Ferguson Incident Reporting Device (F.I.R.E.)

Jacquelyn M. Ingemi, EE, Brian Gleadle, CSE, Andrew Kelley, EE, and Shane Ryan, EE

***Abstract*— F.I.R.E. (Ferguson Incident Reporting Device), a wearable camera unit. This device will record video and audio and send them to a Local Memory Unit. The Local Memory Unit will encrypt and compress the video data. The data will then be downloaded to a computer and be used as evidence. One unique feature in this system is the NFC tagging system. In the case that an officer does not remember to turn on their wearable camera, the system automatically activates the camera unit upon removing an item from their duty belt (firearm, baton, handcuffs, etc.) . The camera unit will ultimately be small, easy to use and allow both veteran and rookie police officers to interact with it easily.**

I. Introduction

INSPIRED by the events that occurred on August 9th of 2014 in Ferguson, Missouri, along with many other similar scenarios, interest was generated for this project. Michael Brown, an 18-year-old black male was fatally shot by Darren Wilson, a 28-year-old white Ferguson police officer. Numerous disputes and protests have arisen due to the dubious circumstances surrounding the shooting and questions have been raised regarding what actually took place [1]. It is believed that had Officer Wilson been equipped with a wearable recording device at the time of the incident, the sequence of events that took place would be indisputable, due to the existence of unbiased documentation. As a consequence, justice could have been dispensed to the satisfaction of all.

Since then, there has been increasing pressure for police departments around country to adopt wearable body cameras. The International Association of Chiefs of Police (IACP) has led the way by endorsing body cameras and has assembled a compendium of policy resources for body-worn cameras [2]. The American Civil Liberties Union (ACLU) has also made similar recommendations, and has asked various police departments across the nation, such as the New York Police Department (NYPD), to adopt them for testing purposes [3].

The topic of body-worn cameras has been, and continues to be, highly debated and many companies have already invested into the idea of creating such devices for law enforcement. Large companies such as Tazer[4], Wolfcom[5] and DigitalAlly[6], along with new start-ups like VieVu[7], L3[8] and ICOP[9] already have products on the market. When investigation was started for the idea of a body-worn camera, research was done on these companies and recognized the need to differentiate this project from such existing product lines.

In order to discover the unique needs of a police force, in regards to wearable technology, several meetings were held with the local University of Massachusetts Amherst Police Department (UMPD). Their input and opinions about the different body-worn cameras available allowed this project to be steered in a direction that was general enough for any department to adopt, but unique enough to distinguish it from any product currently available on the market.

A. Overview

The Ferguson incident typifies both the simmering social injustices that many citizens claim to have faced for years, as well as, the seriousness that police departments are forced to take such complaints. What makes this incident relevant to the field of electrical engineering are the recent advances in wearable technology alongside the increasing ubiquity of personal cameras. In order to accurately justify, or condemn, an officer's use of deadly force, clarification of the time-line of a given confrontation is critical. Therefore, a small, secure, comfortable, wearable camera unit that is both easy-to-use and equipped with an additional pre-record option that reflexively-activates by the habitual actions of a police officer offers a solution to the problems typified by this incident. This solution is the Ferguson Incident Recording Equipment (F.I.R.E).

F.I.R.E. is comprised of 4 major subsystems, as shown in Figure 1 below: the camera/microphone unit, the local memory unit, the sensor array and the adjoining software. The camera/microphone unit will be affixed to the officer's torso and will record and compress video and audio data. The data will then be stored in the local memory unit, located on the officer's belt. The sensor array, comprised of NFC readers and tags on the holsters of commonly-used items, such as, pistol, handcuffs, baton, etc., is also located on the officer's belt. The sensor array's tags will activate the camera unit via the local memory unit upon the removal from the holster of any of the above-listed items. Lastly, the software component currently includes the transfer of both video and audio data from the local memory unit to the repository in the police station.

The specifications for this project are as follows: low-power (3.3V rechargeable battery source), reasonable camera resolution up to 10 meters away, microphone sensitivity of -51dB +/- 4dB, automatically activated video feed, via RFID sensor array on officer's duty belt, 2-minute pre-record, compressible and encrypted data handling (MPEG-4 and AES, respectively), allowing for storage on 4 GB SD card. Memory and power will be located on a wearable local memory unit and accessible via USB connection. Lastly, a GUI will be created to oversee the upload of data to its final storage repository.

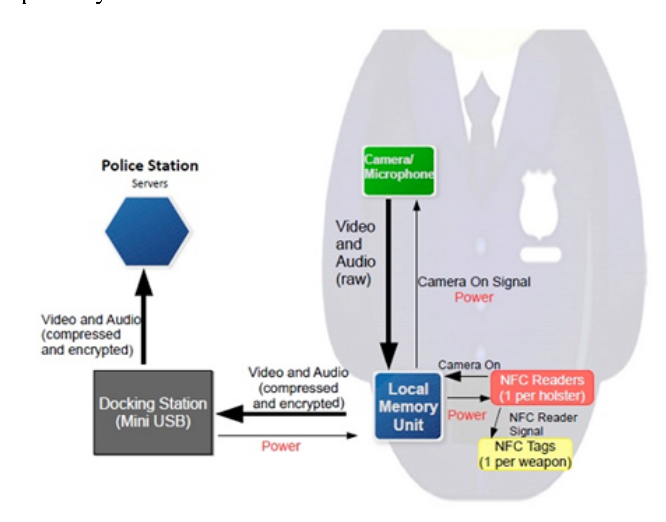

Fig. 1. F.I.R.E block diagram. Illustrates the major subsystems as well as the communications between each subsystem.

B. Camera/Microphone Unit

The camera/microphone unit is responsible for the capturing, compression and transfer of video and audio data to the local memory unit. This unit will be activated automatically by the sensor array via the local memory unit or can be activated manually. For MDR the functionality of the camera and the microphone was split into two separate sub-units. The video capture and compression was implemented with the BeagleBone Black with an HD camera cape (an attachment to the BeagleBone Black). The audio capture was implemented separately with a PUI electret microphone, a TL074CN op-amp chip, an LM-386 audio amp chip, an ISD4002 Voice Record/Playback chip [10] and an Arduino Uno micro-controller [11].

The video subsystem required a variety of techniques from courses that have been taken previously. Most relevant were op-amp analysis from Circuit Theory, hardware/software interface and basic MIPS instruction processing from Hardware Organization and programming language protocols primarily from Software Intensive Engineering. The BeagleBone Black works best with a language called 'bonescript', a version of Javascript, although Bash was utilized for video capture and compression and C/C++ was used in both the BeagleBone Black and the Arduino Uno. Development will be continued with these languages, though the final version might require some other language [12].

Further plans for development included rebuilding the camera/microphone units into one single unit. From there, initial tests will confirm the concatenation of the video and audio data streams. Then, independent activation of both the camera and microphone will be demonstrated, since different levels of government dictate independent legality of video and audio capture of an individual (for example, in Massachusetts, video recording by an officer without permission is entirely legal, but audio recording must be requested first [13]).

Lastly, compression must be confirmed by performing tests on both transmitting data streams to ensure that memory specifications are adequate for the level of usage that are expected. Further testing could also be done to demonstrate that the microphone's frequency response, sensitivity and signal-to-noise ratio are well within expected parameters.

C. Activation Sensors

The activation sensors consist of both Near Field Communications (NFC) readers, which will be affixed to each of the holsters for the weapons that the officer carries, as well as their tags, which will be affixed to each weapon. These sensors send a signal to the Local Memory Unit (LMU), which is then relayed to the camera unit, which instructs the camera to start recording video. The reader consists of the evaluation module for the TRF7970A Multi-Protocol Fully Integrated 13.56-MHz RFID/NFC Transceiver IC, which includes the ultra low power MSP430F2370 microprocessor. The code for this evaluation module will configure the reader such that it will use low power to poll continuously when there is a tag in the NFC field, then when the tag has been removed, the reader will send a signal back to the LMU [14].

The tags affixed to each weapons are ISO 15693 transponders. Testing is being done to determine which size tag will give us the optimal read range given the size of the antenna on the evaluation module and the 13.56-MHz signal from the NFC reader [15].

The MSP430F2370 microprocessor is programmed in the C programming language. The environment that Texas Instruments has uniquely configured to program the MSP430 line of microprocessors is the Code Composer Studio (CCS) Integrated Development Environment (IDE). A twelve-pin JTAG programmer is used to download the software onto the evaluation module [16].

Experience using Arduino and PIC-32 microprocessors from independent study projects is increasingly useful when setting up and using the CCS IDE to communicate to the evaluation module. Experience programming in C from software engineering and computer systems courses aids with the development of the software that will control the reader making it low power and fully functional, using skills to sample and process the feedback in particular.

The microprocessor and NFC transceiver IC are complex devices that present a steep learning curve. Learning exactly how each of them functions is crucial in determining the best process for reducing power as well as increasing accuracy of removal detection and reducing false positive reads. Additionally, a broad knowledge of radio frequency integrated circuit and antenna design will assist in making decisions if the evaluation module will be physically cut down to reduce the reader area on each weapon holster. Knowledge will also be obtained on the ISO 15693 protocols and standards to optimize the software for the ISO 15693 tags.

One test that will be performed will be to determine the read range of the reader when placed behind different types of holsters. The tag will slowly be pulled away from the holster until the evaluation module detects that the tag is no longer in the field. Testing will be done with tags of varying sizes of antennas. From this test, a tag antenna size will be chosen for the different types of holsters.

Another test that will be performed will be evaluating different read techniques in the software for power consumption. Different pieces of software will be developed, which then will be tested for power consumption when a tag is in the field, leaving the field, and out of the field. Static power consumption measurements will be done when the tag is in the read field as well as out of the read field, and dynamic power consumption measurements will be done when the tag is being removed from the read field. From these tests, the overall power consumption will be determined and the most power saving method will be chosen.

D. Local Memory Unit (LMU)

The Local Memory Unit will provide all of the components necessary for operating the entire system. It will include the main Beaglebone Black unit as well as the custom cape. Also, it will contain a battery, which will be connected via wire to the camera and microphone units. The amount of power being sent will determine the desired video recording quality. The raw video and audio data will be sent to the Local Memory Unit along another set of connections. At the LMU, the video and audio data will be combined, compressed, and encrypted. Also the data will be tagged with GPS coordinates and time-stamped. After encryption, they will then be stored on an SD memory card. The LMU will also relay signals from the activation sensors on the officer's duty belt to the camera. These signals turn the camera on and off.

The decision to develop a custom cape as opposed to designing a custom PCB was made as a result of several factors. First, no members of team 10 have experience in PCB design. Thus, the process of learning how to design a custom circuit would be significant. Although a custom cape also involves the design of a custom PCB, the design of a cape will be much simplified. This is due to several factors. First, each of the desired components (encryption, power, audio, video, GPS) already have capes available which can implement these features. Also, the encryption as well as GPS and power capes have EAGLE layout files available to download. Finally, there are schematics in PDF form available for each cape. Given that every member of the team has experience with circuit design and analysis, the goal of creating a custom cape is attainable.

The custom cape must include several components. Encryption will be handled using the Atmel ATAES132 chip. The chip is capable of an AES algorithm with 128 bit keys. The inspiration for the design of the encryption section of the custom cape will come from the already developed CryptoCape [17]. The compression of video will be handled on the processor which is on the Beaglebone Black. The AM335x ARM processor which is built into the Beaglebone Black can handle the incoming video and audio and can compress it accordingly. Also, power will need to be handled by the LMU. The custom cape will also be designed to receive and regulate the power. The design for the power section of the custom cape will be based off of the PowerCape developed by Andice Labs [18]. Finally, the custom cape must be able to handle GPS tagging as well as time-stamping. The design of this portion of the custom cape will follow the design of the TrackingCape by Ciudad Oscura [19].

Before the custom cape is even ordered, the PCB must be edited and created in EAGLE. However, instead of loading circuits directly into EAGLE, each individual sub-circuit will be designed and simulated in PSPICE. Only after the sub-circuits are working in PSPICE will they be created in EAGLE. Each part of the custom cape will be successfully simulated and designed in EAGLE before moving on to the next part. For example, the first two sections that will be built in PSPICE and EAGLE are the audio and video support on the custom cape. Once these parts are found to be functional, the final PCB design in EAGLE must pass tests. The two tests which the design must pass are the Electrical Rule Check and the Design Rule Check.

In order to test the functionality of the custom cape, it must be ensured that each part of the cape functions correctly. The testing portion of the encryption hardware will be predominately done in software. The hardware test will involve making sure the ATAES132 chip functions correctly. Once functioning correctly, the data should be ready for encryption. Since the audio and video synchronization will happen in software, the testing for audio and video in the LMU will mostly involve making sure each of the chips works successfully. The audio system will involve a microphone as well as an analog to digital converter chip. The chip is a TLV320AIC23B. Tests will be run in order to determine whether the analog to digital conversion process is happening successfully. Testing the GPS functionality will be more significant than the other parts. The GPS part of the custom cape will be developed from the TrackingCape by Oscura. The GPS chip will be tested by taking GPS reading at different locations. These locations will be selected based on differing geographical features (on a hill, in the woods, in a building). Once GPS measurements are taken they will be checked for accuracy.

Finally, tests for power will be performed. There are a multitude of different capes available for powering a Beaglebone Black. The challenge is that not only does the Beaglebone need to be powered, but also the custom cape. Multiple factors need to be considered when determining how much power is required to run the Beaglebone Black as well as the custom cape. The higher the quality of video, the more battery will be consumed. Also, at a higher quality video, compression and encryption become more taxing. Beyond the compression, encryption, and video quality, the operations performed on the custom cape must be taken into account. The most direct way of quantifying the custom cape is to go through the requirements chip by chip. For example, when operating, the power consumed by the GPS chip will be measured. Once all of the power requirements are calculated, the size of the battery can be determined.

E. Software

The beaglebone black is able to utilize a full version of Linux called Angstrom. The Angstrom build is specialized for a number of embedded devices and is lightweight enough to run on the BBB yet powerful enough to utilize the 1GHz processor and all include all the tools needed for this project.

The camera chosen for this project outputted it's video in YUV4:2:2. This allowed for an immediate reduction in bandwidth, as YUV422 is a color space that encodes video while taking in consideration human perception. However, that was still a significantly large amount of data, and needed to be encoded by the BBB into something more lightweight. By taking into consideration all the requirements of the project, it was determined that H.264 would be best for encoding this video. H.264, otherwise known as MPEG-4 is one of the most commonly used video codec's on the market right now. MPEG-4 is a block-oriented motion-compensation-based video compression standard. It works by only saving data for the motion between frames. All background information that doesn't change between frames is discarded and only information that has changed since the previous frame is saved and encoded. This allows for a lossy compression ratio of over 100:1 in best case scenarios.

In order to capture data from the camera cape the BBB uses the capture function from the open source project OpenCV. OpenCV was released under a BSD license and is designed for computational efficiency with a strong focus on real-time applications [4]. The capture function allows the Beaglebone Black to select from a wide range of options. These options include setting the framerate, resolution, capture encoding and frames to capture. Many other options are available through the OpenCV library but it was kept minimal to only include the functions needed for this project.

The goal of the project was to have the video capture started when a signal was received from the RFID sensors. That data was fed into the GPIO pins of the Beaglebone Black so the capture function waits for the signal then executes in a script to start capturing video and saving it to the SD card. The video data would be split into multiple two minute sections. That way as the RAW YUV data is fed in it will not become too large to manage. As each two minute section is completed it gets fed into a script that encodes the video in H.264 to significantly compress the video.

The pre-record system will also be implemented in software. The video will constantly be recording so that when the signal comes in from the NFC sensors, the video will be saved from a point two minutes before the signal. In order to save on the amount of data and processing required for that two minutes. That two minutes of data will not be compressed or encrypted and will just be saved RAW. Once the NFC signal comes in the data will start being compressed and encrypted so it is secure and doesn't take up as much storage space.

Once the data from the camera has been saved in RAW for two minutes, it will go to compression then encryption. Both of which will be performed in software by the 1GHz processor. Compression will be performed as described above so encryption is being formed on the minimized data. Encryption will be performed based on a public-key cryptography algorithm. The end user software will require a login that will associate with the police departments active directory domain. Since each user will require a separate login, that software will generate a private key associated with the public key on the device. Every user will have to setup their device using the software so that a public key can be generated based on their private key. Now that the device has a public key stored, the video will be encrypted using that public key. Since that public key was generated using the end user software, the only one able to decrypt that video would be the user logging into the end user software and using the private key. By using this method of encryption, it allows for basic encryption on the Beaglebone Black, while keeping the large decryption process on a server, which has more processing power to handle it.

II. Project Management

At this point, the overall system design has been described, and now attention will be given to the individual component blocks.

For the camera/microphone unit, a camera prototype has been developed using a Beaglebone Black with a camera cape and its attached camera. This device can record and playback, and is capable of data compression rates of varying degrees, as well as variable resolution rates. The microphone prototype is partially functional, meaning the microphone amplifies sound, but the code enabling the record and playback functions is not fully operational.

For the activation sensors, an evaluation board has been used to determine which function codes will be valuable and necessary to the final reader. The evaluation board comes pre-equipped with a stand-alone mode where the reader detects when a tag is in the field and flashes an LED when that tag is detected. It also comes with a GUI, which was used to determine the effectiveness of reading and writing to a tag, inventorying that tag, and setting its status to either active or idle.

For the LMU, all of the necessary cape schematics have been collected to include the necessary functionalities. Additionally, power consumption estimates are being made with the goal of figuring out which size battery will be necessary. Finally, EAGLE design has been started with the goal of learning how to use the program.

In terms of software, a comparison has been made between avconfig, ffmpeg, and v412 as options for video and audio encoding. Investigations into OpenCV and OpenSSL were done to determine compression and encryption options. Additionally, how to build Windows applications using C++ has been determined.

TABLE I
MDR GOALS

Team Member	Block	Accomplished	To Do
Kelley	Camera/ Microphone Unit	-Camera BBB prototype record and playback functional -Microphone prototype partially functional	-Camera and microphone must be merged -Microphone power specs reconsidered for 3.3V -Testing for LMU storage, sensor activation, and performance analyses -PCB designed and printed for integrated camera and microphone
Ingemi	Activation Sensors	-Evaluation module functionalities determined using built in GUI -CCS environment set up - Low-power NFC reader code written	-Program and test code for reader -Determine reader power consumption -Send signal from reader to LMU with code of which weapon was pulled
Ryan	Local Memory Unit	-Collected all cape schematics to merge to one custom cape -Power consumption estimates for custom BBB cape -Began EAGLE design	-Determine exact cape components -Consolidate individual cape schematics to single custom cape design -Complete EAGLE PCB design -Order PCB and test
Gleadle	Software	-Avconv/ffmpegv4l2 comparison for video/audio encoding -OpenCV and Open SSL for compression and encryption options -Determined how to build Windows applications in C++	-Identify peak power consumption for BBB -Identify quality, resolution, frame rate, for power optimization -How long for compression and encryption determined - Tag geo-location and timestamp -Implement AES

Figure 1. Table of Responsibilities

Despite the work done so far, there is still a lot of work to be done. For the camera/microphone unit, the camera and microphone data streams must be merged and synchronized. The microphone power requirements must be reconfigured to work for 3.3V that are coming from the BeagleBone Black. Following this, a PCB will have to be designed and printed with both the camera and microphone integrated. Finally, this unit will need to be thoroughly tested with the LMU storage and sensor activation, as well as performance analyses should be performed.

For the activation sensors, code that configures the NFC reader as ultra-low-power needs to be written and reconfigured to sample only when a tag is in the field, rather than when a tag is not in the field. This code will also have to be configured to send a signal to the LMU identifying which weapon was pulled, as well as signaling the LMU to send a signal to turn the camera on to start recording. Following all of this, the power consumption of the reader will need to be determined to see if the evaluation board will require its own power supply.

The individual components from each of the individual required capes will need to be determined for the LMU. From there, the information will be consolidated and designed into a single custom Beaglebone Black Cape. That will lead into the completion of a PCB design using EAGLE. Then the PCB design will be sent out to be manufactured and will come back for us to test all functionalities.

For the software, peak power consumption is going to need to be investigated for the Beaglebone Black. Additionally, testing will be done to determine the best combination of quality, resolution, and frame rate for power consumption. The amount of time it takes for the compression and encryption will need to be tested as well. Research and implementation of software solutions for geo-location tagging, time stamping, video and audio encoding, and AES implementation will need to be completed and implemented.

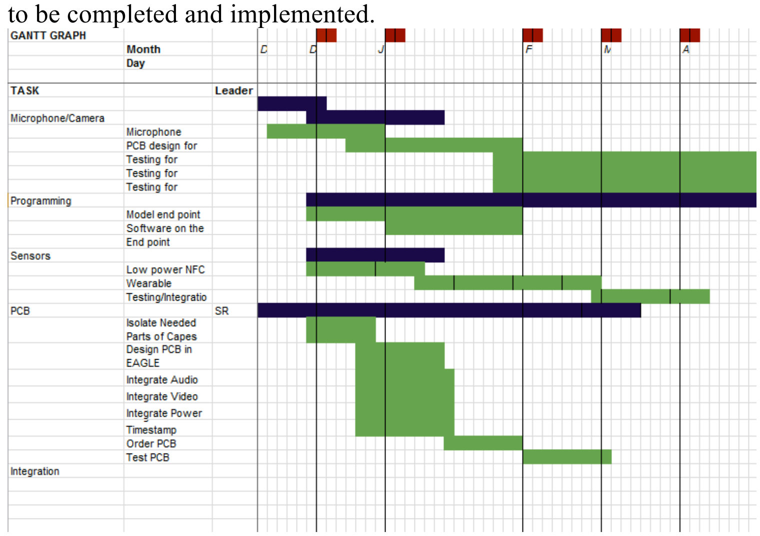

Fig. 2. Gantt Chart.

Each team member brings his or her own set of expertise to the project. Brian brings both industry and academic experience in software design, so he has been leading the effort on the software of the project. Jacquelyn also brings both industry and academic experience in hardware design, in both analog integrated circuit design and VLSI experience, and as such is leading the effort on hardware design. Andrew brings industry and academic experience in semiconductors and circuit design. Finally, Shane also brings industry and academic experience in VLSI and circuit design.

Team members have been sharing experience, especially since only one team member has a solid software background. Brian has assisted Andrew with bringing up the Beaglebone Black with the camera and camera cape to be functional, as well as assisted Jacquelyn with setting up the CCS environment to program the evaluation board. Jacquelyn has been assisting Andrew and Shane in the research and development of the PCBs. In terms of getting work done, everyone has been making sure that everyone else is able to get their work done, and done on time. The team has been communicating with advisors primarily through email with decent response times. The team has been communicating with each other primarily via phone and Facebook with decent success.

III. Conclusion

In conclusion, the project is behind schedule. However, the MDR presentation has resulted in valuable feedback, regarding the major obstacles to come and the overall time-line that will be adhered to. Each subsystem has had its successes although additional progress must be made.

For example, the camera/mic unit has achieved benchmark compression rates for video, utilizing H.264 (MPEG-4) format and will base much of its future design from the Beaglebone Black prototype, including the Aptina image sensor with 1.26 Mega-pixel camera and the AM355x 1GHz ARM Cortex-A8 processor. The microphone unit partially functioned, but further software development is needed to ensure accurate and compressible memory management.

Future plans include the synchronization of both audio and video data streams and their software must also be merged to handle both memory management and independent activation. Also, the microphone unit must also be re-calibrated without the speaker to bring it into the low-power range of 3.3V.

The sensor array performed as expected, but further progress must be made to calibrate the reader's detection range. This will prevent accidental camera activation and discourage sensor tampering. Also, the algorithms that will allow the sensor array to interact with the other subsystems must be written, implemented and tested.

The local memory unit already has several major components from the camera/mic unit in its design, such as the processor and image sensor from the Beaglebone Black camera cape and ISD4002 Record/Playback memory and LM386 op-amp chips from the microphone sub-unit Further progress must be made to solidify and test power and memory requirements as well as verify the right connectors to fully integrate the system.

Lastly, the software component has already achieved H.264 compression rates for the camera through the Beaglebone Black. As was previously stated, existing code must be improved upon for full functionality of the microphone subsystem and both components must be merged, on both the hardware and software levels, to achieve full system integration. Also, code for the station-side interface must be created. The coding aspects are not expected to be overly problematic (barring the separate audio and video activation protocols), as once the hardware specifications have been met for the local memory unit, much of the remaining work will fall into place. Therefore, much attention will be given to this subsystem.

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