Hands Free Infrared Cameras For Firefighting

Executive Summary

Currently, firefighters face a serious visual problem when fighting fires: smoke. One of the current solutions to “see through” the smoke is using an infrared (IR) camera allowing firefighters to see heat emanated from objects in the infrared band just outside of human vision (Figure 4). However, the major drawback when using IR cameras currently on the market is that they require one, sometimes two, hands to operate effectively, which means that the firefighter must make a decision to either fight the fire, carry a person in search and rescue operations, or use a camera. Our proposal is a hands free IR camera with a linked heads up display (HUD) that will enable the firefighter to fight the fire, carry out search and rescue operations, and use the camera at the same time to aid in navigating poor visibility fire zones.

Cost is a significant factor as well; a single IR camera can cost upwards of $15k per device, limiting the accessibility of this valuable 6th sense to a single person per truck at any one time. Our goal is to significantly reduce this price point, allowing every firefighter on a truck to use IR. We are able to achieve this savings using the recently released Lepton thermal imaging camera from FLIR Systems, Inc., the sponsor of this project.

Our proposed solution is a hands-free IR camera (Figure 1). The camera unit would be mounted on the side of the firefighters helmet (Figure 2) and wirelessly relay video from the camera to a HUD device (Figure 3). Inside the camera unit would be the FLIR Lepton IR camera, the smallest and lowest power IR camera on the market, ensuring long battery life, low cost, and a small device size.

The output of this camera would be sent wirelessly to the Recon Instruments Snow2 HUD device (shown below as it is assembled in a pair of snow goggles) which would be mounted...
inside of a firefighter's Self Contained Breathing Apparatus (SCBA) unit. The Snow2 HUD simulates a 14 inch screen seen from 5 ft away, yet enables you to keep a very small screen next to the user’s face to avoid getting in direct field of vision.

Figure 3: Receiving device (Snow2 HUD device and SCBA mask)

Figure 4: The Difference between what people see and what IR can see

Winter 2015 Product Development Cycle
Above is a pictorial representation of the camera-side system as the quarter progressed. Initially we had planned to use the Blackfin as our DSP as it is very low power and relatively cheap. However problems occurred when it was discovered that Analog Designs would not be releasing an open C compiler for the chipset. GCC is required on a linux distribution if you wish to compile programs on a platform. The alternative was developing a bare-metal program, which meant producing the drivers for the wireless card in-house. Writing drivers far exceeds the teams current embedded skills/knowledge. It was necessary to look for another microprocessor to develop for.

The Raspberry Pi appeared to be a viable alternative initially, especially since a prototype unit had been built using the Pi. However the compute module took up too much space and consumed too much power to be viable.

After further testing and research it was decided that the final product would be developed on the Intel Edison. It is a small SOC with an integrated wireless and bluetooth module that requires half the space of the Pi Compute module and draws less power than the Blackfin.
The system can be broken down into the following pieces: the Lepton IR Camera, a wireless transmitter, the power management system, the video processing system, and the Snow2 HUD unit (Figure 6). Below is a picture of how the devices are interconnected and following that there is a description of the device as well.

**Figure 6: System Diagram**

1. **LEPTON IR Camera**
   a. Resolution: 80x60 or 160x120
   b. Spectral Range: 8um to 14um
   c. Operating Temp: -10C to 65C
   d. Shock: 1500G at 0.4 ms
   e. Max Power Consumption: 150 mW
   f. Power Source: 1.2V, 2.8V for the sensor (must be low noise), 2.8V IO voltage
   g. Purpose: Provides IR video with optional auto gain correction at 9 frames per second over a SPI bus with camera configuration over I2C.

2. **Intel Edison SOC with integrated wireless**
   a. Processor:
      i. Model Num: Intel® Atom™ processor Z34X
      ii. Max Clock Speed: Dual Core 500 MHz
   b. Memory Available
      i. 4 GB eMMC for storage and 1GB LPD DR3 for RAM
   c. Integrated Wireless and Bluetooth
      i. Model: Broadcom BCM43340
      ii. Modes: Dual-band 2.4 GHz and 5 GHz IEEE 802.11 a/b/g/n and Bluetooth
      iii. Data Requirements:
          1. Worst Case Data Per Frame:
             \[
             \frac{225 \text{ kilobytes}}{\text{frame}} = 225 \frac{\text{kilobytes}}{\text{frame}}
             \]
          2. Worst Case Data Rate Required:
             \[
             \frac{225 \text{ kilobytes}}{\text{frame}} \times 9 \text{ frames/second} = \frac{2025 \text{kilobytes}}{\text{second}} = 1.97 \frac{\text{Mb/s}}{s}
             \]
3. With worst case scenario of 30% packet loss:

\[
\frac{(225 + 67.5)}{9 \text{ frames/second}} = 2632 \text{ kB/s} = 2.57 \text{ Mb/s}
\]

iv. Purpose: Transmit video from Edison by acting as an access point to allow the SNOW2 HUD to connect as a client.

d. Supported Peripheral Interfaces
   i. USB 2.0
   ii. SPI / I2C/ UART

e. Max Power Consumption: 800 mW

f. Power Source: 3.15 - 5 V

g. Purpose: Cheaply upscale, colorize, and apply overlay HUD to IR video from LEPTON.

3. Power Management System

a. Rechargeable battery: Lithium Ion (greater than 2.391Wh)

b. Charger: MCP73831 (Charging through USB)

c. Voltage Converters: LP5907, PAM2306

d. Battery fuel gauge: MAX17043

e. Purpose: Provide proper voltage and current to each system and to monitor battery life/battery charging for display on HUD

4. Snow2 HUD Unit

a. CPU: 1 GHz dual core ARM cortex-A9

b. Memory: 1GB DDR2 SDRAM, 2GB flash

c. Display: 16:9 widescreen WQVGA at 428x240

d. Wireless Capabilities: 802.11 a/b/g/n, Bluetooth 4.0

e. Power Source: Independent of rest of project, 1200mAh built-in battery

f. Purpose: Receive and display video transmitted from Edison in real-time.

5. Overall Power Estimates

a. LEPTON Camera: 150mW

b. Intel Edison: 800 mW

c. Total Max power: 1.196 W

d. Conclusion of power analysis:
   i. Minimum battery size for 2 hours of operation is:
   ii. 2 hours * 1.196W = 2.391Wh

\[
\frac{1}{.85} \left( 800 \text{ mW} + \frac{2.8V \times 4mA}{.95} + \frac{1.2V \times 110mA}{.87} + \frac{2.8V \times 16mA}{.8485} \right) = 1.196 \text{ W}
\]
Signal Flow:

Figure 7 represents the path the video data will take through the wireless system. First, IR light enters the lens assembly and strikes the focal plane array, where a change in temperature at each sensing element (pixel) results in a proportional change to the resistance across the sensing element. The resistance is measured and reported back as a relative intensity value. To align all reported pixel values, a flat field correction is usually performed with a shutter or blackbody. The shutter has a low emissivity and will theoretically report the same temperature across the surface, meaning that all resistances measured across all pixels on the focal plane array can be considered to be equal. There will also be a temperature gauge on the shutter so that the reported pixel value can be correlated with temperatures and fairly accurate temperature measurement can be performed. The Non-uniformity feature correction applies additional help to clean up the image, using factory calibrated values to compensate for pixel resistance variation. The dead pixel replacement feature also substitutes any pixels identified as defective during factory calibration using a replacement algorithm based on neighboring pixels. Lastly the spatial filtering enhances the signal to noise ratio by eliminating temporal noise. Once per frame the LEPTON senses the resistance of each pixel detector and forms an image from the results. The image is then packetized into 14 bit grayscale pixel values, fed out through Video over SPI (VoSPI) in rows, 164 bytes per row for the 80x60 sensor. The Lepton is technically capable of producing 27 frames per second (FPS) video, however due to government export control laws on infrared technology, the Lepton is software limited to 9 FPS for exportable versions.

After the on-chip signal processing is done by the LEPTON it is sent out over an SPI bus to the Edison Compute Module. The Edison is responsible for upscaling the image from 80x60 to 320x240 (the resolution needed by the Snow2), colorizing the image, and overlaying the firefighter’s HUD specified in the National Fire Protection Association (NFPA) 1801 Basic Interface section.
The Lepton offers a 14-bit image as well as an 8-bit AGC image. We’re opting to use the 14-bit image because it offers a greater dynamic range than the 8-bit image. To colorize the image, we will map the grayscale 14-bit intensities to colors defined by NFPA 1801. We will have additional lookup tables for other modes consistent with FLIR’s existing K-Series firefighting product.

Once the Edison has performed all image processing, it is ready to be queried by the Snow2. The Edison has a built in wireless module which will act as an Access Point (AP) that the Snow2 will connect to upon its’ power-on and boot-up. Once the Snow2 is connected to the camera AP it will automatically query a pre-set location in memory on the Edison unit for the video stream. Right now, the solution we’re using to stream video is Motion JPEG (MJPEG), which is popular in security cameras and has been available since 2007. While MJPEG doesn’t provide the best compression for video, compression of our stream is not critical due to the size of each frame and it is a tried and tested format and many different devices can natively view MJPEG streams. Once the data is received on the Snow2 a small android application will display the video image in the proper location on LCD screen.

Power Flow

![Power Flow Diagram]

The minimum input voltage for the Edison is 3.15V for proper operation, while the PAM2306 converters only require 3.0V. From our battery testing we have determined the Lithium Ion Battery stays above 3.15V until it is completely drained, therefore no buck/boost is required before the Edison or the Step-down switching converters. The LDO is powered by the 3.3V regulated output from the Edison itself so that efficiency does not change as battery voltage...
changes. All sensors are compatible with unregulated battery voltage and thus the 3.3V regulator of previous versions was removed in order to increase power efficiency. The logic level converter (LSF0204) converts between the logic level associated with the current battery voltage down to 1.8V logic to be compatible with the Edison GPIO inputs. The SPI and I2C bus going to the Lepton camera are upconverted from 1.8V logic to 2.8V logic to avoid the issues related to having a 1.8V logic level (such as pixelation in the 80x60 version and greater problems in future versions of the camera).

**PCB Layout:**

![Lepton PCB Layout](image)

**Risks:**
The electrical team is working with a mechanical team. Unfortunately, the Lepton max operating temperature is low, as is the max operating temperature for the battery. It will be a
significant challenge for the ME team to handle thermal environmental stresses while keeping the electronics inside at a safe operating temperature. In addition, the electrical team will need to use extremely efficient electronics to minimize power lost as heat, since there will be no way to dissipate this heat from the inside of the unit to the outside.

The Blackfin MPU initially chosen was a pre-release product, which is inherently more risky. The risk did not pay off this time and the Blackfin proved more of a bust than a boon. While we have moved on from the Blackfin and have a new microprocessor that will work, it did require a substantial amount of time to find a replacement microprocessor.

Our replacement MPU, the Intel Edison, has a very low reported max temp. To prove that this product works in extreme environments, we will need to heavily validate our prototypes over temperature to be sure that the electronics can handle the heat. To aid in heat management, a heatsink will be added and temperature controlled fan has been designed into the PCB and can be implemented if necessary.

**Minimum Viable Product Specs:**

- Meet all NFPA 1801 Standards
  - 6.1.2: Operate at least 120 mins without battery replacement or recharge.
  - 6.1.3: Display images that fall within the 8.0-14.0 micron wavelength range.
  - 6.1.4: All components must be rated for a service life of 50,000 cycles.
  - 6.1.5: Designed to prevent unintentional activation.
  - 6.1.6: Must be operational with a gloved hand.
  - 6.2.2: Power button must be green in color, no other buttons can be green.
  - 6.2.5.1: Power button should only require to be held for no more than 1 second to turn on.
  - 6.4.1: Require a TI BASIC operational format and permitted to have a TI BASIC PLUS operational format. TI Basic is default when power cycling or powering up.
  - 6.4.3: TI BASIC operational format shall show:
    - Grayscale imagery with white-hot polarity
    - Power Source Status
    - Internal Electronics overheat indicator
    - Thermal Imager “on” indicator
  - 6.4.4: TI BASIC PLUS may include:
    - Heat indicating color and a color reference bar
    - Temperature bar
    - Numeric temperature measurement indicator
  - 6.6.2: Viewing area shall consist of three vertical sections.
  - 6.6.3: Image shall conform to layout specified in figure 5(below)
  - 6.6.3.1: Left section of the screen is reserved for:
    - 1) Low sensitivity indicator
    - 2) TI BASIC Plus activation
    - 3) Activation and status of optional TI Basic features/ functions
6.6.3.2: Center column is reserved for:
- Power source status
- Temperature measurement zone
- Internal electronics overheat indicator
6.6.3.3: Right section of the screen is reserved for:
- Temperature sensing indicators
- Heat color reference bar(s)
6.6.4: Indicators shall appear and function as below:
6.6.4.1.5: The temperature bar shall be green in color and divided into 4 sections. The approximate temperature of each division shall be shown next to the section.
6.6.4.1.11: The heat color reference bar shall have a color scale consisting of the following colors: (though they can change in hue to correspond to increasing temperature: 6.6.4.2.4 to 6.6.4.2.6 cover the hue changes)
  - Transparent
  - Yellow
  - Orange
  - Red
6.6.4.2.2: Colorization shall overlay the grayscale thermal images produced.
6.6.4.3.1: Power source status shall have 4 colored segments to show available power (which is detailed in 6.6.4.3.2 for how exactly it should look)
6.6.4.4.1: All images equipped with internal overheat indicator.
7.1.17: Field of view is 36 degrees horizontal and 20 degrees vertical

- Non-NFPA Standards
  - Device transmits wirelessly to Snow2 HUD
  - Frame rate should accommodate real-time, or near real time, updating speeds
  - Data-rate needs to accommodate lost packets (data rate require specified previously)

Prototype Section
Division of Labor:
Our team consists of 3 electrical engineers: Jason Farkas, Sean Tauber, and Sullivan Morsa. Jason and Sean both have coding experience in Java, which will help in Android App development. Jason, Sean, and Sullivan all have experience coding in C and C++ which will help with coding our Edison Embedded platform. Sean and Sullivan both have power system knowledge from the special topics course offered by Bob York at UCSB and will be able to architect the battery system from that knowledge. In addition, Sean has knowledge of PCB design, PCB layout, schematic capture, and part sourcing from his internship and the group will be leveraging that experience during the second quarter.

Schedule of Builds:

I. General Proof Of Concept - 12/10/14
   Lead: Sean Tauber
   The first prototype consists of constructing a proof of concept build that uses a similar but different design from the final product. The goal with the first prototype is to successfully communicate with the Lepton and stream wirelessly to demonstrate proof of concept. To make this easier, the group will use a Raspberry Pi to interface with the Lepton. The Raspberry Pi will take each frame, upscale it, colorize it, and save it to disk. An Access Point will be created on the Raspberry Pi to enable wireless devices to establish connections with the Pi and query the system for data. A streaming package called MJPEG Streamer will be used to host a web server that clients can navigate to in their browser when connected to the Pi AP where the video from the LEPTON can be seen in near-real time.

   While a Raspberry Pi will not be used in the final version, it is similar to the BlackFin unit that we are designing. The Blackfin MPU will be running a Linux kernel called uCLinux, whereas the Raspberry Pi runs a Linux kernel called Raspbian, thus many of the packages and steps that were used to create streaming video to a remote device can be used again with some modifications on the Blackfin.

   Result: Blackfin did not work out - Raspberry Pi prototype did work. We were able to successfully demo the video stack with about 0.5 second latency.

II. Edison Proof Of Concept - 03/02/15
   Lead: Sullivan Morsa
   Since difficulties with the Blackfin DSP required that we find another microprocessor, this demo was about demonstrating that we could wirelessly stream video from the new platform, the Intel Edison, and also have it host an Access Point that users could connect to.
Result: Intel Edison was able to host an access point that and stream video to connected devices over that established link. Time lag between movement in real-time and movement noted on screen was within tolerance. Time lag will be reduced during software refinement in Spring Quarter.

III. Android Application - 05/04/15
Lead: Jason Farkas

The goal of this prototype is to create an android application that will run on the Snow2 HUD at startup of the system. Once the program starts it will display the video data from the LEPTON camera unit without user input. It will continue to display video until the camera unit is turned off, at which point the program will continue running (in standby mode) awaiting the activation signal when the camera is re-activated. Additionally the PCB board should be finished and in working order.

Cost Estimates:

<table>
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<tr>
<th>Description</th>
<th>Cost</th>
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<tbody>
<tr>
<td>Intel Edison Evaluation Board</td>
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<tr>
<td>Electronic Components (PMIC, Supplies)</td>
<td>$1050.00</td>
</tr>
<tr>
<td>PCB Fab and Assembly</td>
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