Homework 3: Design Constraint Analysis and Component Selection Rationale

**Team Code Name**: Augmented Reality Project\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ **Group No.** \_\_5\_\_\_

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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:**

|  |  |  |  |
| --- | --- | --- | --- |
| SEC | DESCRIPTION | MAX | SCORE |
| 1.0 | Introduction (including updated PSSC) | 10 |  |
| 2.0 | Design Constraint Analysis | - |  |
| 2.1 | Computational Requirements | 10 |  |
| 2.2 | Interface Requirements | 5 |  |
| 2.3 | On-Chip Peripheral Requirements | 10 |  |
| 2.4 | Off-Chip Peripheral Requirements | 5 |  |
| 2.5 | Power Constraints | 5 |  |
| 2.6 | Packaging Constraints | 5 |  |
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| 3.0 | Component Selection Rationale | 20 |  |
| 4.0 | Summary | 5 |  |
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| App A | Parts List Spreadsheet | 5 |  |
| App B | Updated Block Diagram | 5 |  |
|  | TOTAL | 100 |  |

**Comments:**

1. Introduction

We propose an Augmented Reality Simulator that allows at least one user to play an electronic game in a mobile, outdoor environment. This simulator will be divided into two parts. A central control unit will coordinate the simulation logic while per-player headsets will overlay appropriate game-object pixels on a semi-transparent panel that is suspended in front of the users’ eyes. This product is intended to be used for gaming and other potential simulations that require an augmented environment.

Project specific success criteria:

* An ability to render graphics based on the orientation of the user’s head.
* An ability to render graphics based on the user’s current geospatial location.
* An ability to monitor and display the battery power level of the headset to the user.
* An ability to monitor and display the status and quality of the wireless connection to the central control unit.
* An ability to load headset graphics for a new simulation without re-flashing software on the headset’s microcontroller.

1. Design Constraint Analysis

Augmented reality means that the user will wear the device, so the most important constraints include the packaging, power management, and convenience of the headset. Fluctuating CPU processing demand presents challenges for graphics and microprocessors, but the self-contained nature of the project relaxes requirements on general purpose I/O and isolation/signal drive. The central control unit will perform fewer tasks and thus has limited real-time and power constraints.

* 1. Computation Requirements

The microcontroller component of the headset must handle the wireless communication and all of the sensors installed, as detailed in Table 1. The most intensive task of the microcontroller will be decoding and filtering the 9-DOF IMU data describing the orientation of the user’s head. Since this requires floating point math and must run at a constant rate for best results, this task imposes strong real-time constraints. String processing will be required on the GPS data to turn the NMEA strings into latitude and longitude coordinates.

Table : Computational tasks and real-time constraints for headset and central control unit

|  |  |  |  |
| --- | --- | --- | --- |
| Task | Runs on | Data Rate | Jitter Requirement |
| IMU filtering | Microcontroller | 800 Hz | 5 us |
| GPS string parsing | Microcontroller | 20 Hz | None |
| Wireless communication | Microcontroller | 11.5 KB/s | 1 ms |
| Battery monitoring | Microcontroller | 1 Hz | None |
| Graphics rendering | Headset GPU | 30 Hz | 5 ms |
| Simulation logic | CCU | Varies | Varies |

Wireless communication will require parsing packets received, but data reception rates will be limited to 115200 baud by the wireless module [1]. The wireless signal level and battery level will only be checked once per second to save CPU time. Interrupt processing can be reduced due to the DMA support on many microcontrollers [2], which can automatically transfer SPI, UART, or I2C data to and from memory and interrupt only when a fixed number of bytes have been processed.

On the dedicated headset GPU board, the only task will be performing GPU rendering. As the GPU is designed for this task, it should be able to render at the required 30 Hz for screen updates. The GPU will receive data over SPI which can be processed in parallel with rendering. The central control unit has to handle only wireless communication and simulation logic, so it has few real-time processing constraints. CPU usage will depend on the complexity of the active simulation.

* 1. Interface Requirements

General purpose I/O requirements are relaxed on both the headset and the central control unit. The motherboards on both units will not interface over their GPIO. Microcontroller pins will also not be used to drive loads and can be placed in reduced drive mode to conserve power. Since all peripherals are supplied with 3.3 V, processors with 3.3 V levels are preferred to satisfy peripheral voltage level constraints. Only the USB charging port will have external connections, minimizing the need for isolation; only a diode is required for electrostatic discharge suppression.

* 1. On-Chip Peripheral Requirements

On the headset, the microcontroller must be able to handle each sensor connection as shown in Appendix B, Block Diagram and Table 2. The connection to the external GPU will be handled via SPI, requiring five dedicated pins for clock, data in, data out, data ready, and chip select. An I2C bus will be used for both the inertial measurement unit [3] and the battery monitor chip [4]. Two UART ports will be used for the GPS [5] and wireless units; while the GPS port needs only to receive data, the wireless port must be bidirectional, for a total of three additional pins.

Table : Required on-chip microcontroller peripherals for headset

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Device | Peripheral | Special Features | Minimum Speed | Pin Count |
| External GPU | SPI | Master Mode, Chip Select | 800 KHz | 5 |
| GPS | UART |  | 115.2 Kbaud | 1 |
| Battery Monitor | I2C | Open-Drain, Current Sink | 400 KHz | 2 |
| IMU | I2C | Open-Drain, Current Sink | 400 KHz | 2 |
| Wireless | UART | Full Duplex | 115.2 Kbaud | 2 |
| Future Expansion | GPIO | Configurable Data Direction | N/A | 10 |
|  |  |  | **Minimum Pins:** | 22 |

The headset GPU motherboard must have a compatible SPI port to interface with the microcontroller over SPI as described above. It also must support a standard display output such as VGA, composite, or HDMI for rendering to a commercially available screen. A second available standard interface such as USB or UART will also be preferred to allow for future expansion to input devices worn by the user for more advanced simulations.

The central control unit motherboard will require a USB port for a keypad for initial user configuration input. It must have either a dedicated UART capable of 115200 baud or another USB port to connect to the wireless communication device. A standard display output such as VGA, composite, or HDMI will also be required to provide initial user configuration feedback.

* 1. Off-Chip Peripheral Requirements

To satisfy the project criteria, a GPS unit, wireless communication, inertial measurement unit (IMU), and battery monitor chip must be installed on the headset. The GPS unit should be able to function in a difficult landscape with minimal loss of accuracy. GPS update rate is also important to bring real-time screen updates, but time to first fix is not a concern. Almost all GPS units interface over a standard UART interface. The IMU determines the orientation of the user’s head using three 3-axis sensors: a gyro, an accelerometer, and a compass. Low noise and good resolution are important for increased orientation accuracy, and the IMU must interface over SPI or I2C.

Wireless communication keeps the central control unit and the headset connected throughout the simulation. High reliability and low latency are paramount to meet the real-time requirements of the simulation. The wireless device must also transmit at least 6-8 KB per second of data and must be able to report the signal quality and strength. A range of 150 yards line of sight will handle most simulations, but longer ranges, especially near obstructions, will add a variety of usable simulations. Battery monitoring components must provide either an alert pin or preferably an estimate of capacity remaining, but they should not use a current sense resistor as the heat dissipation and quantization error of most coulomb counting approaches would be unacceptable.

For the central control unit, a wireless communication device compatible with the headset and user input devices must be installed. The user input device must be interfaced over an available motherboard USB port and must have a comparable size to the motherboard. As a regular computer keyboard would be bulky, a simple numeric keypad will be adequate.

* 1. Power Constraints

Power will be significantly limited on the headset, as it will run on a lightweight single lithium ion cell worn by the user. The biggest power consumer will be the GPU and display used to render images. Adjustable display brightness will be used to reduce power requirements. The wireless radio and GPS also consume power at a low duty cycle to send and receive data. By comparison, the current draw of the microcontroller, inertial measurement unit (IMU), and battery monitor is negligible. The headset aims to waste no more than 1 watt as heat to increase battery life. Low-dropout regulators are required since no available switch-mode regulator can efficiently convert a battery voltage as low as 3.7 V to the core 3.3 V supply as shown in Table 3.

Table : Power supply constraints and supply rails in use on headset

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Supply Rail | Voltage | Current Supplied | Current Use | Peripherals Powered |
| Vcore | 3.3V LDO | 800 mA Low-ripple | 500 mA | GPU Motherboard |
| VMCU | 3.3V LDO | 500 mA | 350 mA | Microcontroller, Wireless, GPS |
| VADC | 3.3V LDO | 50 mA Low-noise | 30 mA | IMU |
| VDISPLAY | 5V Boost | 500 mA | 300 mA | Display, USB |

Power consumption is not a significant factor on the central control unit motherboard, as it will be AC powered via a USB wall wart. Active cooling is inconvenient to install, so the heat dissipation must be low enough to be adequately managed by passive cooling systems.

* 1. Packaging Constraints

The headset is designed to be portable and worn by the user. Of the peripherals in use, the display, inertial measurement unit, and antennas must be placed on the user’s head. An adjustable mount for the half silvered mirror and reflection shield must be provided to allow users with different eyesight to position the device for optimal viewing conditions. The device should be packaged in one unit without exposed wires, as non-technical users should not be expected to plug in parts. Packaging must be able to withstand the vibration and impacts that are inevitable for wearable electronics, and must be able to tolerate outdoor temperatures.

The central control unit has fewer size restrictions as it will remain stationary throughout gameplay. It must be durable enough to withstand outdoor temperatures. Any packaging materials selected must also be compatible with the antenna to avoid signal reflections that could reduce the range of the headsets. The central control unit should have a simple keypad interface to ensure casual users can simply select a simulation and start immediately.

* 1. Cost Constraints

While cost is a consideration when differentiating between similar parts, cost is not an overriding constraint at this time and is secondary to other design constraints. A soft limit of $250/headset and $100/CCU was used to guide parts selection, as competing products are generally very expensive even in quantity. For example, Google Glass [6], a product with higher quality compact optics, is currently priced at $1500, and several other augmented reality products such as ARQuake [7] and CastAR [8] have not left development.

1. Component Selection Rationale
   1. **Microcontroller**

Processing power, particularly with floating point, is the biggest concern for microcontroller selection. Even with the removal of graphics, high-speed filtering is required for the IMU. Direct memory access peripherals can help ease the data movement strain. Current consumption is secondary as other devices dominate the power use. With these constraints set, only a few choices remain as shown in Table 4, all of which meet constraints for on-chip peripherals and pin count:

Table : Most viable microcontroller choices for headset

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Part | I/O | RAM | Flash | Clock | DMA | Special Features | Cost |
| STM32F405RGT6 | 51 | 192K | 1M | 168MHz | 16 | Floating Point Unit | $11 |
| PIC32MX695F512H | 53 | 128K | 512K | 80MHz | 8 |  | $10 |

The STM32F405 chip was chosen due to the availability of a low cost $15 development board and its very high computational performance, particularly with single cycle floating point operations. This device features extra RAM and processing power for future expansion.

* 1. **Motherboard/Graphics Processing Unit**

As the GPU motherboard is the largest power consumer on the headset, low power consumption is mandatory. Small size and light weight is also important for a portable device. Since any dedicated GPU vastly outperforms the microcontroller, relative performance is not a concern. The motherboard should also feature a USB port and SPI interface, as this project aims to re-use the same part on the central control unit to reduce development effort.

Table : Most viable central control unit motherboard/headset GPU choices

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Part | Idle Power | RAM | USB | SPI | Clock | Cost (board) |
| Raspberry Pi Model A | 2 W | 256M | 1 | 1 | 700MHz | $25 |
| BeagleBone Black | 2 W | 512M | 1 | 2 | 1GHz | $45 |
| Intel Atom Board | 12 W | 2G | 4 | 1 | 1.8GHz | $150 |

As shown in Table 5, the Raspberry Pi Model A was chosen for its low power consumption, cost, and outstanding community support. Examples exist all over the Internet for handling tasks on the Raspberry Pi, whereas the BeagleBone Black is fairly new. The added power use of an Intel Atom board does not justify increased performance which is unnecessary for this project.

* 1. **Inertial Measurement Unit**

Due to advancements in MEMS technology, most inertial measurement units provide excellent noise performance and accuracy. Power consumption is not an issue as most units draw little current. A breakout board must be available since most IMUs come in LGA packages.

Table : Most viable choices for 9-degree of freedom inertial measurement unit

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Part | Gyro | Accelerometer | Compass | Resolution | Cost (board) |
| STEVAL-MKI108V2 | L3GD20 | LSM303DLHC | LSM303DLHC | 16/16/12 | $27 |
| MPU-9150 | MPU-9150 | MPU-9150 | MPU-9150 | 16/16/13 | $50 |

As seen in Table 6, the slightly increased resolution of the MPU-9150 is offset by its cost and lack of documentation, particularly for the use of its powerful internal filtering algorithms. The cheaper SGS Thomson part was chosen instead.

* 1. **GPS Receiver**

Past groups often experienced problems with low resolution and slowly updating GPS. The real-time constraints of this project call for a fast and high-resolution receiver module. Power consumption is a concern, but most available modules draw similar amounts of power.

Table : Most viable choices for GPS receiver, with typical smartphone GPS shown for comparison

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Part | Resolution | Update Rate | Accuracy | Antenna | Power Use | Cost |
| Venus638FLPx | ~0.3m | 20Hz | 2m | External | 29 mA | $50 |
| GP-635T | ~1m | 5Hz | 2m | Integrated | 56 mA | $40 |
| (Smartphone) | ~5m | 1-5Hz | 10m | Integrated | N/A | Varies |

The recently released Venus638FLPx vastly outperforms comparable units due to its excellent resolution and astonishing 20Hz update rate as shown in Table 7. Real-world tests confirm the superior signal quality of external antennae. Smartphone data is provided for comparison.

* 1. **Wireless Communication**

This project initially planned to use XBee wireless radios, as these have the required low latency and acceptable data rates as shown in Table 8. In addition, these modules interface easily over UART. Range tests, however, indicate that unrealistically tall antennas are required to obtain the advertised range.

Table : Most viable wireless communication strategies between headset and central control unit

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Part | Data Rate | Range (LOS) | Latency | Cost |
| XBee Pro 900HP | 11.5 KB/s | 300 m | 50ms | $40 |
| Bluetooth and Cell Phone Radio | 100+ KB/s | 2000+ m | 500ms | $30 |

Despite the range and data rate advantages of offloading wireless to a cell phone and communicating to the phone over Bluetooth, the latency in tests was shown to be unacceptable. Cell phone signal reliability also left much to be desired, meaning that the XBee Pro will still be used. The low range, especially near obstacles, places emphasis on the signal quality indicator.

1. Summary

Our proposed project, an augmented reality simulator, aims to display an image to the user that adapts to their position and direction. A headset with an inertial measurement unit, GPS receiver, and dedicated GPU board will be interfaced with a powerful microcontroller to handle the computational constraints. This headset must be lightweight and packaged suitably to be worn by the user. At the same time, a battery monitor will ensure that the battery is not depleted during use, and strict constraints on power consumption must be navigated to attain acceptable battery life. Actual simulation logic will be delegated to a stationary central control unit communicating over a virtual serial wireless link to allow for complex games and multiple headset users. The cost of this system is affordable for prototyping and compares well with similar products.

**5.0 List of References**

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6. Olsson, et al., "Wearable device with input and output structures" U.S. Patent 20130044042, Aug 18, 2011
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Appendix A: Parts List Spreadsheet

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| *Vendor* | *Manufacturer* | *Part No.* | *Description* | *Unit Cost* | Qty | *Total Cost* |
| Digi-Key | SGS Thomson | STM32F405RGT6 | Microcontroller | 11.45 | 1 | $11.45 |
| Digi-Key | Digi Corporation | XBee Pro 900HP S3B | Wireless Communication Device | 39.00 | 2 | $78.00 |
| Digi-Key | Miscellaneous | N/A | Passive components | 10.00 | 1 | $10.00 |
| Digi-Key | SGS Thomson | STEVAL-MKI108V2 | Inertial Measurement Unit 9-DOF | 27.60 | 1 | $27.60 |
| SparkFun | OnShine | ANT-555 | GPS Antenna RP-SMA | 12.95 | 1 | $12.95 |
| SparkFun | SkyTraq Technology | Venus 638FLPx | Global Positioning System Receiver | 49.95 | 1 | $49.95 |
| Adafruit | Unknown | N/A | Composite Input Display 4.3” | 49.95 | 1 | $49.95 |
| Newark | Raspberry Pi Foundation | Model A | Central Control Unit Motherboard and Headset GPU Motherboard | 25.00 | 2 | $50.00 |
| Newark | Miscellaneous | N/A | Wall Supply/SD cards for Raspberry Pi | 12.00 | 1 | $12.00 |
| Newark | L-Com | HG905RD-RSP | Wireless Antenna | 19.28 | 2 | $38.56 |
| Micrel | Micrel | MIC5216 | Regulator LDO 500mA MSOP-8 | 0.00 | 2 | $0.00 |
| Micrel | Micrel | MIC5219 | Regulator Low Noise LDO SOT-23-5 | 0.00 | 1 | $0.00 |
| Maxim IC | Maxim IC | MAX17043 | Voltage Based Battery Fuel Gauge | 0.00 | 2 | $0.00 |
| Microchip | Microchip | MCP73831 | Linear Charge Management Controller | 0.00 | 1 | $0.00 |
| TOTAL | | **$340.46** |

NOTE: Prices are for one (1) central control unit and one (1) headset.

Appendix B: Updated Block Diagram

