Knight Watch Security (KWS)

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Abstract — **This paper presents the theory and implementation of a standalone solar powered surveillance camera with advanced network capability. The surveillance camera utilizes COTS (Commercial Off The Shelf) parts as well as a custom fabricated MPPT (Maximum Power Point Tracking) charge controller that efficiently and effectively powers the onboard battery and surveillance circuitry. This paper also discusses the algorithms and methods used to achieve MPPT.**

Index Terms — *Cameras, Digital Cameras, Solar Energy, Photovoltaic systems, Wireless networks*

I. INTRODUCTION

A reliable, home security system has been desired by humankind since the dawn of time. While many homes throughout the world have implemented various designs for home security, very few homes use an energy efficient system. If homes were to use an energy efficient home security system, it will ease their daily struggles with safety, security, and finances. In addition, previous security systems have limited connectivity. With today's technology and society's "Go Green" outlook, many homes and families have a desire to implement a home security system that is dependable, energy efficient, and easy to use. With a system like this, homeowners will be able to live their daily lives reassured that their personal assets are kept safe in a resourceful manner. They would also be satisfied knowing this system was simple to implement as well as user friendly.

In order to provide homes with a better sense of protection and a more versatile structure, we are proposing Knight Watch Security (KWS). KWS is an autonomous, solar-powered security system camera with network capabilities.

Our security camera can be placed anywhere outside the user's home. The camera has a wide viewing angle and Wi-Fi connectivity, so the location of the camera is up to the user's discretion. The system will be powered using a COTS (Commercial off the shelf) solar panel and battery. Furthermore, the video being recorded is transmitted via Wi-Fi to a specified computer and can be stored as well as viewed live. Similarly, the video feed is able to be viewed from a Smartphone using an application that can stream the video feed.

Homes that desire a safe household or asset protection will want to use KWS. The amount of break-ins and robberies would decrease substantially. Users will be able to go on vacation and monitor their home from across the globe. They will even be able to have a good night's sleep knowing that KWS is always vigilant. KWS is the future of energy-saving security systems.

II. CAMERA

This project utilizes a Logitech C110 webcam to record video. The Logitech webcam utilizes a CMOS image sensor. This image sensor records at a definition of 640x480p (at 30fps). The lens on this camera has a liquid crystal autofocus with a 68° horizontal viewing angle. One of the most important features of this camera is its low power consumption.

Additionally this camera is a UVC compliant device. The Operating System for this device is Angstrom Linux distribution, which came preloaded on an SD card with the TI AM335X development board. Since this is a UVC device, it is supported by the Angstrom Linux distribution. This camera connects through a USB port, which our development board contains two.

Figure 1. Logitech C110 WebCam

This camera features a plastic lens. These lenses are vulnerable to scratches, so the entire webcam is mounted in a standard surveillance camera housing. This housing ensures weather protection for the camera. Additionally it contains vertically and horizontally adjustable hinges, allowing the user to point the camera in a desired direction. This housing also allows the camera to protrude from underneath the solar panel that is mounted atop the device housing.

III. Video Processor Selection

On the market there are many processor solutions that would have satisfied the form fit and function of our project. Through our research we investigated the use of embedded video processors, FPGAs, or embedded OMAP solutions. The embedded processor solution lacked critical functionality that was desired for this project. Wi-Fi integration and networking would have been complicated to execute. The FPGA solution, while rich with features and low in power consumption, has a steep learning curve so it was not chosen.

The embedded ARM OMAP was chosen because it fulfilled our project specifications. In this category we chose the AM335xEVM-SK from TI. The 335x is a versatile development platform for a wide variety of projects. The features that interested us the most were the standard 720 MHz processor, integrated Wi-Fi and the integrated USB.
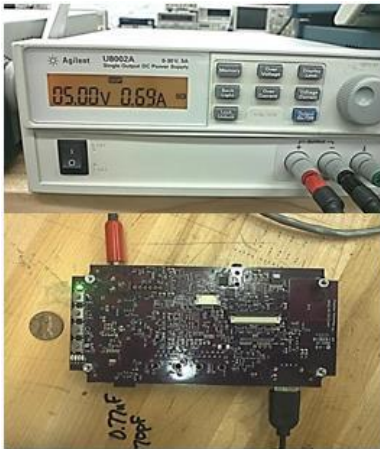
Figure 2. Am335xEVM-SK Powered up and transmitting

TI provides a Linux Argo/Angstrom distribution and software development kit with the 335x. After simply acquiring a Linux host machine, development could begin. The 335x's integrated Wi-Fi card made network development strictly software based, without the worry of loading drivers or possible incompatibility. The 335x also included a host USB allowing for multiply slave USB devices to be attached. In our case we attached a camera and USB to serial converter used to collect diagnostic data from the solar MPPT intelligent charger.

As an added bonus, the 335x was surprisingly power efficient. It consumes approximately 1 to 1.6 amps while transmitting data and processing video. This improved our power budget and allowed our team to use a smaller and lighter battery.

IV. Camera Processor Integration

In the previous section the rational for using the TI AM335xEVM-SK was discussed. The 335x allowed for quick prototyping as well as the ability to implement advanced features. In this section the scheme for saving and transmitting the video stream using the 335x will be discussed.

As discussed before the AM335xEVM-SK is compatible with the Argo/Angstrom distribution of Linux. This distribution is an embedded Linux project based off of the Durbin distribution. To implement video recording and transmission over Wi-Fi open source video software for Linux was investigated. The most promising of the software available was Mjpg Streamer. Mjpg Streamer was originally compiled for x86 architecture.

Mjpg Streamer include the source code and the make file needed to compile the code for the Arm architecture on the 335x. Using TI's SDK we were able to cross compile Mjpg Streamer successfully and with full functionality for Arm.

Figure 3. Image from MJPG Streamer

Mjpg Streamer allowed us to simultaneously save sequential jpeg images and transmit an mjpeg stream from the 335x. The images are saved at 5 frames per second on the SD card of the 335x. The images are saved in a 50,000 image loop. 50,000 images take up about 780 MB on the SD card. This currently allows for 3 hours of saved frames but it is expandable to 12 hours. 12 hours is equivalent to around 200,000 images. 200,000 images consume about 4 GB of space on the SD card. Saving the video as sequential jpeg images saves resources such as power and memory by not having to encode the images into Mpeg4 or some other video format.

Streaming video is where most of the processors resources have been diverted. The stream is a full 640x480 (0.3MP) resolution at 30 frames per second (depending on network traffic). The stream is available via a Wi-Fi connection to the local network or with port

forwarding from anywhere on the internet. The 335x hosts a small web server from which the video stream is available.

V. DIAGNOSTIC INTERFACE

An added feature of the KWS project is the ability to view diagnostic data from the solar charging architecture remotely. The MPPT intelligent circuitry is able to communicate to the 335x via USB with the help of a FT232RL USB to Serial Converter. The 335x executes a recursive script that poles the MPPT intelligent circuitry for its status. The status given includes information about; run time, solar current, solar voltage, charge state, battery voltage, ext.

Figure 4. FT232RL USB to Serial Converter

Once the 335x receives the serial data via USB the information is saved and updated to the small web server allowing it to be accessed remotely by the user.

VI. NETWORK INTERFACE

The 335x communicates with the Wi-Fi network via its onboard wireless card. In order to make the system user friendly the 335x was programmed with a start script that automatically accesses the wireless network. In addition the start script initializes the camera stream and starts the serial data collection. The 335x has a static IP address so that the user and associated applications know where to go to reach the video stream and diagnostic data. Some router settings need to be modified to allow for this and to also allow port forwarding.

Networking has become the most user intensive part of the project because it is impossible to predetermine the users network configuration. The user must enable port forwarding and put the 335x's IP address on a exception list so that the wireless router does not give out the same IP address to a different device or try to reassign the 335x a different IP address.

The 335x's current firmware does support wireless encryption but only to the WEP level. WPA and WPA2 is not currently supported mostly because of the Linux OS. On the current revision of Argo/Angstrom WPA is supported but not natively. There is a WPA supplicant

which has proven intermittent and has problems establishing a link automatically.

It is important that KWS can establish link and start the stream and diagnostic without user input. The camera may be located out of reach or in a covert location.

VII. SOLAR ENERGY

Solar energy provides an environmentally friendly alternative to fossil fuels and is vastly growing in electronic product applications. Knight Watch Security utilizes solar energy as its primary power source through the use of a 50 Watt Monocrystalline solar panel.

Many factors affect the efficiency of the energy produced from the solar panel. One of these factors is irradiance or the amount of solar radiation on the panel. The intensity of irradiance or solar radiation determines the amount of power produced. Irradiance is measured in units of watts per square meter (W/m^2).
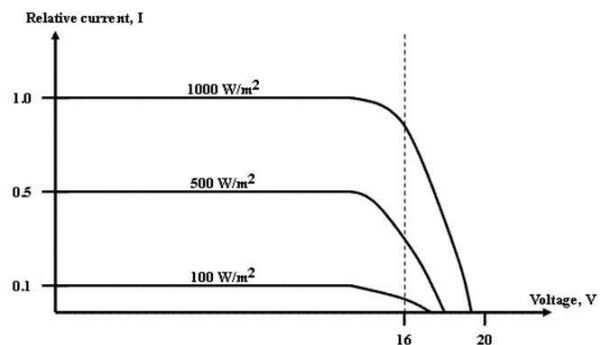
Figure 5. Effects of irradiance on I-V curve [1]

There are a few methods to improve solar panel performance to account for times of low-level irradiance. Direct methods of solar tracking and light concentration can be used or an indirect method known as Maximum Power Point Tracking (MPPT), which was utilized in this design, can be used to improve performance efficiency. A MPPT charge controller was designed to optimize the output voltage from the solar panel to match the required voltage level of the battery.

VIII. BATTERY CHARGING

Battery charging takes place in three basic stages, bulk charge, absorption charge, and float charge. The first stage of battery charging is the bulk charge, where current is sent to batteries at the maximum safe rate they will accept until voltage rises to around 80 – 90% full charge level. The second stage of battery charging is called the absorption charge, where the voltage level remains constant and the current gradually decreases as the

internal resistance in the battery increases. The third and final stage of battery charging is called the float charge stage. After the battery reaches full charge, the voltage level is reduced to typically around 12.8 to 13.2 volts to prevent overcharging and damage to the battery. This charge maintains the voltage to prevent the charged battery from discharging.
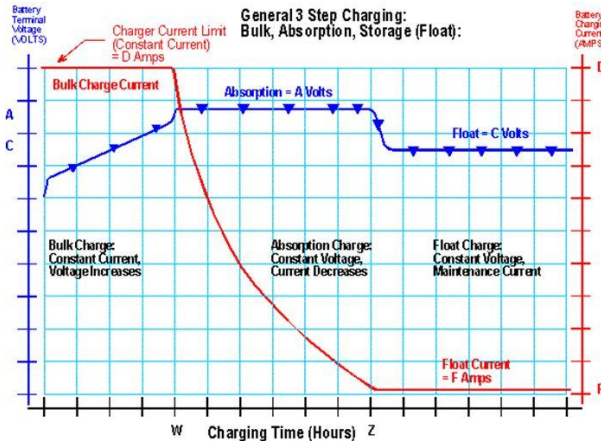

Figure 6. General Three Step Charging Algorithm [2]

Understanding the charging stages of the battery aided in the determination of the charge controller design. A charge controller with an implemented maximum power point tracking algorithm was designed to regulate voltage levels to achieve maximum power efficiency and battery life.

A. Battery Indicator

A battery status indicator was designed to monitor the available battery voltage. The battery indicator for this device is a simple circuit with cascaded LEDs powered by TI LM393 comparator chips. There are five LEDs, each depicting a voltage level from 9v to 13.5v. This device is powered by a motorcycle battery. This upper threshold for this battery is 13.8 volts. Once the battery is drained to 9 volts the device begins to stop functioning.

Voltage Level	LED Color
9	Red
10	Yellow
11	Green
12	Green
13.5	Green

Table 1. This table specifies the voltage level and color association

The circuit utilizes a comparator for each of these voltage levels. The battery voltage level is compared to a reference level. The reference levels for each of these comparators are held steady by appropriate zener diodes. Once the battery voltage level drops below the reference voltage the LED is deactivated.
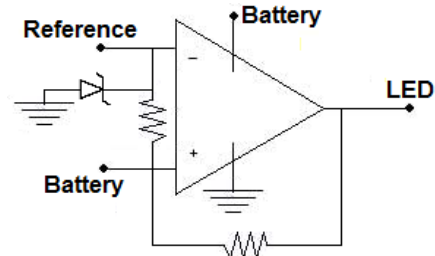

Figure 7. This circuit depicts one comparator for the LED indicator. The entire circuit consists of five of these comparators cascaded with specified reference levels.

B. Floodlight

This circuit also controls the flood light. The floodlight is used to illuminate the camera's surroundings during night use. This flood light is a strip of LEDs that are turned on or off by the lighting level of the environment. This is also accomplished using a TI LM393 comparator chip. A zener diode is used to set a reference voltage of 5 volts.

This circuit is similar to the battery indicator circuit. The two reference input voltages are swapped and the battery input is replaced with the solar panel input. The input voltage from the solar panel is compared to reference. Once the solar panel voltage falls below the reference voltage a MOSFET is activated. This MOSFET amplifies the message signal from the comparator and then sends power to the flood light to activate it. The circuit is depicted below.
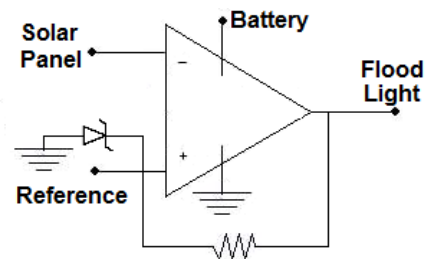

Figure 8. This is the circuit that controls the flood light based on the voltage level of the solar panel

IX. MPPT ALGORITHM

MPPT charge controllers use smart technologies, such as microcontrollers to compute the highest possible power output at any given time. The input voltage from the solar

panel will be monitored and regulated to prevent power loss.

MPPT VS. NON-MPPT

Array Rated Wattage: 1,800 W   Battery Nominal Voltage: 24 V
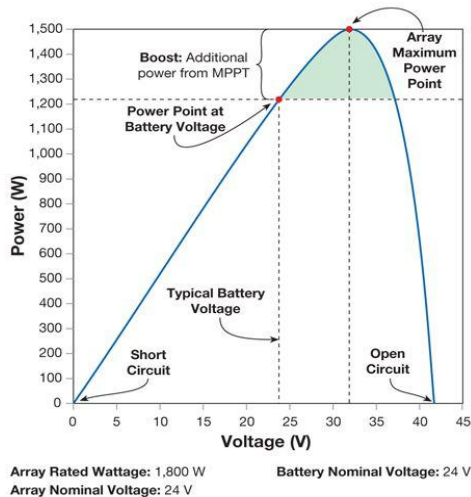Array Nominal Voltage: 24 V

Figure 5. Power Output Boost with MPPT [3]

When the input voltage is higher than the required output voltage, the MPPT charge controller will lower the voltage while simultaneously increasing the current to the battery. The result of using a MPPT charge controller to regulate the input voltage is higher power efficiency.

There are several common algorithms that are used to implement the maximum power point tracking feature. The "Perturb and Observe" method is the most commonly applied algorithm due to its ease of implementation. This method was used in this design and modifies the operating voltage or current from the solar panel until the maximum power point is obtained. The system increases the operating voltage supplied to each cell until the power output starts to decrease. The operating voltage is then decreased back to the maximum power point value of the system.
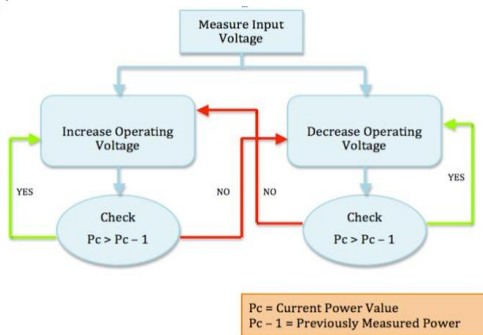

Figure 6. MPPT Algorithm Flowchart

The algorithm was programmed in C code using Arduino software 1.0.3. The algorithm was then programmed on to the Atmel ATmega328 8-bit AVR

RISC-based microcontroller. The ATmega328 microcontroller has 14 digital I/O ports, 6 of which can be used as pulse width modulation outputs. The PWM pins allow the input voltage to be varied in order to locate and track the maximum power point.

X. DC-TO-DC CONVERTER

The input voltage from the solar panel varies in magnitude based on the irradiance and temperature of the solar panel. A DC-to-DC converter or regulator is required to regulate the input voltage of the panel to match the required operating charging voltage of the battery. The supplying battery voltage can also vary based on the load connected to it.

The power supplied to the load of the Knight Watch security camera should be consistent because user operation does not need to be considered. The security camera runs on a single invariant mode 24 hours of the day so the power required by the system will remain constant. In order to maintain optimized battery charging efficiency, the input panel voltage and current should coincide with the required battery charging stage at all times.

In this design a buck converter was utilized to regulate the voltage and current. A buck converter converts a high voltage and a low current into a lower voltage and higher current. The software controlled Arduino charge controller with the implemented MPPT algorithm controls the buck converter to step down the input voltage when the input voltage exceeds the voltage limit of the battery.

In a simple model of the buck converter a diode utilized as an uncontrolled switch is connected in parallel with a capacitor, the input voltage and a load, which dictates the output voltage of the circuit. A MOSFET used as a controlled switch is connected between the input voltage source and the diode, and an inductor is connected between the diode and the capacitor.

The uncontrolled switch of the diode and controlled switch of the MOSFET achieve unidirectional power from the input to the output. The capacitor and inductor serve to store and transfer energy from input to output. They also filter the input voltage and current to make the measurement more accurate.

The programmed microcontroller takes in voltage and current readings and creates a pulse width modulation that turns the MOSFET switch on and off, creating two different circuit configurations for the buck converter. The two operating states for the buck converter are one in which the switch is closed, and one when the switch is open. When the switch is on for a time duration, the switch conducts current through the inductor and the

diode becomes reverse biased. When the switch is closed the inductor absorbs power as the current increases.

When the switch is turned off, the inductor current continues to flow due to the energy stored in the inductor. The current then flows into the diode for a time duration until the switch is turned on again. The resulting positive voltage across the inductor causes a linear increase in the inductor current.

The transfer ratio of the voltage in vs. voltage out is based on the duty cycle of the generated PWM signal. This duty cycle is determined within the programmed algorithm based on the voltage and current readings from the solar panel and the battery. The DC-to-DC buck converter circuit will send the maximum power of the solar panel to charge the battery, which powers the security camera and its components.

XI. REMOTE MONITORING

Remote monitoring refers to the three methods of interacting with the KWS camera. The user can control the various functions of the camera through either the user's home computer, through the user's smartphone, or through a compatible web browser. The home computer or laptop will be referred to as the base station. These three methods will not have all of the same features, but the important feature that they share is the ability to view the live video feed.

XII. REMOTE DESKTOP ACCESS

A desktop application is required for the KWS camera. This is the main method of viewing and accessing the KWS video stream. This program was written in C++ while developed and tested in Microsoft Visual Studio 2010. It was also developed to run on a PC running Windows XP or newer. The program will be fully functional only if the base station is connected to the KWS network. When this is done correctly and successfully, the user will be able to use the KWS desktop program to properly connect to their KWS camera.

The program can be used to display the video stream, display the diagnostic information, and record the live video stream. When the user launches the program for the very first time, they will be prompted to enter the IP address of the KWS camera. The IP address will never have to be entered again unless the IP address changes or the user wants to connect to a different IP address. There will be an option to allow the user to change the IP address.

After the user has entered the IP address, their computer will serve as the base station and the user will be able to

access the camera whenever they desire from the KWS program. The program will be displaying in real time two important items; the video stream and the diagnostic information as discussed earlier.
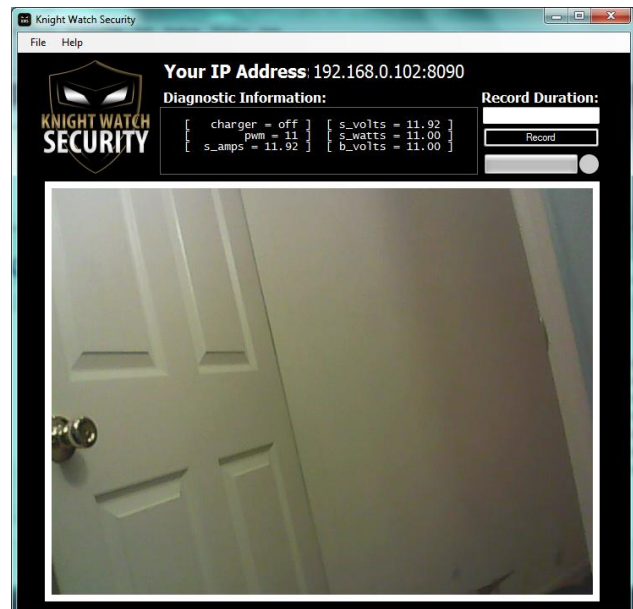

Figure 7. KWS Desktop Application

The other feature the KWS desktop program provides is the ability to record the live video feed. The user must specify the duration of the desired recording as well as the destination of the recordings. Those two details help make the features of the KWS camera user specific. In short, the user can implement their configurations.

To producing large files, the recorder forces a cutoff duration for the video files. The recorder can only record five minutes of video or less into a video file. This means that if a user wanted to record 21 minutes and 30 seconds of video, the recorder will output five video files: four 5-minute long videos and one that is 1-minute and 30 seconds long.

Additionally, there are two external requirements that are needed in order for the KWS desktop program to work properly. The first requirement is that the user must have the program VLC Media Player installed onto the base station. The second requirement is that the user must also have the internet browser Mozilla Firefox installed onto the base station. The explanation of these requirements will be discussed in the sections XIII and XVI.

XIII. VIDEO STREAMING

As discussed earlier, the format in which the camera will output the video feed is MJPEG. MJPEG is an

excellent video format that separately compresses each frame into a JPEG image. It then transmits the video as a sequence of JPEG images. This is the most widespread picture compression format used today. It can be seen in everyday uses such as in a digital camera.

MJPEG is the best fit for the KWS project. As a security system, frame by frame playback is a very important feature. This is especially true when a user wants to view video to identify who dropped off a package or who approached their house for example. Additionally, due to its less computation-intensive nature, less expensive hardware can be used and the overall cost of the camera can be reduced.

Once an MJPEG stream is produced, it can be further transcoded and saved in an MPEG-4 format. An MPEG-4 codec uses prediction algorithms to achieve higher levels of compression than MJPEG while preserving image quality. The main advantage of an MPEG-4 format is that it reduces the amount of storage space needed. This is essential to the KWS desktop application because it has the potential to save a large amount of videos to the base station's hard drive. To perform this transcoding, the KWS program requires the VLC Media Player.

XIV. REMOTE SMARTPHONE ACCESS

An important feature that the KWS system must have is smartphone compatibility. From a smartphone, the user will be able to launch the KWS app that allows them to interact with the KWS camera. At every launch, the user must enter the IP address of the camera. After a successful connection the user will be brought to a display showing the live video feed.

The KWS app that was developed is an Android application. Developers can develop Android apps using Windows, Linux, or a Mac, which was ideal for the KWS project. One perk to developing an Android app is its free resources such as the Android Software Development Kit (SDK). The KWS app was written, developed, and tested using the Android SDK.

Figure 8. KWS Smartphone App

XV. TRANSCODING AND SAVING VIDEO

VLC Media Player will be used in conjunction with the KWS desktop program. It is a cross-platform media player and streaming media server. It supports various audio and video compression methods and file formats, such as MPEG-4. VLC is also able to stream over a computer network and transcode multimedia files. KWS will use VLC to transcode the MJPEG video stream into an MPEG-4 format and save it to the user's desired directory.

XVI. REMOTE INTERNET ACCESS DESIGN

As mentioned earlier, the KWS camera will be streaming in an MJPEG format over a network. In order to view this video stream, a web browser must be used that has support for MJPEG. Three popular web browsers were considered and it was determined that the KWS camera should use Mozilla Firefox if the user wanted to view the video stream from a web browser only.

The first web browser considered was Internet explorer. Immediately this was turned down because it does not have MJPEG support. The second web browser considered was Google Chrome. Google Chrome does have MJPEG support and can be used to view the KWS video stream.

However, it is Mozilla Firefox that should be used to view the video stream because it supports MJPEG and it is already a required by the desktop application to be installed onto the base station. The reason for this is because the desktop application had two web browser options available during development: Internet Explorer and Mozilla Firefox. Internet Explorer cannot be an option, therefore, Mozilla Firefox is left.

XVII. PORT FORWARDING

Remote monitoring from outside the home network will require port forwarding. Port forwarding is the redirecting of information packets that are sent through the internet so that they can reach their intended destination without being inhibited or blocked. Port forwarding must be set up through the user's router and the process can be different for different routers.

XVIII. NETWORK CONNECTIVITY

To assist with development and testing, a D-Link Xtreme N Gigabit Router was used to establish a LAN or local area network. A LAN is needed to allow the Wi-Fi devices on the network to communicate. This router is a newer 802.11 h router that capable of 54 Mbps. Having

the LAN established allows developers and inevitably all users signed into the router to access the video stream from the camera.

XIX. THE PROTECTIVE HOUSING

The protective housing is an all inclusive. It contains the battery, solar panel, all the power circuitry, the camera and the 335x. The camera is in a subsection of the housing that can be adjusted independent of the bulk of the housing.

The housing has been designed to be weather resistant. The current prototype is designed form ¼" plywood reinforced with 1-2" struts. The housing could be easily rebuilt out of aluminum or Plexiglas.
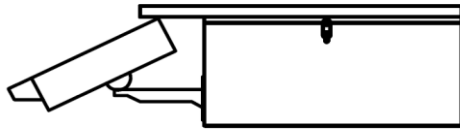
SIDE VIEW
HOUSING WITH SOLAR PANEL ATTACHED

Figure 9. Side View of camera housing with panel

On the back side of the panel there are switches and fuses that can be accessed from the outside of the housing. There is a protection fuse for the battery, the solar panel, the 335x and the 12v power outlet. The switches on the back side of the housing control the analog battery status indicator, the automatic spot light and the 12v power outlet. The 12v power outlet is a standard cigarette lighter that can be used to charge a cellular phone or power a lightly loaded 12v device.

XX. CONCLUSION

KWS has accomplished its goal of a self sustained network compatible surveillance camera. The processes and methods described were generated through extensive research. MPPT proved to be a very achievable and cost effective way of maximizing battery recharge time and battery over charge protection. The AM335xEVM-SK provided an excellent launch pad for development and prototyping. Software development through the Android SDK and Visual Studio provided a friendly environment to develop and debug our user applications.

ACKNOWLEDGEMENT

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THE ENGINEERS

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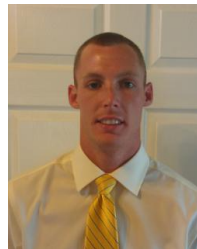
Joseph T. Coffaro is receiving his BSEE from the University of Central Florida and will be graduating Spring of 2013 with plans of attending graduate school starting Fall of 2013. Joseph spent three years interning at Harris Corporation and is currently working for the UCF Wave Propagation Research Group.

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