Cost Effective Panoramic Infrared Camera

Laith Charles, Alejandro Drausal, Nicholas Gaor, and Tyler Johnson
Department of Electrical Engineering and Computer Science, University of Central Florida, 32816-2450

***Abstract*—Creating a panoramic picture using an infrared camera mounted on a stepper motor. This is achieved by incrementally pulsing the motor and transmitting frames over WiFi, ultimately using software to display the images to the end user.**

I. Introduction

A cost effective infrared panoramic is a platform which can supplement current security solutions. Infrared detectors provide a unique advantage over normal charged coupled device (CCD) and complementary metal-oxide-semiconductor (CMOS) detectors. Infrared detectors can see outside the human vision spectrum which allows them to detect warm blooded animals and other hot items without the need of supplementing illumination. This technology has been widely used in military applications to provide situational awareness to troops in the field and help protect bases from incoming threats. Taking this previously expensive military technology and implementing a budget 360 degree panoramic solution to be used in commercial and residential application could be extremely beneficial at increasing safety while protecting high value targets, increase the efficiency of surveillance solutions, and reducing the frequency of false alarms.

As infrared technology decreases in price the amount of applications for this detection hardware increases. The solutions currently available for residential and commercial applications are limited. It is expected this technology will become more appealing for public. There is a need for the capabilities the infrared detectors offer. A product packaged correctly, marketed efficiently, and sold at reasonable price could have great success in the surveillance market. There is a potential to generate a large amount of revenue with the correct infrared detector solution.

Our proposed solution is a panoramic long-wave infrared (LWIR) device. Infrared detectors are dropping in price, however, they are still expensive for the commercial, residential, and non-military government applications. Therefore, maximizing the potential of a single medium resolution to create a product which provides the most imagery for the least amount of money is desirable in making a successful product. By rotating an infrared detector about an axis parallel to the detector plane a panoramic visual of the surrounding environment can be realized and output a visual which can assist surveillance applications.

This product will be mounted on a motor driven rotating platform powered by a driver which can be controlled by a computational unit. The images captured from the camera will be to a computer where it can be viewed. A heavy design consideration is expandability. This will allow the device to be integrated into a variety of existing security systems. The product should also be able to serve as its own surveillance solution. A versatile device which can be mounted both indoors and outdoors and provide good image clarity under a variety of environments which can be easily controlled by an operator.

The most demanding design consideration for this product is the cost of the final device. This is key to making a prosperous product in a established security industry which currently doesnt widely utilize the capabilities of infrared detectors. Making add on modules which can expand the functionality of this detector to make a solution which can satisfy any number of security needs.

A. Related Projects

Before beginning development on the panoramic camera, it is important to consider alternatives which may already have solved the problem we are going after. If a product already on the market meets the need we are trying to meet, it may be possible to take design elements from this products and improve upon them. Examining similar systems can show us where these products fell short, or what considerations we aren't currently aware of.

SmartPhones: Currently, the most widely used panoramic solutions globally are smartphones. These solutions typically involve the user holding a smartphone and activating the panoramic mode on the cellphones camera feature. The user begins on one side of the desired panoramic capture and slowly pans the environment until the desired area has been captured. This is a convenient solution as it takes hardware already included in today's phones and re-purposes them to create a panoramic image which can be used to capture a wide horizontal FOV. The smartphone takes advantage of the accelerometers, gyroscope, and the data from the camera to determine the direction of the device and then using a large amount of image processing the information is stitched together into a single image.

Fisheye Panoramic: The fish-eye panoramic is another solution to infrared panoramic imaging which offers a unique solution. This is a lens which you can put on a standard FLIR camera. Instead of utilizing a rotational interface to provide a panoramic solution for surveillance this lens extends the FOV of a regular infrared detector.The lens bends light to offer a complete panoramic solution for an uninterrupted complete 360 degree view. The benefit of a solution like this is live video feed from an infrared array. Unfortunately, this solution would be rather expensive to implement. A high resolution detector would be required to provide useful imagery at range. Specialized lenses for infrared light are expensive.

Digital Rotating Panoramic: This solution utilizes a controllable motor which can rotate the focal plane of the camera.The camera has a single strip of pixels, a one dimensional array which as the motor scans the environment, which reduces the cost associated with the focal plane of the device. The cameras orientation can be changed and configured to rotate around any number of axis. A stepper motor shifts the camera slightly the strip of CCD pixels capture light data which the device is pointed towards at that moment. Then the camera shifts slightly to capture the next strip of data. By doing this process repeatedly the camera is able to create a panoramic representation of the environment at a fairly minimal cost respectively. The disadvantage of such a process is the time it takes for a single scan of the environment to occur.

II. Overall Design

A. Hardware Design

The focus of this section will be mostly the moving and components of the project. Playing by this strategy, it was much simpler to break down the section into 4 smaller pieces:

- Rotational Platform
- Motion
- Base Unit
- Viewing Interface

If you refer to Figure 1, you will see the design flowchart for the overall hardware design. The rotational platform portion is color coded orange, Base Unit corresponds to blue, the Rotational Platform matches with the green, and the motion design aspect is found all throughout all 3 sections.

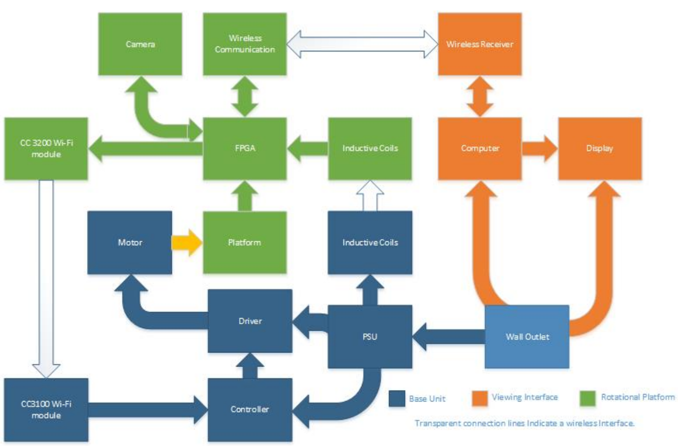


Figure 1: Hardware Design Flowchart

1) Rotational Platform: Of the 3 main areas that house the entire project, the rotational platform acts as the pivotal point for the camera. With that being established, the platform is the foundation of the following components:

- Tamarisk
- MicroZed
- Carrier Card
- Wireless Communication
- Inductive Coil Interface
- Platform

We have the rotational platform made of printed plastic and dimensioned at 5.5" in diameter. A hole small enough will be drilled directly in the middle of the platform so that the OMHT17-075 Stepper Motor may be installed, giving the platform its rotational ability. For clarification of the components being placed on the rotational platform, please refer to Figure 2.

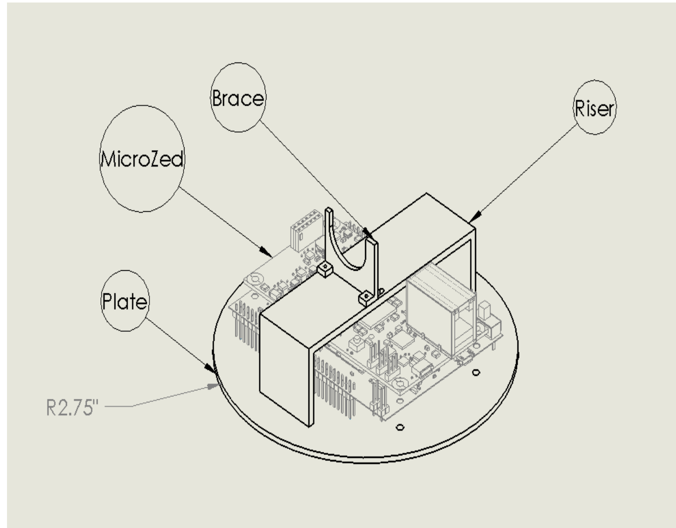


Figure 2: Rotational Platform Components

Tamarisk: The Tamarisk camera comes with two options when configuring the hardware of the device[3]. The first is called the base configuration. The advantage of this configuration is that it allows for RAW frames to be transferred in 14-bit format. It also provides more control over the shutter of the camera, which will help with the timing section. The other configuration includes a feature board which allows for USB serial control as well as analog video out.

The second configuration of the camera is unfavorable since it does not allow access to the RAW information coming from the camera. The Base Configuration was chosen.

Pin Layout: If you refer to Figures 3 and 4, you can see that there are 60 pins in the base configuration. However, only 28 of them are used. 14 pins are used for the pixel data, 8 pins are used to control the camera and to get the status of the camera, and the rest correspond to power and ground[5].

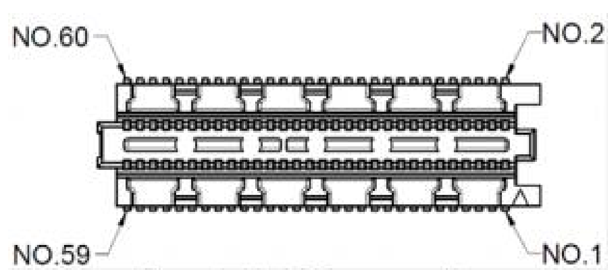


Figure 3: ST4 Tamarisk Pin Connection

Data Out: Odd pins 59 - 37 contain the first 12 bits (bits 0 - 11) of the Parallel Digital Data Output, even pins 48 - 46 contain bits 12 and 13 of the Digital Data Output.

MicroZed: We are using the MicroZed board which has a Zynq XC7Z010-1CLG400C as its core. This board allows for us to attach a carrier card to it. This carrier card allows for the I/O pins to be configured on the MicroZed in any way we configure for our project. It allows for us to communicate and power various other components[1].

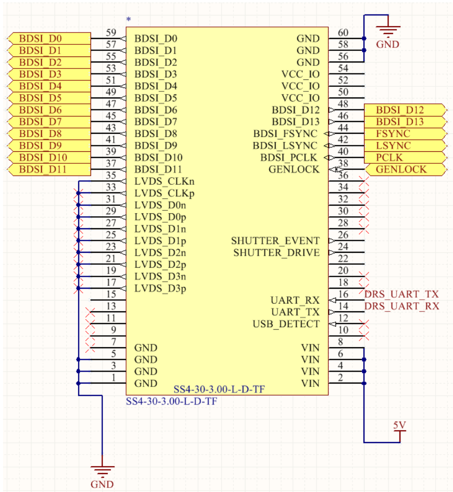


Figure 4: Tamarisk Pin Connections

Carrier Card: The carrier card is the main hardware component of the project. It houses the WiFi module as well as the camera connection. We designed it in such a way that it can connect to the MicroZed seamlessly and provide an interface to the camera as well as the CC3200. The carrier card has all of the necessary components to provide power to the MicroZed, Camera, Wireless module. There is even an environment that allows for more components to be attached to the device.

Wireless Communication: In the process of developing for the Zynq operating system, we found that it is problematic to get direct memory access through the operating system. As a result, we are instead using a TI CC3200. The CC3200 will receive the frames from the MicroZed through a hardware serial connection provided by the Zynq's PL instead of the operating system, eliminating the issues we had with memory access. The CC3200 will communicate to a CC3100 on the base platform, informing it when to spin the motor, and also getting feedback about motor position.

Inductive Coil Interface: The design chosen for the inductive coil on the rotational platform and the design on the stationary base will be the same[6]. The solenoids will have the same radius to maximize efficiency. The coils will have the same number of loops (n). The coils must be mounted directly above one another. Any misalignment ensuring the coils are mounted with the origin of each solenoid about the rotational axis would end up with inconsistent power transfer from base to platform. The coils will be made out of the same material, copper. All of these factors will ensure a good coupling between the coils. Also, reducing the distance between the respective coils as much as possible will increase the coupling of the coils.

Winding the actual coil will be done manually. In order to ensure ideal quality (q) of the inductive winding there are several considerations. The coil must be wound uniformly the loops should be as parallel to the pairing loop. The spacing between each loop should be uniform also. Wrapping the inductive coil will need to be done on a jig of some kind to ensure uniformity. Calculations on the inductive loop are as follows:

$$L = \frac{\mu * N^2 * A}{\ell}$$

$$Q = \frac{\omega * L}{R}$$

$$N = 12$$

$$A = \pi * r^2$$

$$r = 5cm$$

$$A = 78.5cm^2$$

$$\ell = 5cm$$

$$\mu_{copper} = 0.999994H/m$$

$$L = 2.26mH$$

$$P_{resistivityofcopper} = 1.796 * 10^{-8}\Omega$$

$$R = ((2 * \pi * r * N) + \ell) * P$$

$$R = 6.86 * 10^{-6}\Omega$$

$$Q = 329.42$$

The quality factor of the designed induction is 329.42 which is considered a good quality factor. The quality factor of the coil being good means the inductive power transfer from one coil to the next will be more efficient. Therefore, there will be less heat generation by the system and less interference from other components. It is theoretically possible to get infinite quality. However, attaining a Q factor of over 1000 is difficult. Given our space restraints a Q of 329 will be sufficient for the power transfer.

Platform: The platform will hold many of the significant subsystems for this project. On it will be mounted the Tamarisk camera, which feeds its data lines down to the PCB. The MicroZed will also be located on this platform along with its carrier card. Apart from the motor and motor controller, all necessary components of the system will be housed on the rotational platform. Figure 5 provides a visual detailing all of the dimensions and hole placements for the platform.

2) Motion: The motion of the Tamarisk camera will define how it will output the panoramic view. The Tamarisk 320 model we are using contains a 9° Field of View(FOV) which will define how the camera will move in general. Simply put, the camera will travel a full 360° while taking pictures every 9° for a total of 40 pictures. This will be done at the maximum possible speed that the motor and Tamarisk can achieve while working in sync with each other. For a better visualization regarding the Tamarisk FOV and how it creates its panoramic effect, please refer to Figure 6.

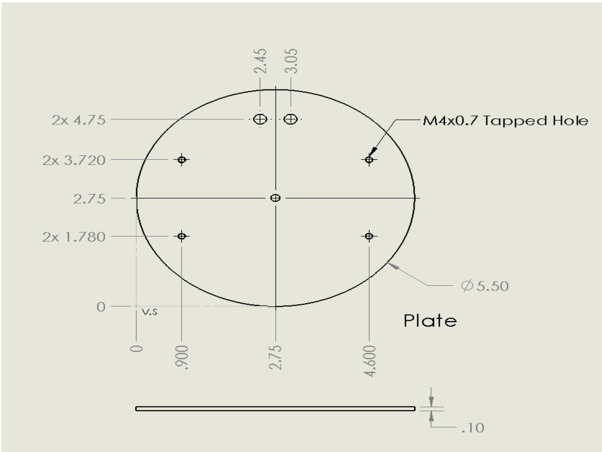


Figure 5: SolidWorks Platform Dimensions

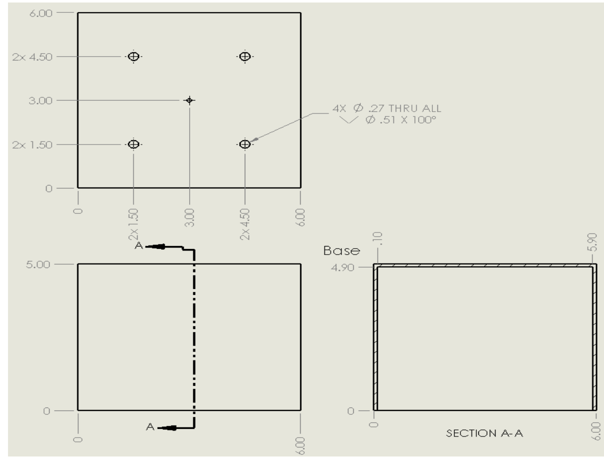


Figure 7: Base Unit Solidworks drawing With Dimensions

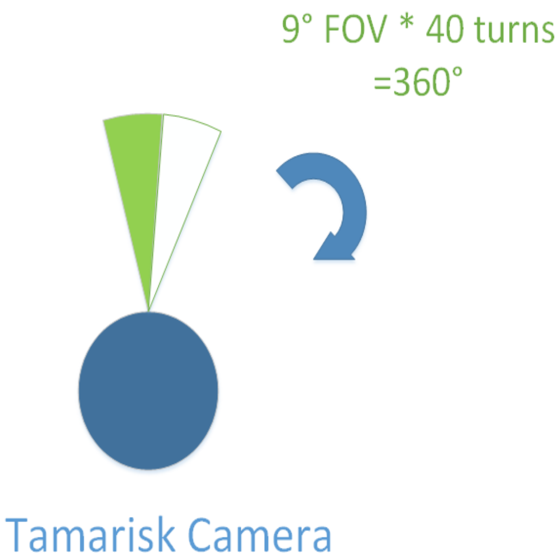


Figure 6: Tamarisk FOV illustration

3) Base Unit: The base unit for the project will act as the central hub where the project is stored. Specifications of the base unit is that it will be a 6”x6”x5” and made of printed plastic. There will be 4 holes that are placed in conjunction with the dimensions of the FPGA board and ultimately the rotating platform and Tamarisk camera. There will also be a hole directly in the middle of the base unit so that the OMHT17-075 Stepper Motor may be placed underneath but still have the rotating shaft above the base unit so it can maneuver the rotational platform. For clarification on how these holes will be placed, please refer to Figure 7 which contains a SolidWorks drawing of the base unit with the holes placed in it.

Power Supply: In terms of powering the stepper motor driver, we chose the OMPS300A24 which offers more than enough power to sustain the different components in the base unit. The OMHT17-075 Stepper Motor is actually powered by the STR 2 driver can use anywhere from 12-48 volts of power in order to operate[4]. We figured that in order to be safe with the voltage usage of the motor, we could settle with the OMPS300A24 model since it gave us exactly what we needed and cost efficiency is extremely important to the integrity of this project.

Battery: A battery must be fitted on top of the rotational platform in order to power the Zynq board and Tamarisk camera. The power requirements for the rotational platform components are:

- Zynq Board= 5 V @ 500mA
- Tamarisk Camera= 3.3 V @ 600mA

With these power requirements known, we can calculate what kind of power we would need from a battery:

$$Power = Voltage(V) * Current(I)$$

$$5V + 3.3V = 8.3V$$

$$500mA + 600mA = 1100mA = 1.1A$$

$$Power = 8.3 * 1.1 = 9.13Watts$$

This means that all of the rotational components require approximately 9 watts of power or 10 watts to be on the safe side. Since the Zynq Board requires 5 volts, we can go with a 5 volt or higher battery with at least 2 aH power rating so that we get the required power.

Motor System: Due to the nature of the project and precision required, we opted to use an OMHT17-075 stepper motor in order to get the desired pulse needed for the project. A fast car is nothing without a proper driver. In order to utilize the full stepping capabilities of the OMHT17-075, the STR2 Microstep Driver is connected in order to micromanage the pulses sent to the stepper motor. To bring it all together, a Tiva 1294XL board is being used to feed logic into the stepper driver.

4) Viewing Interface: Although the output from the camera is formatted with 14 bit greyscale, most displays are not capable of displaying pixels with 14 bit values. Because of this, we will scale down the value of each pixel to an 8 bit representation, making the image more accessible to any type of display.

Website and Display: The panoramic output will be available for any operating system which supports C# Windows Presentation Foundation applications. Our main development platform was Windows, so we designed around this. Given the high resolution of the picture, optimally the output will be viewed on a high resolution monitor. We will split the outgoing video into 4 sections, each 90 degrees field of view, so that it will be easier to view the output on a wider variety of devices. The application will have the ability to allow the user to change various camera settings as well as some of the gain and levels that the Artix-7 uses to correct the images. As seen in Figure 8 there will be a portion where the user can go into the settings and change the way the camera functions. These controls are the ones that DRS provides natively on the camera, which are an interface to those controls. At the bottom there is a message box that shows any errors that have occurred with the communication to the camera. It is placed so that the user can see the error codes without having to search for them.

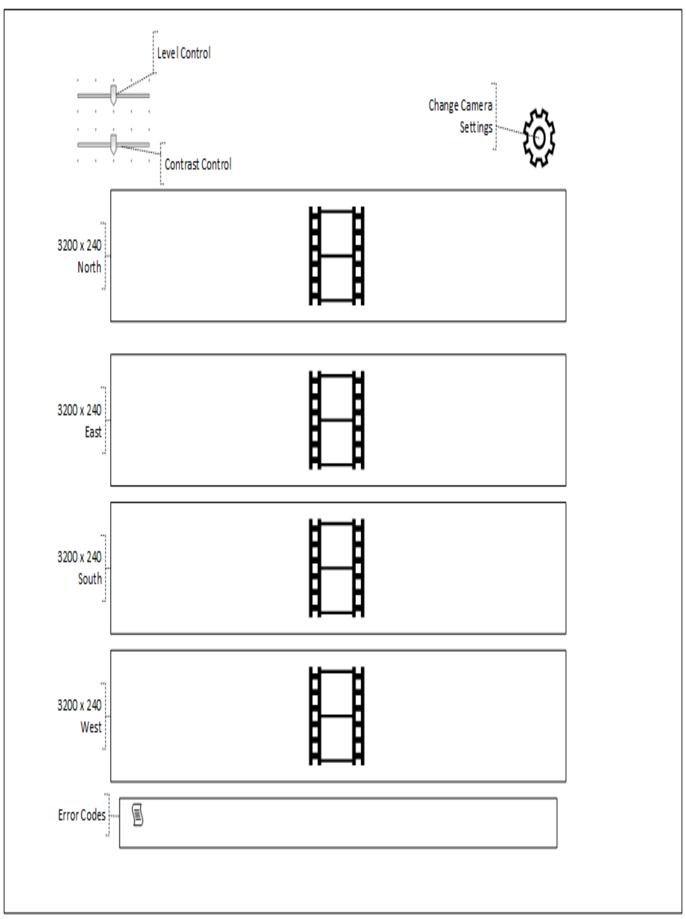


Figure 8: Application View

B. Software Design

The code for the project will be split up into various distinct parts:

- Camera Communication - How the system will communicate to the camera.
- Motor Communication and Control - How the system will communicate with the motor.
- Embedded Linux - The tasks the operating system will have in the system.
- End-User Interface - What the end users interface will look like.

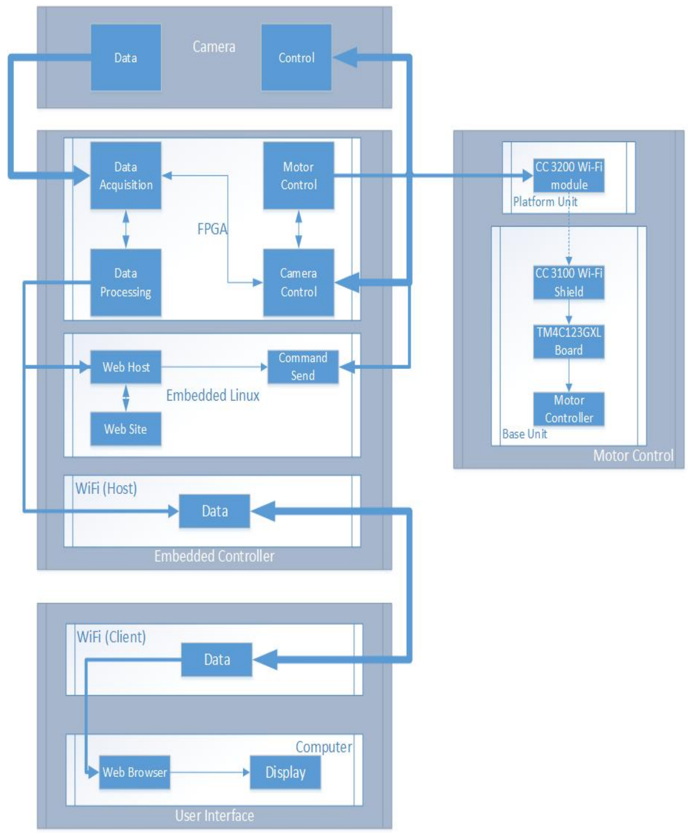


Figure 9: Data Flow in Software

1) Camera Communication: All of the information regarding the camera software communication is taken from Tamarisk software interface control document[2].The Tamarisk camera is capable of outputting in serial through several routes. The most common links used are the RS-232, USB or UART. The RS-232 offers a 57.6k Baud rate by default, enough for the purpose of communicating to the Zynq. However, in order to get output in a digital form, the use of UART is required. Familiarity with UART led the group to determine this would be the best way to receive output from the camera. The baud rate can be set to whatever value is needed when using UART, so the default value of 57.6k will be used. This can be adjusted if it is felt that adjustment is needed. For an in-depth explanation and visualization, please refer to Figure 9.

The Tamarisk supports a set of hexadecimal instructions which will make debugging and adjusting settings easy. Communication back to the camera will be done through the Zynq, as this is the only point of communication to the camera. The Zynq will be configured to signal certain LEDs when communication error occurs to aid in debugging.

There are 25 commands which are of interest to the end-user and us as the developers of this project. These commands handle every setting on the camera from time between camera calibrations to the auto-gain correction level. These commands are sent in the form of messages, which follow a set format.

UART: Since the Zynq is a completely programmable chip there are some configurations that need to be done in order to allow for this communication. Using the Xilinx software. Xilinx makes it easy to configure the pins in software as shown in Figure 10. Each component on there needs to be added before any programming can be done if not the Zynq is unaware of what hardware is attached to it.

UART is part of the MIO ports which the Zynq Z7010 has 31 usable MIO. It is important to note that each MIO port can only be taken up by one peripheral. Therefore, we have chosen specific pins to be used.

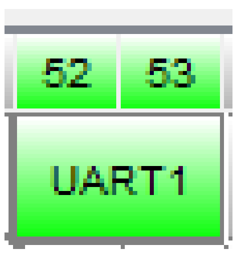


Figure 10: Xilinx MIO UART Configuration

We will send commands to the camera through the CC3200. Most of the composing of messages to the Tamarisk will be done client-side in the end-user application. These messages can then be directly routed to the camera through the MicroZed. From a user perspective, sending commands to the camera will involve selecting one of 25 different commands, and possibly entering a value they want sent. This input will be taken care of in the application to be put in the format that the Tamarisk understands.

To accomodate the simplest method, a C program was written to facilitate commands to the camera from the MicroZed. An example of how to write to the camera is demonstrated in Figure 11. Once the command is written to the camera the camera will reply. Figure 12 shows how to read the information coming from the camera to make sure that it executed the command correctly. If the camera did not execute the command correctly there is an allotted amount of times that the command will be resent before a timeout occurs. At that point the user is alerted that something went wrong with sending that command to the camera.

2) Motor Communication and Control: The main method of communication to the motor will be the Zynq. The Zynq determines when it is an appropriate time to trigger the command to start turning and then wait an appropriate amount of time until the motor is in position and capture an image from the camera. It will determine the timing based on the average time it takes to rotate 9°. The signal which the Zynq transmits will be sent through the CC3200's WiFi module and received by the base unit's CC3100 WiFi module. This in turn will send logic through the Tiva board and pulse the motor to move so that the Tamarisk can take the next picture.

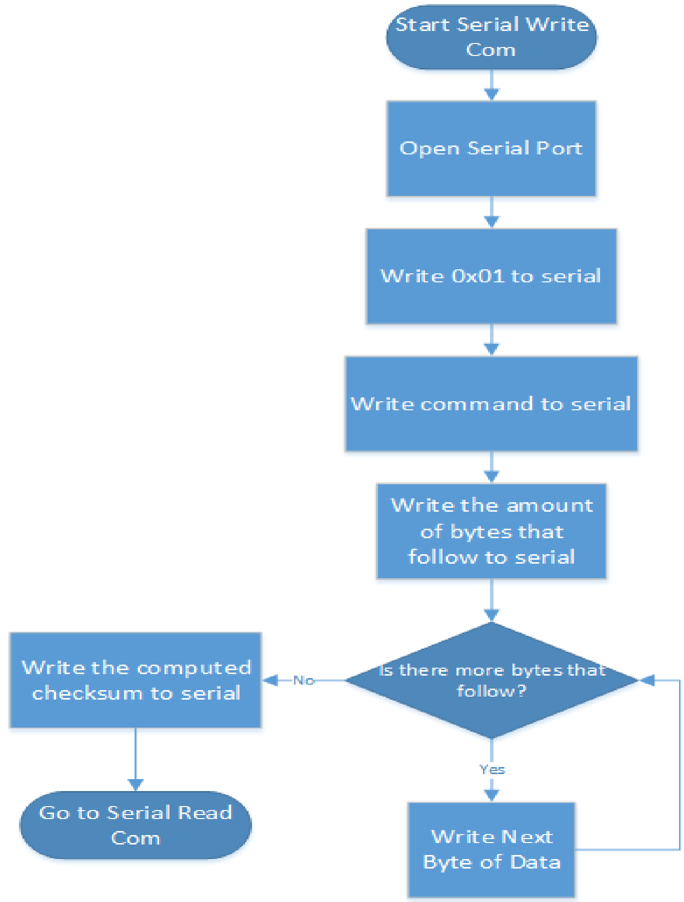


Figure 11: Serial Write to Tamarisk

3) Embedded Linux: The microcontroller we chose for this project, the MicroZed from ZedBoard, comes with a version of Linux built for embedded systems. This aided us greatly in development, as it let us create scripts for giving and getting instructions between the camera and the user. As development progressed we moved away from using the operating system and instead chose to interact more directly with the hardware, giving us direct memory access much more easily. Much of the early development was done on this operating system.

4) End-User Interface: As this project was a great way to gain experience in areas we had not touched upon much before, we chose to develop a C# application which would communicate with the CC3200 through UDP. Because we are utilizing wi-fi and the IP stack, standard to any network connected device, the end-user viewing environment can be any operating system which supports C# applications.

The end user program is minimalistic, but offers the intended output in an easy to read window. The application

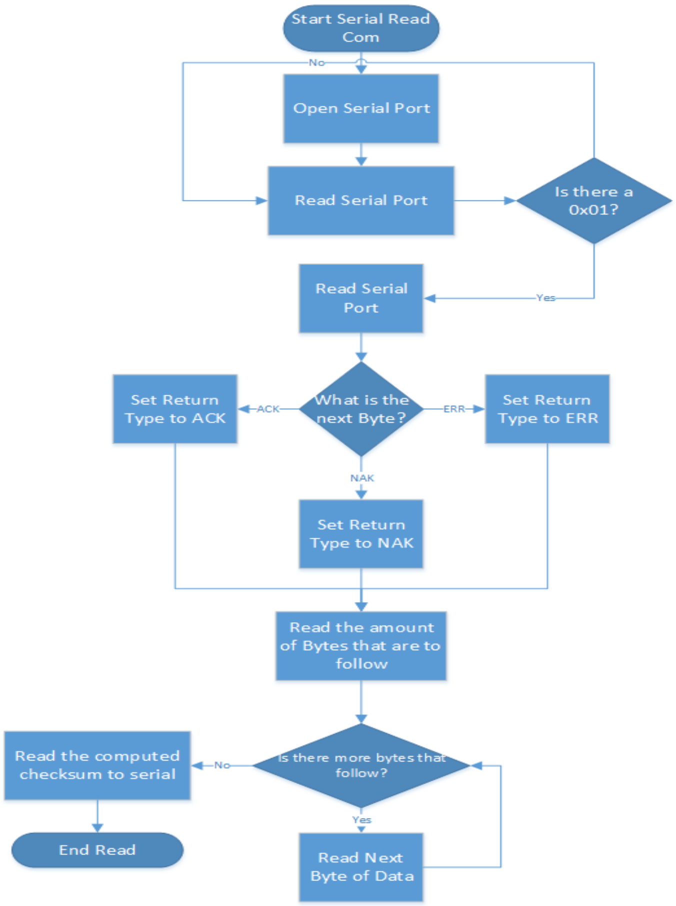


Figure 12: Serial Read to Tamarisk

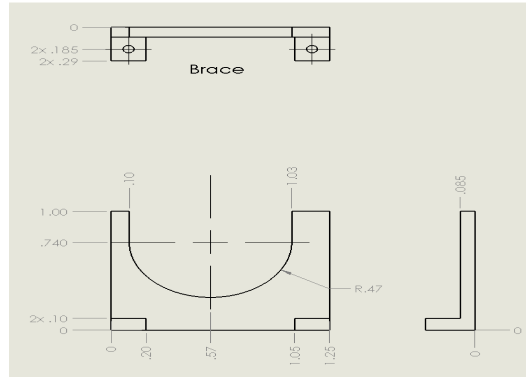
updates images as they are updated server side automatically. Error codes are displayed on the bottom of the page that allows for debugging. The page also contains a menu, which allows the end user to customize the settings and picture output. Figure 13 provides a complementary diagram that illustrates the general process described above.

Figure 13: End-User Communication

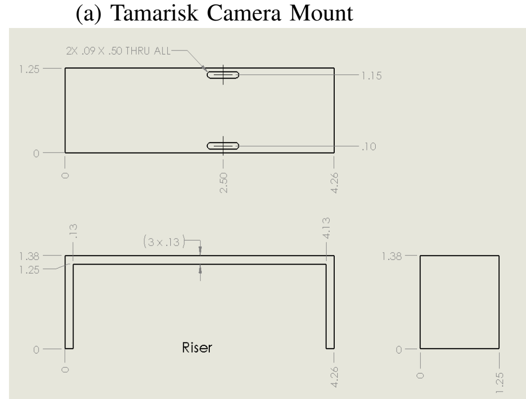
C. Housing and Mounting

One of the things that need to be considered when designing this system is how it will stand up to an outdoor environment. The intended use of the infrared panoramic camera is for surveillance; mounted in a long-term fixed area, which means it will need to withstand a variety of weather conditions. Another consideration when designing the housing is the stability of the system. It needs to be resistant to vibrations and the movement coming from the motor rotation. With these things managed, the camera system should be able to operate in any environment.

Camera Mount: The Tamarisk 320 maximum dimensions are 34x30x30mm and weighs approximately 29 grams. With this in mind, a brace and riser platform have been designed and built in order to accomodate the camera. These mounts ensure that the Tamarisk holds steady while providing housing that isn't obtrusive to the field of view or operation of the Tamarisk. Figures 14a and 14b are solidworks renderings that illustrate how the Tamarisk will be housed.



(a) Tamarisk Camera Mount



(b) Riser Platform

Figure 14: Camera Mount Components

The camera mount system is mounted above the controller and will be fastened to the rotational platform. A small platform will act as a bridge, extending over the Zynq board. This platform will supply a mounting interface for the camera so it will not interfere with the Zynq board.

Motor Mount: The housing for the motor consists of a resilient plastic base. The base is large enough to house all of the base unit components while providing a sturdy foundation for the rotational platform and its components. Since there are many electronics and moving components housed here, a small heat sink or other ventilation solution will be required to adequately dissipate heat.

Mounting Overview: Combining the different mounts and housing systems, Figure 15 shows a rendering of the entire project assembled and integrated with itself.

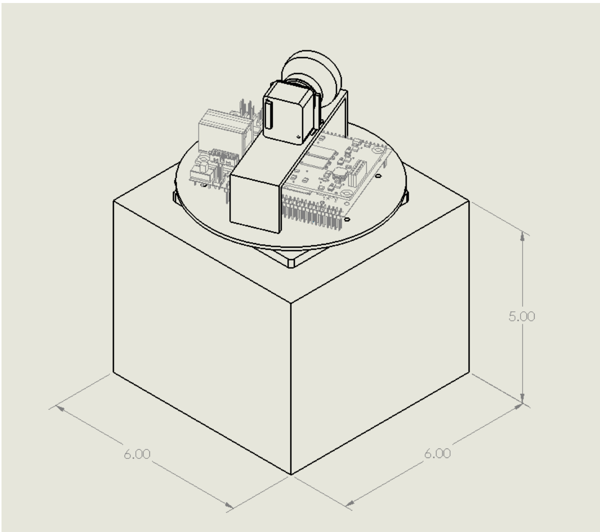


Figure 15: Combining All of the Mount Sub-Systems

III. Conclusions

Holistically, the project encompasses a wide variety of knowledge that was covered or at least touched upon in previous classes. As for material that wasn't taught in class, a lot of research has gone into exploring the ins and outs of specific sub-systems that are apart of the whole project. Categorically organizing the project, we have broken it down into 3 main sections:

- Hardware
- Software
- Housing and Mounting

As luck would have it, our group of 4 is comprised of 2 electrical engineers and 2 computer engineers. This allowed us to focus on our respective majors in that the electrical engineers focused on hardware while the computer engineers focused on the software aspect with everyone equally working on the Housing and Mounting system.

The hardware portion focused mainly on the motor, power supply, camera, and board that were going to be used for the project. On the other hand, the software aspect is centered around setting up the Zynq board and all of the logic that will go between each sub-system i.e. how all of the sub-systems communicate with each other. Lastly, the housing and mounting portion of the project focuses on how each different component and subsystem will be placed and ultimately housed. Since the project is going to be used in different environments, a lot of consideration went into how each of the components will be placed and logistically connected to each other.

Acknowledgment

Collectively, Group 2 would like to thank all of the professors and peers who gave us advice and motivation to take on this project. This project would not be possible without the aid and guidance of St. Johns Optical and its affiliates, as well as the helpful sponsorship of Applied Motion Products.

References

[1] Avnet Electronics Marketing. *MircoZed Production*, 1 2014. Rev. F.
[2] DRS. *Tamarisk 320 Software Interface Control Document*, 11 2013. Rev. E.
[3] DRS. *TAMARISK INFRARED SOLUTIONS THAT FIT*, 1 2013. Rev. 7.
[4] Omega. *Power Supplies for Open Frame Stepper Drives*, 12 2013.
[5] Omega. *Tamarisk 320 Electrical Interface Control Document*, 5 2014. Rev. D.
[6] Dries van Wageningen. An introduction to wireless charging, 7 2013.