low complexity in implementation	3	3	7	5
Low data overhead	3	5	8	5
Signal travels through truck / trailer	6	6	8	8
Affordability	5	4	8	5
Size	7	8	7	7
Availability	8	0	8	2
Total	**48**	**47**	**72**	**60**

Blind Spot Detection

To select the most appropriate technology we evaluated various proximity sensor types[2], discarding those that violated essential requirements:

Light sensors: Determine the distance based on changes in light intensity. As an object approaches the sensor, the intensity of light at the receiver is diminished, and the device concludes that the distance to the object has been reduced. This technology is not very reliable because it assumes that the luminosity of the environment stays the same. Since our blind spot detector should be able to function during the nighttime, we cannot utilize this type of sensor.

Capacitive sensors: Determine the distance based on changes in capacitance. These do not require light, so they present an advantage over light sensors for our purposes. However, they are highly dependent on the dielectric constant of the material. This means that the material of the detected vehicle could drastically affect the distance readings, which is undesired. Also, capacitive sensors are not directional, which again violates a crucial requirement. Therefore, capacitive sensors cannot be utilized for our purposes.

Laser sensors: Use laser technology to get very accurate distance readings. However, they are extremely expensive. For instance, the Hokuyo URG-04LX Laser Sensor is listed as $2695.00.[3] Since it is advertised as a "reasonably sized, reasonably priced, high performance laser," we can conclude that lasers are exorbitant for our low budget. Even if all the rest of the requirements were fulfilled, we cannot afford the device. Therefore, laser technology must be discarded.

Acoustic sensors: Devices that utilize this technology generally send an ultrasonic signal. When the signal reaches the object, it echoes back to the receiver. Distance is determined by measuring the total time taken for the acoustic signal to return. Since the time is proportional to the distance, the distance to the object can be easily found using this technology. This type of sensor requires a device with a digital clock (e.g. microcontroller) to keep track of time intervals. The average distance range of a common ultrasonic sensor is about 10 feet and priced at $30[4] . They are also very directional. Popular ultrasonic devices have three pins: Vdc, Gnd, and Sig. At this point, it is not evident if acoustic technology would violate any of the requirements. The device meets range requirements, low cost (relatively), simple interface (1 pin) to microcontroller, and daylight is not required. However, we do not know if the device will function properly under various weather conditions such as rain. Therefore, if we opt for this technology, we must actually test it to verify that it actually meets all requirements.

IR sensors[5]: These determine distance by sending an infrared signal and waiting for it to bounce back to the receiver. Like acoustic sensors, IR sensors are very directional. Their maximum distance range is approximately 5-6 ft. They generally do not require a clock source because they "fire" continuously.

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[2] http://www.solarbotics.net/library/circuits/sensors_prox.html
[3] http://www.acroname.com/robotics/parts/R283-HOKUYO-LASER1.html
[4] http://www.jameco.com/webapp/wcs/stores/servlet/KeywordSearchResultView?langId=-1&storeId=10001&catalogId=10001&searchType=k&searchValue=ultrasonic&categoryId=753040&rscount=1
[5] http://www.acroname.com/robotics/parts/R144-GP2Y0A02YK.html

Their price varies from $10 - $20, which is less than ultrasonic technology. However, even though IR would be cheaper, we had specified that the device's range must be at least 15ft. Since IR does not fulfill this essential requirement, it must be discarded.

After considering the various technologies, the ultrasonic (acoustic) proximity sensor fits the requirements the best. However, as previously explained, we are not certain that it will fit every condition. There is no published information that guarantees that accurate readings can be obtained at various trailer speeds. Therefore, the best way to determine this will be to physically test the device. Before ordering multiple sensors, we will order one sensor and test it to make sure it meets the requirements outlined above.

Backup Ranging

The three possibilities for the backup are laser, ultrasonic, and IR. The best choice based on stated requirements is IR. The following chart has each technology rated against each requirement on a scale of 1-10 (10 being the best).

Requirement	Ultrasonic	Laser	IR
Read Distance(4-6ft)	10	10	10
Accuracy within inches of actual	6	10	5
Work in nearly all weather cond.	9	7	9
Durability	8	4	10
Read off of any object	9	8	8
Easily interface with micro	5	7	9
Price	7	0	10
Use little power	10	7	10
Total	**64**	**53**	**71**

IR scores the highest score based on the requirements. Laser is simply too expensive to be a viable option. Ultrasonic could be considered overkill for this particular application. The read distance is well over what is needed and the packaging is not as durable as IR. IR is able to reasonably meet all the requirements while remaining the cheapest option.

Brake/Blinker Light Burn-out Detection

This subsystem will be used to provide the driver with information on the status of the brake lights and turn signals. There are only a few ways to tell if a light bulb is on without looking at it. A photoelectric sensor could be placed next to each light to determine if the light was functional. While photoelectric sensors are relatively inexpensive, outside interference such as sunlight or headlights from other vehicles could cause the sensor to give a false reading; a more practical solution is a current

sensor. A current sensor could be placed in line with each light to determine if the light was drawing any current. Typical automotive brake light and turn signal bulbs draw about 2A ± .5A[6], so our current sensor will need to be capable of measuring that amperage. The current sensor should also be capable of operating independently of temperature.

Inside Temperature Monitoring

There are a limited number of ways to measure temperature with electronics. The first method is to simply buy and IC chip that performs this function. This is an easy solution, but it requires that the chip be placed where the temperature is to be measured. The chip would need to be placed inside the trailer and would require its own board. A second method of electronically measuring temperature is to use a thermistor; a resistor whose resistance is temperature dependant. This solution would not require a separate board to be put inside the trailer, but the resistance of the wires connecting the thermistor to the on-trailer unit would affect the measurement. The resistance of these wires must be accounted for when using a thermistor to get accurate results.   Special temperature probes with calibrated leads can be purchased, but for a premium cost.

Requirement	IC Chip	Thermistor	Temperature Probe
Operational over -10°F to 110°F	10	10	10
Accurate to ±3°F within range	10	5	10
Low cost	8	10	0
Low power	10	10	10
Total	**38**	**35**	**30**

From the above comparison table, it can be seen that the IC chip is the best choice. It is sufficiently accurate, low power and low cost. It also removes the problem of the connector wire's resistance affecting the measurement. The 'additional board' the chip will require can be fabricated alongside either the on-trailer board or display board and separated later to save cost.

The 'safe temp range' function will be implemented in software.

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[6] http://www.topbulb.com/find/prod_list.asp_Q_p_E_3_A_intSubCategory_E_431_A_sortby_E_watts_A_sortdir_E_

Outside Temperature Monitoring

The outside temperature monitoring hardware will be identical to the indoor temperature monitoring to save on complexity; their requirements are sufficiently similar. The outdoor temperature board will need extra weatherproofing/casing as compared to the indoor temperature sensor. It is possible that the outside temperature chip could be incorporated onto the on-trailer board if the on-trailer unit is placed outside the trailer.

The 'icy conditions' indication will be implemented in software.

Door Monitoring

There are two classes of sensors that could provide the appropriate door open/closed status information: 1) Contact sensors and 2) Non-contact sensors. Contact sensors have a physical connection that is either broken or connected. Non-contact sensors, such as lasers, IR, or magnetic devices have no physical contacts. These non-contact sensors are typically more expensive, but they do not have any moving parts that might wear out over time. IR and laser sensors will additionally require 'line of sight' between devices. Magnetic sensors do not require a 'line of sight' but must therefore be place closer together.

Requirement	Contact Switches	Laser	IR	Magnetics
Operational over -10°F to 110°F	10	10	10	10
Robust	3	5	5	9
Reliable – does not trip under normal travel vibrations	4	4	4	9
Low power	9	8	8	10
Low cost	10	2	7	8
Total	**36**	**29**	**34**	**46**

From the above comparison table, it can be seen that the magnetic sensor is the best choice given the requirements. It is the most robust and reliable means of detecting if the trailer door is open.

The 'door open' alarm will follow the following scheme (to be implemented in software):
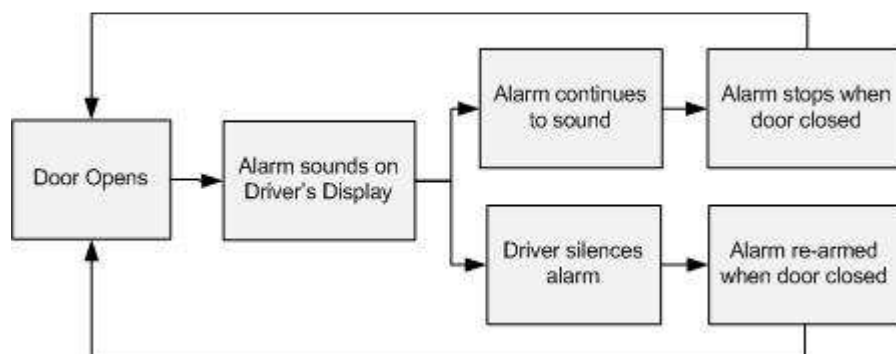
Major Component Costs

Component	Unit Cost	Quantity	Total Cost
Display Unit			
Microcontroller	$0.00	1	$0.00
LCD Display	$10.00	1	$10.00
LEDs	$0.10	15	$1.50
Speaker/Buzzer	$3.00	1	$3.00
Buttons	$1.00	4	$4.00
Wireless transceiver	$15.00	1	$15.00
Plastic Casing	unknown	1	$0.00
Board Fabrication	$33.00	1	$33.00
On-Trailer Monitoring Unit			
Microcontroller	$0.00	1	$0.00
Wireless transceiver	$15.00	1	$15.00
IR backup sensors	$15.00	2	$30.00
Ultrasonic blind spot sensors	$30.00	3	$90.00
Current sensors (bulb monitoring)	$11.00	3	$33.00
Temp. Sensors	$2.00	2	$4.00
Door Sensor	$3.00	1	$3.00
Board Fabrication	$33.00	1	$33.00
Casing	unknown	1	$0.00
Cabling (for sensors)	$15.00	1	$15.00
Sensor attach hardware	$15.00	1	$15.00
Board Shipping Costs	$15.00	1	$15.00
Total			$319.50

This table shows the cost of each major component of our proposed system.   The total cost of $320 is reasonable as it will allow us some room in the budget to allow for any extra parts we did not foresee or for any mistakes in our initial design.   Cost permitting, we would like to construct cases for both the display unit as well as the on-trailer unit. The cost of such cases/enclosures was not included in the above cost analysis.

One important decision based upon the above cost analysis was to only implement one side of the blind spot detection in our prototyped device in May. Three sensors are required per side, and at $30 each that cost adds up quickly. We intend to design the on-trailer unit and the display unit to be capable of blind spot detection on both sides of the trailer; we simply will only purchase sensors for one side. If we have adequate funds at the end of the project we will purchase the sensors for the other side and plug them into the on-trailer unit.

Conclusion

After more closely examining each part of the proposed trailer towing assistance system, we now have a more detailed understanding of our entire system. By stating the requirements and choosing a technology for each functional block, we have more clearly defined our project and how we will approach it. Besides examining all available technologies for each functional block, it was extremely important to analyze the cost of each technology chosen to make sure the project will stay on-budget. In fact, the decision to only implement one side of the blind spot detection for the prototype in May was based solely on cost. Now that we have more specifically defined each functional block of our system, we look forward to choosing parts, designing circuits and performing the additional low level design necessary to continue to move this project forward.

References

1) IR sensors explained : http://www.acroname.com/robotics/info/articles/sharp/sharp.html#e2
2) Laser Information: http://www.dimetix.com/Products/EN/_FRM_DLS_B_EN.html
3) http://www.gmw.com/magnetic_sensors/ametes/CS.html
4) http://www.gmw.com/magnetic_sensors/sentron/csa/CSA-1.html
5) http://www.jameco.com/webapp/wcs/stores/servlet/ProductDisplay?langId=-1&storeId=10001&catalogId=10001&productId=482409
6) http://www.national.com/ds/LM/LM45.pdf
7) <http://focus.ti.com/docs/prod/folders/print/cc2420.html>
8) <http://www.mouser.com/search/refine.aspx?Msid=59500000&Mkw=CC2420RTC>
9) <http://www.maxstream.net/products/xbee/xbee-oem-rf-module-zigbee.php>
10) http://us.digikey.com/scripts/DkSearch/dksus.dll?Detail?name=102-1060-ND
11) http://www.acroname.com/robotics/parts/R287-SRF02.html