May 14-05
Augmented Reality Accessory for Firearm Target Practice
Design Document

Alec Jahnke
Brock Mills
Collin Gross
Dan Roggow
Scott Schmidt
Travis Mallow

Table of Contents

Project Overview

Problem Statement:

Often, when training with a firearm without help, it can be difficult to analyze one's individual technique, especially when the only feedback available is how many holes are in the target after a round of shooting. The target cannot provide information about shots that missed. Our solution will provide a shooter with this missing information. The product will consist of a hardware device, as well as a software application targeted at Android and iOS mobile platforms. The device will attach to a firearm via a standard picatinny rail mount and will snap a picture every time the weapon is fired. The image is then transmitted via Bluetooth to the user's mobile device, where it is processed. After processing completes, the mobile application will display an image of the target with the estimated locations of the bullets highlighted. The shooter obtains immediate feedback, allowing corrective actions to taken promptly.

Operating Environment:

The firearm attachment will operate in an outdoor environment. This means it will be subject to the elements such as wind, dust, heat, cold, and varied forms of precipitation. Additionally, the firearm attachment will be exposed to extreme changes in acceleration during the firing sequence, and potentially gunpowder residues and other byproducts from the discharge of the weapon.

Intended Uses and Users:

At the most basic level, the system is designed for any firearm user who would like feedback on how well he or she is shooting. Possible users include:

- Individuals who would like to improve their shooting,
- Instructors who would like an alternative way to evaluate pupils as well as provide them with feedback, and
- Law enforcement officers who need to provide justification for discharging their weapon.

End Product Deliverables:

The following items will be delivered:

- A Project Plan.
- This Design Document.
- A prototype device.
- Schematics for the device casing.
- The PCB schematics for the device internals.

System Requirements

Design Requirements Overview:

Functional Requirements:

Functional requirements are operations and activities that a system should perform in order to meet the specific demand that is placed on the product. The functional requirements for this device have been listed below:

1. The device must connect to a mobile phone via Bluetooth.
   1.1. Bluetooth is a short-range radio protocol in the ISM band from 2400 – 2480 MHz.
2. The device must be able to be calibrated (zeroed).
   2.1. It is important for the user to be able to calibrate the mounted device to properly align with the target in order to achieve optimal results.
3. Device must mount on a picatinny rail compliant with MIL-STD-1913.
4. The application software must be compatible with both Android and iOS devices.
5. The application software must apply image processing techniques to the images received from the device and display the results to the user in an appropriate manner.
6. The system must have an operational range from 3-50 yards.
7. Device must be able to correctly operate when attached to the firearm on the top of the barrel, on either side of the barrel, and underneath the barrel.

Non-functional Requirements:

1. Device fabrication cost shall be no more than $60.00 (US).
2. Device shall be able to withstand forces associated with the normal operation of firearms.
3. Device shall be water resistant.
4. Device shall be powered by 1 Li-Ion battery.
5. Device shall not exceed the dimensions 3.0” (L) x 1.0” (W) x 1.5” (H)
6. Device shall not exceed a weight of 4 ounces.
   6.1. The device must be as light as possible in order to reduce the impact on the ballistics properties of the unmodified firearm.

System Block Diagram:

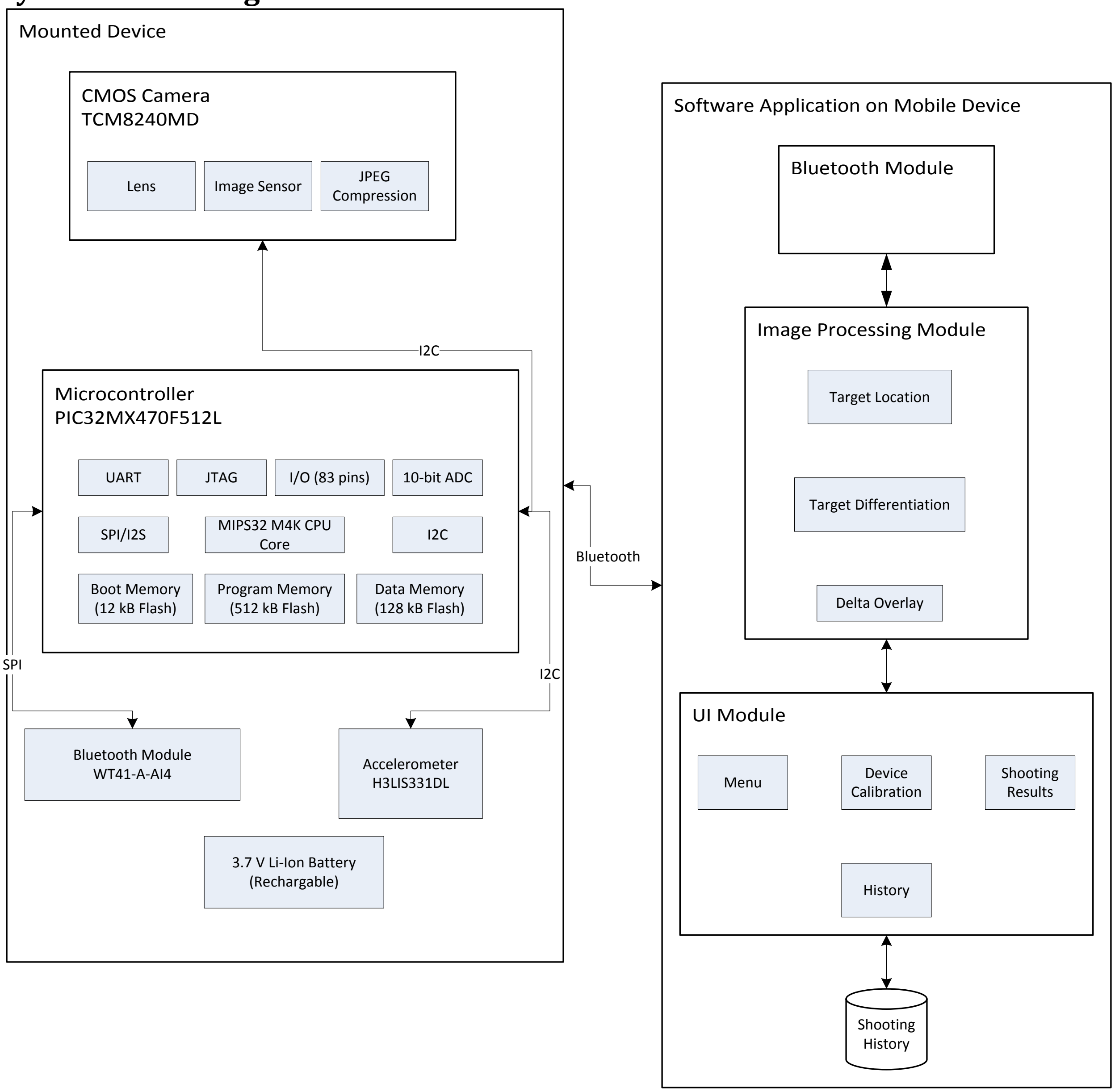

Figure 1 - System Overview

Design Specifications:

Input/Output Specification:

Bluetooth
The device communicates to the mobile platform via Bluetooth v2.1.

User Interface Specification:

Device

- On/off switch.
- Picatinny rail mount.
- Replaceable battery.

Hardware Specification:

Camera: **Toshiba TCM8240MD**

1. General

- Large flexibility in external clock frequency range by PLL operation
- (JPEG is not available in case of w/o PLL operation)
- Frame rate: up to 15 fps for every resolution
- Output data rate reduction for full 1.3 Mega resolution by JPEG compression
- Dual power supply: Either 2.5+/-0.2V or 2.8 +/- 0.2 V, and 1.6+/-0.1V
- Operation temperature: -20 to + 60 degree C
- Storage temperature: -30 to +85 degree C
- Dimensions: 10mm x 10mm x 7mm

2. Sensor

- Optical size: 1/3.3 inch optical format
- Effective pixel numbers: 1300(H) x 1040(V)
- Output pixel number: 1280(H) x1024 (V) maximum
- Pixel pitch: 3.3um(H)x3.3um(V) (square pixel)
- Image size: 4.29 mm(H) x 3.43mm(V)
- Color filter: Primary color filter, Bayer arrangement
- Rolling shutter

3. Camera signal processing

- Digital output mode
- Output terminals: 8bit parallel data output along with DCLK, HBLK, and VBLK
  - YUV=4:2:2 or RGB=5:6:5 data (multiplexed 8bit parallel output
  - JPEG encoded data (8 bit parallel) for full 1.3 Mega data
- Multi-step digital zoom for downsized VGA, QVGA, QQVGA, CIF, QCIF and subQCIF
- Vertical and horizontal flip

- ALC (automatic luminance level control) with fluorescent flicker-less operation
- AWB (automatic white balance)
- Automatic blemish detection and correction
- Strobe pulse for flash trigger

Microcontroller: Microchip PIC32MX470F512L

- Dimensions: 14mm x 14mm x 1mm

Operating Conditions

- 2.3V to 3.6V, -40ºC to +105ºC (DC to 80 MHz), -40ºC to +85ºC (DC to 100 MHz)

Core: 100 MHz/131 DMIPS MIPS32 ® M4K ®

- MIPS16e ® mode for up to 40% smaller code size
- Code-efficient (C and Assembly) architecture
- Single-cycle (MAC) 32x16 and two-cycle 32x32 multiply

Clock Management

- 0.9% internal oscillator
- Programmable PLLs and oscillator clock sources
- Fail-Safe Clock Monitor (FSCM)
- Independent Watchdog Timer
- Fast wake-up and start-up

Power Management

- Low-power management modes (Sleep and Idle)
- Integrated Power-on Reset, Brown-out Reset, and High Voltage Detect
- 0.5 mA/MHz dynamic current (typical)
- 50 µA I PD current (typical)

Advanced Analog Features

- ADC Module:
  - 10-bit 1 Msps rate with one Sample and Hold (S&H)
  - Up to 28 analog inputs
  - Can operate during Sleep mode
- Flexible and independent ADC trigger sources
- On-chip temperature measurement capability
- Comparators:
- Two dual-input Comparator modules
- Programmable references with 32 voltage points

Timers/Output Compare/Input Capture

- Five General Purpose Timers:
  - Five 16-bit and up to two 32-bit Timers/Counters
- Five Output Compare (OC) modules
- Five Input Capture (IC) modules
- Peripheral Pin Select (PPS) to allow function remap

- Real-Time Clock and Calendar (RTCC) module

Communication Interfaces

- USB 2.0-compliant Full-speed OTG controller
- Up to five UART modules (20 Mbps):
    - LIN 1.2 protocols and IrDA ® support
- Two 4-wire SPI modules (25 Mbps)
- Two I 2 C modules (up to 1 Mbaud) with SMBus support
- PPS to allow function remap
- Parallel Master Port (PMP)

Direct Memory Access (DMA)

- Four channels of hardware DMA with automatic data size detection
- 32-bit Programmable Cyclic Redundancy Check (CRC)
- Two additional channels dedicated to USB

Input/Output

- 15 mA or 12 mA source/sink for standard V_{OH} /V_{OL} and up to 22 mA for non-standard V_{OH1}
- 5V-tolerant pins
- Selectable open drain, pull-ups, and pull-downs
- External interrupts on all I/O pins

Debugger Development Support

- In-circuit and in-application programming
- 4-wire MIPS ® Enhanced JTAG interface
- Unlimited program and six complex data breakpoints
- IEEE 1149.2-compatible (JTAG) boundary scan

Accelerometer: STMicroelectronics H3LIS331DL

- Wide supply voltage, 2.16 V to 3.6 V
- Low-voltage compatible IOs, 1.8 V
- Ultra-low power consumption down to 10 µA in low-power mode
- ±100g/±200g/±400g dynamically selectable full scales
- I 2 C/SPI digital output interface
- 16-bit data output
- Sleep-to-wakeup function
- 10000 g high-shock survivability
- ECOPACK ® , RoHS and “Green” compliant
- Dimensions: 3mm x 3mm x 1mm

Bluetooth: Bluegiga WT41-A-AI4

- Fully Qualified Bluetooth v2.1 + EDR end product, CE and FCC and IC
- TX power: 18 dBm

- RX sensitivity: -90 dBm
- Highly efficient chip antenna, U.FL connector or RF pin
- Class 1, range up to 800 meters
- Industrial temperature range from -40° C to +85° C
- RoHS Compliant
- USB interface (USB 2.0 compatible)
- UART with bypass mode
- 6 x GPIO
- 1 x 8-bit AIO
- Support for 802.11 Coexistence
- Integrated iWRAP TM Bluetooth stack or HCI firmware
- Dimensions: 35mm x 14mm x 3.5mm

Power: **3.7V Li-Ion battery**

- Capacity: 2200mAh
- Voltage: 3.7V
- Dimensions: 69mm Height x 19mm Diameter
- Weight: 1.9 oz
- Maximum charge current: 6 A
- Discharge current: 3.5A
- Cut off voltage:
- Over-Charge Protection: 4.35V
- Over-Discharge Protection: 2.4V

Software Specification:

Test Specification:

Prototyping:

System Analysis and Design Tradeoffs:

Firearm System:

The amount of time from the time the trigger is pulled until the bullet leaves the barrel of the weapon is highly dependent upon the type of firearm, as well as the type of the ammunition. Rough calculations, however, place the time on the order of hundreds of microseconds (10^{-6}). Our system must be able to respond to events within that time frame.

Camera:

CMOS vs CCD

Speed

CMOS cameras can capture images a great deal faster than most CCD cameras within our price constraints. CMOS is therefore typically preferred in most high speed cameras. As an added benefit, CMOS cameras allow reading of individual pixels, allowing us to take subsections of the image. This will increase the speed at which we can capture images as well as reduce the amount of data needed to transfer.

Size

CMOS cameras tend to be smaller than CCDs, which allows us much more flexibility in the design of our accessory. Since we are dealing with a very limited amount of space, we cannot afford to have a bulky camera. A smaller size will also reduce the weight of the end product.

Image Quality

CCD cameras provide higher quality images with less noise, but at a much higher cost. We have determined that the speed of image capture and the size of the camera outweigh the benefit of a higher quality image for our design.

JPEG Compression

A raw image captured by an image sensor is very large. A 1280 x 1024 image, for example, with 2 bytes of data per pixel, requires 2,621,440 bytes total. With JPEG, the amount of bytes can be cut in half, and greater compression ratios are possible. Therefore, it would be to our advantage to compress the image data on the device itself, rather than sending uncompressed data. A camera module that includes support for hardware JPEG compression should be selected.

Microcontroller:

Bluetooth:

The primary consideration for Bluetooth was the data transfer rate. All standards of Bluetooth have relatively low power consumption (~100 mW or less) compared to other components on our accessory, but because our design involves sending continuous image data to a mobile device we need to have as much bandwidth as possible. We wanted to minimize the amount of processing done on the accessory, which means transferring a larger amount of data to be processed on the smartphone.

Accelerometer:

To pick an accelerometer we had to consider durability, sensitivity, and the maximum threshold it can read. The forces involved in discharging a firearm such as gun vibration, recoil, and heat discharge are fast and intense. We need to be able to read accelerations many times that of gravity and distinguish a shot from normal hand movement, and not damage the parts in doing so.

Memory:

Flash:

The code running on the firearm accessory will need to be stored somewhere where it can persist across reboots. The microcontroller has 512 KB of flash memory that allows us to store the program and not worry about it being reset or erased upon powering down.

SRAM:
SRAM allows us to actually run the program on our microcontroller. We will need memory to initialize the system, perform timing calculations, and send data to the smartphone for further processing. We wanted to minimize the amount of processing done on the accessory by pushing as much of it to the phone as possible since most modern smartphones have significantly more memory and faster processing speed than our accessory will provide.

Power Source:
We chose a 3.7V power source because we must be able to supply enough power to Bluetooth, a camera, microcontroller, and accelerometer. The device must be able to remain powered on for the duration a user is firing a gun, which could range from a few minutes to an hour.

Standards:

Bluetooth:
Bluetooth (formerly standard IEEE 802.15.1, but no longer maintained) is a wireless communication standard we will use to transmit data from the firearm accessory to a nearby smart phone. Bluetooth is rated in classes based on power consumption and range as well as a version number which specifies data transfer rates. Our device uses a class 1 Bluetooth 2.1 chip.

MIL-STD-1913:
MIL-STD-1913 is the specification for the Picatinny rail. It describes the dimensions and tolerances of the locking slots on the mounting rail found on some firearms. Slot width, depth, and center spacing of the holes on the rail are covered under the standard. Our device shall conform to the dimensions outlined by this standard to ensure it is compatible with firearms off the shelf.

Computer Aided Designs (CAD):

Firearm Attachment:
[Physical design still pending]

PCB:
[Physical layout design still pending]

Operations Manual:
1) Point
2) Shoot

WARNING: Don’t point it at anything you don’t intend to shoot.

Summary:

Conclusion: