Homework 3: Design Constraint Analysis and Component Selection Rationale

Team Code Name: The Incredible HUD **Group No. 03**

Team Member Completing This Homework: Aditya Balasubramanian

E-mail Address of Team Member: abalasub@ purdue.edu

NOTE: This is the first in a series of four "professional component" homework assignments, each of which is to be completed by one team member. The body of the report should be 3-5 pages, **not** including this cover page, references, attachments or appendices.

Evaluation:

SCORE	DESCRIPTION
10	***Excellent*** *– among the best papers submitted for this assignment. Very few corrections needed for version submitted in Final Report.*
9	***Very good*** *– all requirements aptly met. Minor additions/corrections needed for version submitted in Final Report.*
8	***Good*** *– all requirements considered and addressed. Several noteworthy additions/corrections needed for version submitted in Final Report.*
7	***Average*** *– all requirements basically met, but some revisions in content should be made for the version submitted in the Final Report.*
6	***Marginal*** *– all requirements met at a nominal level. Significant revisions in content should be made for the version submitted in the Final Report.*
*	***Below the passing threshold*** *– major revisions required to meet report requirements at a nominal level.* ***Revise and resubmit.***

* *Resubmissions are due within* ***one week*** *of the date of return, and will be awarded a score of "6" provided all report requirements have been met at a nominal level.*

Comments:

1.0 Introduction

The Incredible HUD is a helmet-based heads-up-display (HUD) device. This motivation behind such a device is to augment the user's awareness about their surroundings while performing activities that would require the use of a helmet. This includes, but is not limited to – motorsport participants, extreme-sports enthusiasts and defense applications.

A laser-projector based display system will display relevant information to the user, such as speed, compass bearing, temperature, GPS information and a live video-feed from a camera pointed behind the user. The user will also be able to switch between different display modes, allowing him/her to control the amount of information displayed. All of these features should be seamlessly integrated into the helmet itself. Since this is a portable device, there will also be a battery pack, but due to the bulky and heavy nature of batteries, this component will sit off-helmet for comfort and safety reasons. To add further value to the GPS and telemetry data, it will be recorded on flash memory and stored. If the user wants, he/she can upload the data to a computer where the GPS coordinates will be plotted on a map, and the corresponding telemetry data overlaid on the map for post-journey analysis.

The design constraints associated with this project fall into three main categories: electrical specifications, optical performance and packaging.

Updated PSSCs:

1. An ability to display critical system information via a heads-up-display (HUD)
2. An ability to measure telemetry information (speed, acceleration, temperature, and GPS) and store it to flash memory.
3. An ability to maintain portability through the use of a rechargeable battery system
4. An ability to enable/disable important features within the display (full information, minimal, on/off).
5. An ability to plot recorded GPS data and telemetry data onto a map via computer.

Refer to **Appendix B** for the updated block diagram.

2.0 Design Constraint Analysis

To achieve the desired functionality of our device, several design constraints must be considered and overcome. As mentioned in the previous section, the three main categories under which relevant design constraints fall are electrical specifications, optical performance and packaging – and overlap between each category exists.

The electrical specifications for the design must remain relevant to the two major components of the electrical design – the motherboard, and the microcontroller. The microcontroller is responsible for polling each sensor for information at regular time intervals, assembling the information into packets, and transferring it to the motherboard via a USB or Serial port interface. Upon being received by the motherboard, the packets of data will be parsed and displayed on the HUD as needed. The packets will also be time-stamped and stored to flash memory for post-journey review. All of these processes must occur in synchronization, so that packets of information are parsed and time-stamped correctly. Our microcontroller, motherboard and flash memory need to be fast enough to assemble, process, and store packets of data multiple times a minute. The motherboard will also be responsible for handling the rear-view camera. In this mode, the HUD will display a feed from a video camera (a webcam) attached to the rear of the helmet, provided the user with what is essentially a 'virtual rear-view mirror', which is augmented with the telemetry data. The rear-view camera feature, combined with the fact that our display technology utilizes the VGA protocol led us to choose an Intel Atom (1.1 GHz) based motherboard. Since our device is intended to be portable, it also need to feature a battery with a large enough capacity to provide meaningful running time, and can be recharged as well.

The optical performance aspect of our design involves the display being sufficiently visible so as to be useful. It also must augment the user's perception of reality, but not impede or distort it. This will most likely have to be achieved using a combination of mirrors, lenses and plate beam splitters. All of this will have to be achieved without interfering with the other components of the design or making the helmet unwieldy.

The packaging design constraints will involve integrating all of the components mentioned above into the helmet. Depending on space limitations, the battery may have to be relocated off-helmet, perhaps into a backpack type device.

2.1 Computation Requirements

Computations will be carried out by the Atom board and the microcontroller. The Atom board will handle all of the video processing. This includes processing the rear-view camera video feed, handling the GUI elements of the HUD, and creating the VGA signal the laser projector needs to display the correct information. The Atom board will also be responsible for writing the telemetry data collected by the microcontroller to flash memory.

The computational requirements of the microcontroller relate mainly to the real-time collection of telemetry data and some light processing of the data into a more user-friendly format. The telemetry data from the GPS unit, accelerometer, and thermometer must be periodically collected ten times per second. This process yields latitude and longitude, raw thermometer data, and raw accelerometer data. Following this, the three analog-to-digital channels of the accelerometer and the three analog-to-digital channels of the thermometer must be translated into an equivalent, human-comprehensible format. After the accelerometer data is translated, it is possible to calculate the magnitude of the G-force sustained by the unit from the force vectors translated, yielding a G-force measurement.

It will also be necessary to process the latitude and longitude data to determine the direction of travel and average linear speed of the unit; direction will be determined by the unit vector from start point to end point and will be expressed as one of the sixteen (16) named points (N, NNE, NE, ENE, etc.). Speed calculations will be based on the linear distance traveled between the start point and end point and the time elapsed between measurements of the two points and will be expressed in miles per hour (MPH). GPS data will undoubtedly experience noise, resulting in a small degree of imprecision in measurement. In order to reduce the effect of noise on the measurement of speed and direction, the current location of the unit will be considered as the same location anywhere within a small sphere with a maximum radius of 10 meters surrounding the unit; the nominal size of this sphere will be determined by real-world testing of the unit. Because of this error correction, it may take as many as 7 seconds for a user walking casually in a straight line wearing the unit to notice a change in direction and speed, and, similarly, a user traveling approximately ten (10) miles per hour may notice the unit updating only once every two (2) seconds; for users traveling at these relatively slow speeds, this delay is not significant enough to merit a more advanced algorithm.

After telemetry data has been collected and processed, latitude, and longitude, temperature, G-force, direction, and speed information will be sent via RS232 connection to the Atom motherboard to be time-stamped and logged.

Rotary encoder and button-press actions must also be sampled periodically and translated into their corresponding functions, but the computational requirements and algorithms necessary are trivial at best.

2.2 Interface Requirements

The device will not have any major external interfaces. A debugging-over-Ethernet feature for the Atom board may be introduced if needed. The device will not be internet enabled and will not feature a live map feature. It was decided that it would be best not to overwhelm the user with too much information, especially when presented in a HUD format. The device is expected to be used in more hostile and extreme environments, where internet-connectivity is likely to be unreliable.

The charging voltage of the system will be known once a sufficiently large capacity battery (4500mAh) and charging circuit is found. The Atom motherboard and projector requires a 5V DC supply. The microcontroller, GPS module and various sensors all require a 3.3V DC supply.

2.3 On-Chip Peripheral Requirements

The on-chip peripheral requirements can be summarized in the following table.

Peripheral(s)	Type	Number of channels
Thermometer	ATD	1
Accelerometer	ATD	3
Microcontroller→ Atom board connection	RS-232 **or** USB	1/1
Rotary encoder	GPIO	2
Select/Back buttons	GPIO	2
Rear-view insta-select/Kill-switch	GPIO	2
Data collection algorithms & rotary encoder input decoding	TIM	2
Audio feedback to helmet (tentative)	PWM/ Atom	1/1

2.4 Off-Chip Peripheral Requirements

Our design is based on sensors that interface directly with the microcontroller, and any other interfacing is handled by the Intel Atom motherboard, needing any off-chip peripherals is not anticipated.

2.5 Power Constraints

In the interest of portability and modularity, our battery charging system will consist of removable rechargeable lithium-ion battery packs, which can be recharged using a charging station plugged into A.C. power. The microcontroller and sensors will be powered via USB from the Atom motherboard. This will reduce the need for additional power circuitry, reducing noise and space requirements. The laser-pico projector is specifically designed to be powered via USB, so the Atom motherboard will provide power for that as well. All together, the Atom board is expected to consume about 0.4A and adding on the projector (1A), USB webcam, microcontroller and sensors, total current consumption can be expected to be 1.5A peak. This, added to our desired runtime of approximately 3 hours, will require a battery of approximately 4500mAh.

The three major sources of heat generation will be the Atom motherboard, projector and GPS module. Packaging these components appropriately through the use of heat sinks, and proper placement will allow addressing heat dissipation issues.

2.6 Packaging Constraints

The main packaging concern is to contain as much of the hardware on the helmet itself. This includes the Atom motherboard which will be mounted on the outside of the helmet, and the lithium ion battery pack. The location of the battery pack will depend on the capacity of battery needed and used.

Additionally, to make the device suitable for extreme and hostile environments, it needs to be water-resistant, dust-resistant and impact-resistant. The challenge will be incorporating these features while allowing for appropriate levels of heat dissipation.

2.7 Cost Constraints

There does not seem to be any direct competitor to the device. The closest competitors come in the form of either HUD-enabled ski goggles by Transcend ($350), or an extremely basic HUD that is a helmet add-on by Sportvue (price n/a). Both of these devices optically inferior to the Incredible HUD because they are diopter based, which requires the user to refocus their eyes every time they look at the display. The ski goggles have similar functionality in terms of data logging and telemetry displayed, but the helmet add-on is capable of displaying only speed and a rev-counter, and is quite inaccurate in doing so. Since the Incredible HUD is a novel device using bleeding-edge display technology ($300), the costs are understandably high. A target price of $1000 or less is ideal. This cost will obviously decrease if mass production is implemented.

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3.0 Component Selection Rationale

The two main choices for the display technology were either an Optoma LED pico-projector or Microvision SHOWX+ Laser pico-projector. They were both attractive because they were small; USB powered, and had relatively high resolutions (WVGA).

The Optoma has a slightly brighter output (20 lum. vs. 15 lum.) but it is also heavier (40 grams heavier). This may not seem significant, but when the additional weight is pivoted about ones' neck, it is noticeable. Additionally, the Optoma uses LED based projection technology, which requires manual focusing. The two main choices for the display technology were either an Optoma PK201 LED pico-projector, or Microvision SHOWX+ Laser pico-projector. They were both attractive because they were small; USB powered, and had relatively high resolutions (WVGA).

The Optoma has a slightly brighter output (20lum. vs. 15 lum.) but it is also heavier (40 grams heavier) and larger. This may not seem significant, but when the additional weight is pivoted about ones' neck, it is noticeable. Additionally, the Optoma uses LED based projection technology, which requires manual focusing, and has moving parts and is therefore less rugged. The Microvision however, is completely solid-state. The Microvision projector is quite popular, and has a lot of hobbyist documentation unlike the Optoma, making it easier to determine the inner workings of it without actually buying one. The Optoma also had a lot of unnecessary features such as built-in media playback and flash storage. Ultimately, it was determined that the Microvision projector was the superior choice.

When choosing the motherboard, the main design constraints included low power consumption, small size and video-processing capable (VGA output and rear-view camera handling). Fairly robust packaging (case/shield) was also a desired feature. Most of the ARM based boards considered had low-power consumption. The ARM Cortex A8 based Beagle Board pulls about 2W, but has a clock speed of only 600MHz, and supports only UNIX based OSes. In addition to that, because custom UNIX distributions need to be compiled and run on the Beagle Board, driver support is not guaranteed. On the other hand, the Atom board also pulls 2W of power, but clocks at 1.1GHz, has support for standard UNIX distributions and Windows Embedded 7, and has significantly better driver support. Additionally, the Atom boards have much better standard packaging solutions, so custom case fabrication is not required, which the Beagle Board would most likely require.

Atmel and PIC microcontrollers were considered for use in the device. The features desired for comparison are as follows:

- At least 8 AtD channels (4 plus 4 extra for safety)
- At least 8 GPIO pins
- At least 2 timers
- At least 3 UART/RS232 connections
- At least one SPI
- At least 10 kHz operation (1000 operations every $1/10^{th}$ of a second)
- At least 16kB and ideally 32kB of SRAM for data buffers, etc.
- USB support (optional but a plus)

A wide selection of PIC microcontrollers exist meeting these specifications and Atmel microcontrollers consistently lacked one or more of the features desired; this led to the selection of a PIC. The PIC microcontroller which meets the desired specifications most closely is a PIC24FJ64GB106; however, a PIC32MX564F128L was chosen, as it met all the desired requirements plus extra in all respective categories. In the event an unexpected redesign becomes necessary in the development phase, this was deemed a desirable quality. The PIC32 was also given higher precedence over the PIC24 due to the superior programming libraries available and easier programmability in general; the team's prior experience with programming PIC32 microcontrollers was a large factor supporting the PIC32 over the PIC24.

4.0 Summary

In summary, main purpose of the device is to provide the user with an augmented view of their immediate surroundings via a helmet-based heads-up-display. The helmet will be able to sense various parameters, store them to flash memory to allow the data to be plotted on a map via a computer. The various design constraints and how they relate to design choices and component selection was also highlighted.

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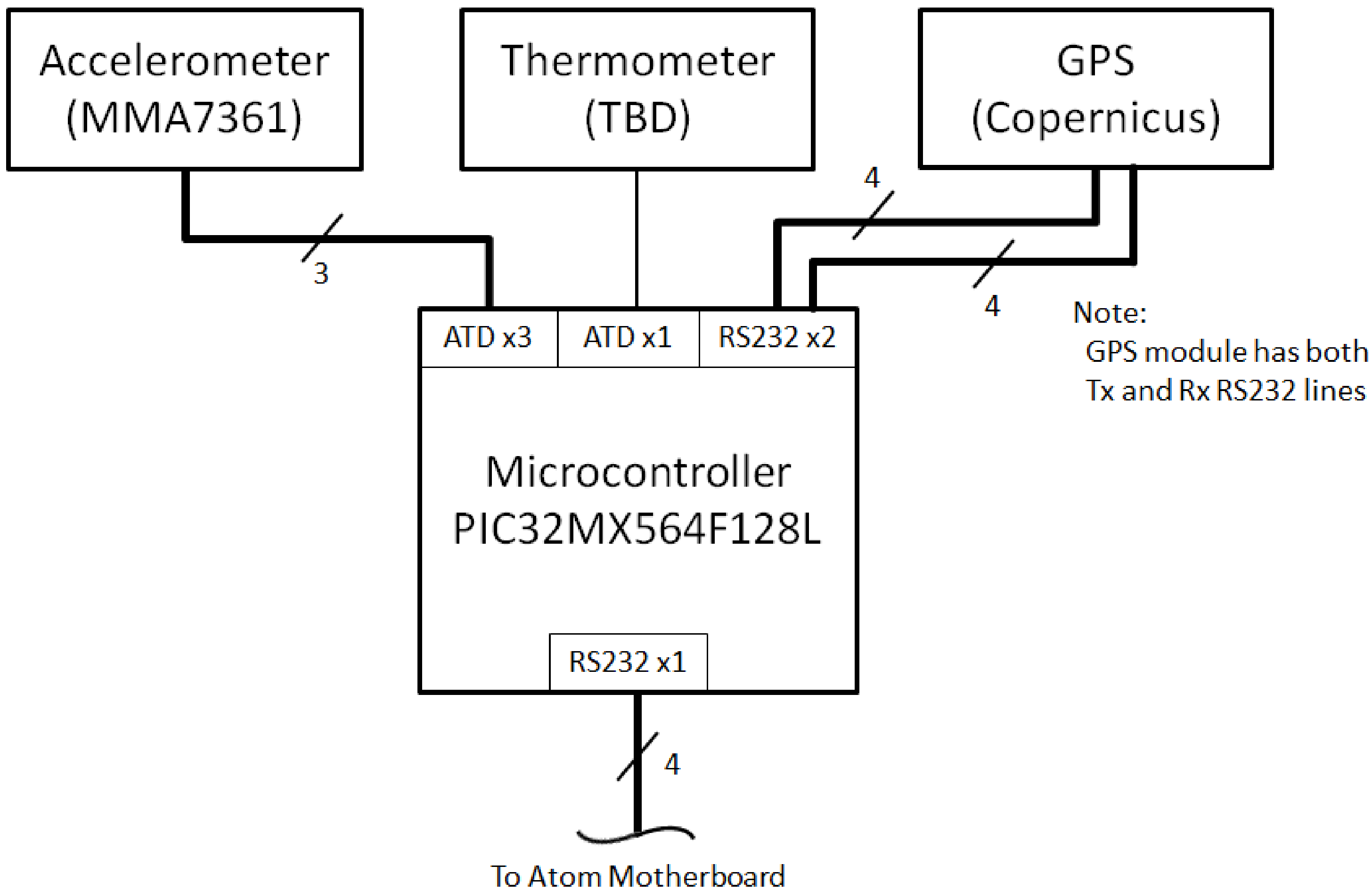
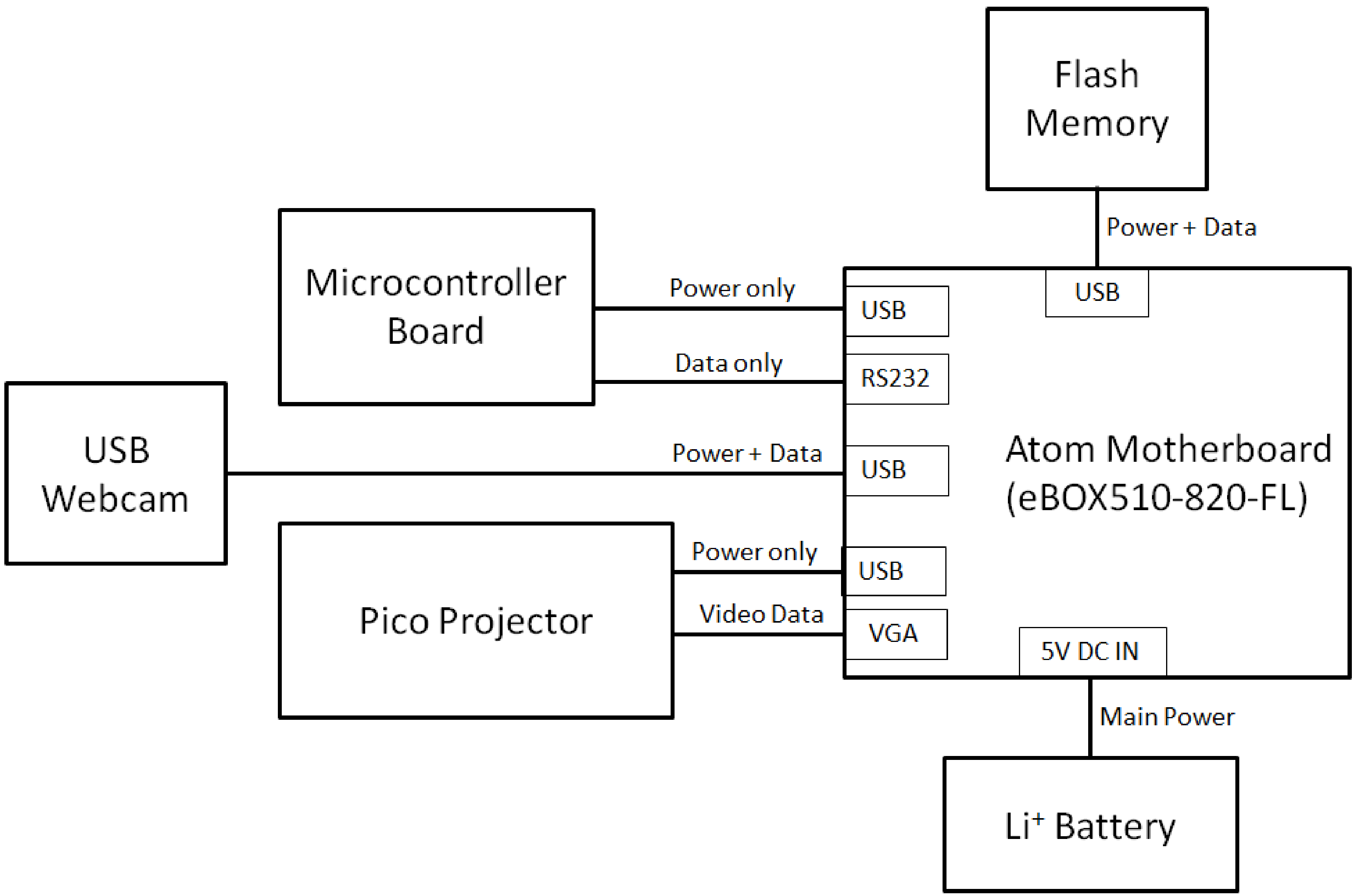
Appendix A: Parts List Spreadsheet

Vendor	*Manufacturer*	*Part No.*	*Description*	*Unit Cost*	*Qty*	*Total Cost*
Microchip	Microchip	PIC32MX564F128L	32-bit microcontroller	samples	6	0.00
Sparkfun	Trimble	GPS-08146	Copernicus™ GPS - DIP	$74.95	1	+s&h
Sparkfun	Onshine	GPS-00464	GPS Antenna - Magnetic	$12.95	1	12.95+s&h
Sparkfun	Freescale	SEN-09652	3-axis Accelerometer	$19.95	1	19.95+s&h
Sparkfun	TI	TMP102	Thermometer IC	$9.95	1	+s&h
Orbit Micro	Intel	eBOX510-820-FL	1.1GHz + 8GB Flash + 2GB DDR	subsidized	1	0.00
Amazon	Microvision	SHOWX+ TM	WVGA laser pico-projector	$298.00	1	$298.00
Ebay	N/A	JX-F603-CARBON FIBER- XXL	TMS Motocross Racing Helmet	$35.00	1	$35.00
				TOTAL		**$450.80**

Appendix B: Updated Block Diagram




Flash
Memory
Power + Data
USB
Microcontroller
Board
Power only
USB
Data only
RS232
USB
Webcam
Power + Data
USB
Atom Motherboard
(eBOX510-820-FL)
Pico Projector
Power only
USB
Video Data
VGA
5V DC IN
Main Power
Li+ Battery