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TITAN Wireless Camera Control System

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SENIOR DESIGN PROJECT II
(4400:402)

TITAN

Wireless Camera Control System

Final Report

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i. Abstract

The Titan Camera Control System is an eletromechanical device that allows the user to wirelessly control a camera's digital operations as well as physical orientation through the use of a mobile device application. The Titan system accepts input in the form of virtual user commands on the mobile app and performs system output in the form of sending photos/video from the camera back to the app as well as changing the orientation of the camera in accordance with the user's commands.

[MT, ID]

1. Problem Statement

1.1. Need

The modern world of electronics boasts of wireless connectivity, though there is a lack of practical and cost-effective camera systems in the consumer market that may be both physically and electronically controlled wirelessly. This device will provide a simple and economic solution to those looking for a way to remotely control most consumer-grade cameras in order to avoid placing themselves in precarious situations or for the sake of convenience.

[MT]

1.2. Objective

The objective of this project is to design and develop a product to provide consumers and professionals with affordable and practical remote camera control. Variations of this product may be easily implemented to tailor its features for civilian (professional and hobbyist), medical, research, and military applications. The particular device used as demonstration for this product is a consumer-grade model suitable for professional and hobbyist photography which features a lightweight design, portability, low cost, and battery operation.

[MT, ID]

1.3. Background

1.3.1. Patent Search

Two identified patents pertain to products that have previously been developed with similar operations and functionality to the Titan Remote Camera Control System. These patents are taken into account while designing this product in order to avoid trespassing legal boundaries.

The first patent is US 20140184829 A1, a Bluetooth-controlled electronic shutter control for a camera [1]. This camera system allows a user to activate the camera's shutter remotely using a Bluetooth connection in order to take a picture without having to manually take the photo or activating a timer [1]. This system is strictly for taking photographs using a Bluetooth remote control. This system only works for camera systems that have an on board Bluetooth module, as the remote control communicates with Bluetooth [1]. This does not allow users to activate a non-Bluetooth device with the remote.

The second patent is US 5073824 A, a remote controlled camera system [2]. This system uses radio to adjust the view and pitch of a camera that is attached to the system, as well activating the camera [2]. This system has a laser that can be controlled by the remote that will indicate to the user on what the camera is focused. This system is in essence the proposed project; however, the Titan project would relay a live video feed for aiming the tripod and the control would be through a mobile application.

[SD, OK]

1.3.2. Bluetooth Low Energy vs Traditional Bluetooth

1.3.2.1. Bluetooth Background

An opening perspective on Bluetooth Low Energy is given in the article Overview and Evaluation of Bluetooth Low Energy: An Emerging Low-Power Wireless Technology [3] . In this article Bluetooth Low Energy (BLE) technology is explained, evaluated, and assessed for its strengths and weaknesses. This is extremely relevant to our project since we want the video stream and controlled to be interfaced over a Bluetooth connection, and BLE is the most energy-efficient and ideal way to implement that.

Additionally, relating this technology to our intention of mobile application control is the article Bluesaver: A Multi PHY Approach to Smartphone Energy Savings [4]. This article explains how to integrate a Wi-Fi connection with a Bluetooth connection in order to reduce power consumption. Also relevant is the article PLC-controlled stepper motor drive for NC positioning system [5], which is in regards to driver stepper motors from a PLC controller. This research is quite applicable for our means of controlling the camera rig's pan and tilt via precise stepper motor control. An online scientific article titled Networking solutions for connecting Bluetooth low energy enabled machines to the internet of things [6] explains the method and background of using Bluetooth low energy technology to network hardware systems to for potential local and/or internet control and monitoring. This may be useful as a consideration of enabling the camera rig control and/or camera feed to be monitored and controlled through the internet. Another article titled Realizing MPEG-4 video transmission over wireless Bluetooth link via HCI [7] sheds some light on transmitting video through a Bluetooth link. The authors tested the transmission of MPEG-4 video across an older version of Bluetooth, which only offered a link speed of approximately 750 kbps, and found that with proper compression and data partitioning, video streaming across Bluetooth is reasonably good [7]. BLE has a link speed of 1Mbps, which should allow for better streaming and playback. This helps support the system's live video feed which is to be used for aiming the camera.

[SD, OK]

1.1.1.1. Analyzing Bluetooth Low Energy's Strengths and Weaknesses

Bluetooth technology exchanges data over short distances using radio transmissions (wireless). It operates at a band of 2.4-2.485 GHz rage [8] and uses an important feature called frequency hopping in order to stay connected to the right device and not have interference from others. Though often connected with one device at a time, Bluetooth devices actually do have the potential to connect with more than one device. Data is split into two packets that travel through 1 of 79 designated channels each with 1MHz of bandwidth (in order to not interfere with one another).

In 2011, Bluetooth Low Energy (aka BLE, Bluetooth 4.0, or Bluetooth 4.1) hit the market. The difference between BLE and the original Bluetooth isn't very fundamental; they both follow the same method of transmission. The most important difference between the two, however, is power consumption. BLE stays in "sleep mode" constantly and it only operates when an active connection is actually made. The data rates that BLE has are also much higher, which in turn makes the connection and transfer time between devices much shorter than original Bluetooth. Transmission range has also been increased with BLE technology. BLE will offer this project a much longer battery life by conserving a lot of power while still offering the capability of wireless communication. The power consumption is much smaller than from the conventional Bluetooth.

[SD, OK]

1.1.2. Similar Products/Projects

A brief market investigation has revealed a few products with similar function to that of our product that are already on the market, but with also distinct differences from our project. The SoloShot [9]. is a camera/tripod rig that automatically follows a user across a field of view. This product has been is development for years and has currently released their new SoloShot3 line. This product is mounted on an automated tripod and is used mainly used for sports due to their ability to track an active user. It is essentially the user's own personal cameraman.

A tracker is attached to the object the user wants the camera to track (usually a person). The camera/tripod system is turned on and the camera will talk to the Soloshot actuators and calibrate itself in order to get a connection to the tracker. The connection used to lock on and track its target is GPS. There are quite a few differences with this product and the Remote Camera Control Rig, however. Our device gives 100% of the control to the user, unlike the Soloshot, which only tracks the user position without the ability to perform discrete commands. We control exactly what we want the camera to capture and how to move with our phone app, while the Soloshot only tracks its target. Our product has many more applications it can be used for. We use Bluetooth communication rather than GPS tracking for communication. The main similarity between the two products is the overall look and basic operation. Cost is another critical consideration; the basic bundle of necessities for the Soloshot sells for upwards of $800, while the Remote Camera Control Rig is targeted for under $200.

Another familiar camera control product is the GoPro with its wealth of powerful accessories [10]. The more recent updates to GoPro's camera line resemble our product in the regard of connecting to a camera and controlling it with a mobile device via an Android (and/or Apple) app. This GoPro connects using WiFi and can even offer a live feed of the camera's image to the mobile device while also being controlled by commands on the app screen to make it take photos and videos as well as performs other commands. This device, however, has no control of the camera's orientation and is not compatible with non-GoPro brand cameras.

[SD, OK]

2. Design Requirements Specification

2.1. Marketing Requirements

The system should:

2.1.1. Be battery Powered
2.1.2. Relay a video feed in real time
2.1.3. Be able to change the camera's orientation
2.1.4. Operate the camera shutter
2.1.5. Handle limited outdoor use
2.1.6. Be simple to set up
2.1.7. Be easily mobilized/carried
2.1.8. Be lightweight
2.1.9. Wirelessly connect to a compatible mobile device

[MT, ID, SD, OK]

2.2. Requirements and Justifications Table

Table 1 relates the marketing requirements to engineering requirements as well as includes the engineering design requirement justifications in relation to the marketing requirements.

Design Requirements		Justification
Marketing	Engineering	
2,4	The system shall connect to an external digital camera.	Most modern digital cameras have USB ports on them in some fashion. Having a USB cable near where the camera is to be attached to the mount will allow the user to remotely control the device using a virtual command library.
2,9	The system shall successfully transmit video feed to a mobile app	Most mobile devices are now designed to be compatible with wireless components. The system is intended to transmit using wireless technology to the app so that the user can see what the camera sees and review pictures.
2,4,9	The system shall display a camera's virtual viewfinder on the mobile app	The companion app is how the user controls the entire Titan system. Showing what the camera sees (virtual viewfinder) on the app allows the user to know what's in the camera shot at any time.
3,6,9	The system shall change the camera's orientation using actuators	Part of what makes the system unique is its ability to physically control the camera's orientation, which allows for interactivity for the camera's visual environment. This is to be done using electromechanical actuators.
1,5,6,7,8	The system shall operate for at least 30 minutes on battery power	This system is meant to be easily mobilized. As such, it should be operated by batteries. 30 minutes of full-load operation should be sufficient for most applications.
5,9	The system shall operate wirelessly at a range of at least 5 meters	Bluetooth wireless method allows for exceptional bandwidth over a respectable distance while using less energy than its predecessor formats. The range of Bluetooth can far exceed 5 meters, though 5 meters is expected to work across multiple transmission mediums.
5,9	The system shall operate within a range of 50%-80% humidity	As part of the outdoor/mobile capacity of the device, it is intended to withstand the average outdoor relative humidity levels of Northeast Ohio (50%-80% RH)

5,9	The system shall operate within a range of 2-25 degrees Celsius	As part of the outdoor/mobile capacity of the device, it is intended to withstand the average outdoor temperature levels of Northeast Ohio (2-25 degrees Celsius)
5,6,7,8	The system shall weight less than 8 lbs	As part of the outdoor/mobile capacity of the device, it is intended to be easily carried and non-intrusive to the user. This requires the system to be relatively lightweight.

Table 1 – Design Requirements and Justification

[ID,MT]

2.3 Objective Tree

The objective tree is a visual representation of how the marketing requirements can be broken down into discrete demands with relative importance.

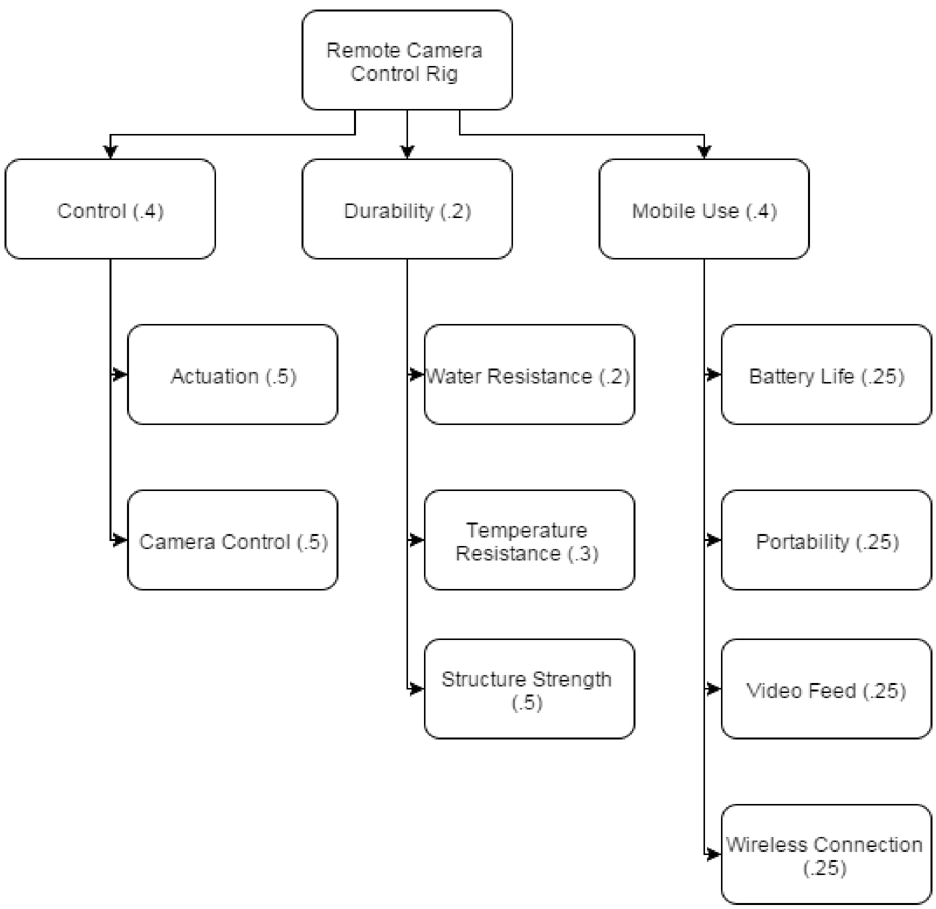

Figure 1: Objective Tree for Remote Camera Control Rig

[MT, ID, SD, OK]

3. Accepted Technical Design

3.1. General Operation

The Remote Camera Control Rig aceepts command inputs from the user via the mobile application over a wireless link and expresses output in the form of camera orientation actuation, digital camera control, and a feedback video stream (if enabled).

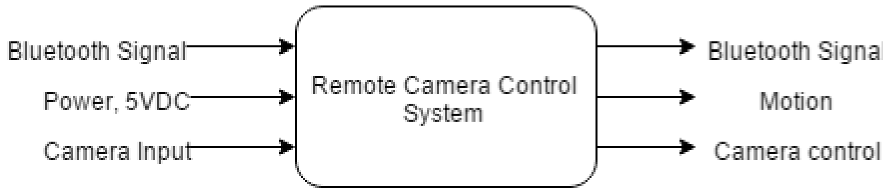

Figure 2 - Level 0 Block Diagram for Remote Camera Control Rig

Module	Remote Camera Rig
Inputs	• Wireless Communication • Camera Input • Power (5V nominal)
Outputs	• Video Feed Over Wireless Communication • Digital Camera Commands • Mechanical movement
Functionality	• Streams video to mobile app, orientation controlled by mobile app

Table 2- Level 0 Block Diagram for Remote Camera Control Rig Inputs and Outputs

The system is hosted by a Beaglebone microprocessor development board that interacts with the actuators, the wireless module (and thereby the app), and the digital camera interface. An on-board, integrated camera sensor module is used in conjunction with the microprocessor board so that digital cameras which do not support streaming video via the digital control library over USB link may still be accurately controlled (via actuation and, to an extent, digitally). Two options for embedded camera modules to be used are the HD Camera Cape by RadiumBoards and an average USB webcam. The HD Camera Cape is connected to the microprocessor board with an expansion module suitable to the microprocessor's design (A camera sensor cape, for example, is designed to marry to the BeagleBone board seamlessly.) The external, user-owned digital camera itself is controlled using the "libgphoto2" command line frontend on the BeagleBone board over a USB cable link. The image data and/or command data may then be streamed through the board to the Bluetooth module to be sent to the paired mobile device. The companion app on the paired device receives the image/command data and interprets it to display the video/image feed and/or camera control status. The board is battery powered as a staple design element of mobility, so the battery voltage and output must be regulated for the sake of the board's health as well as the battery's health via a power regulating circuit. Regulated power may also be distributed to the actuation servos so that they may operate without risk of loading effects to the microprocessor board (effects observed experimentally in the HS-422 servos) [11].

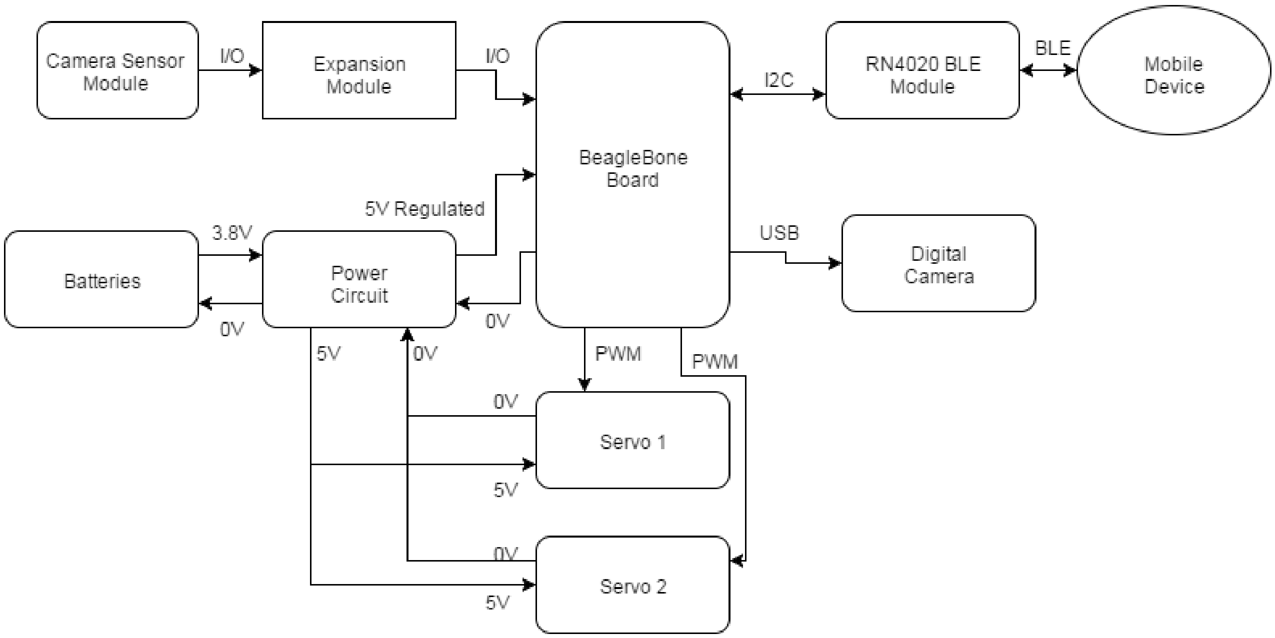

Figure 3 - Level 1 Block Diagram for Remote Camera Control Rig

Module	Camera Sensor Module
Inputs	• Light
Outputs	• Various digital I/O
Functionality	• Back-up camera

Table 3 - Functional Requirements for Camera Sensor Module

Module	Expansion Module
Inputs	• Various digital I/O
Outputs	• Various digital I/O
Functionality	• Marries camera sensor to Beaglebone board

Table 4 - Functional Requirements for Expansion Module

Module	Batteries
Inputs	• Charging current
Outputs	• Unconditioned voltage/current, 7.2V
Functionality	• Powers the system

Table 5 - Functional Requirements for Batteries

Module	Power Circuit
Inputs	• Unconditioned voltage/current, 7.2V
Outputs	• Conditioned voltage/current, 5V
Functionality	• Converts and regulates battery voltage to useable level

Table 6 - Functional Requirements for Power Circuit

Module	Servo 1
Inputs	• PWM signal 1, 5V
Outputs	• Z-axis rotation, GND
Functionality	• Panning actuation

Table 7 - Functional Requirements for Servo 1

Module	Servo 2
Inputs	• PWM signal 2, 5V
Outputs	• X-axis rotation, GND
Functionality	• Tilt actuation

Table 8 - Functional Requirements for Servo 2

Module	Digital Camera
Inputs	• Light, USB link
Outputs	• USB-link data
Functionality	• Camera sensor

Table 9 - Functional Requirements for Digital Camera

Module	Bluetooth Module
Inputs	• Digital commands/data to app, Wireless commands/data from app,
Outputs	• Wireless commands/data to app, Digital commands/data from app,
Functionality	• Enables wireless communication with mobile app

Table 10 - Functional Requirements for Bluetooth Module

Module	Mobile Device
Inputs	• Wireless commands/data from Titan, user touch
Outputs	• Wireless commands/data to Titan, picture/video display
Functionality	• Allows user to control Titan system and see camera image

Table 11 - Functional Requirements for Mobile Device

Module	Beaglebone Module
Inputs	• Expansion module I/O, digital camera USB link, digital commands/data from mobile app, 5V regulated
Outputs	• Expansion module I/O I/O, digital camera USB link, digital commands/data to mobile app
Functionality	• Main Titan system electronics processor

Table 12 - Functional Requirements for Beaglebone Module

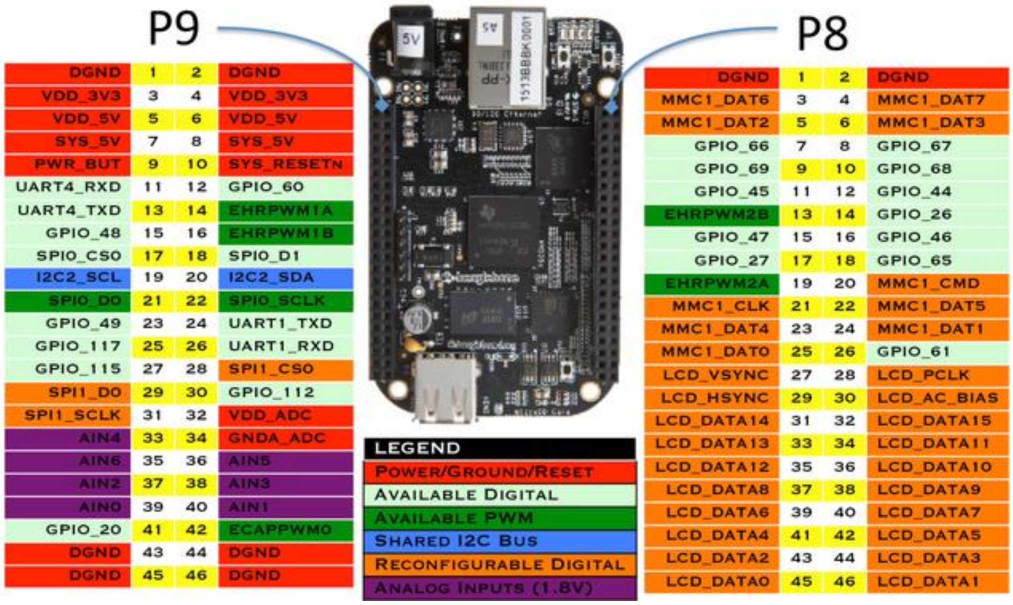

Figure 4 - All available pins on the Beaglebone Black

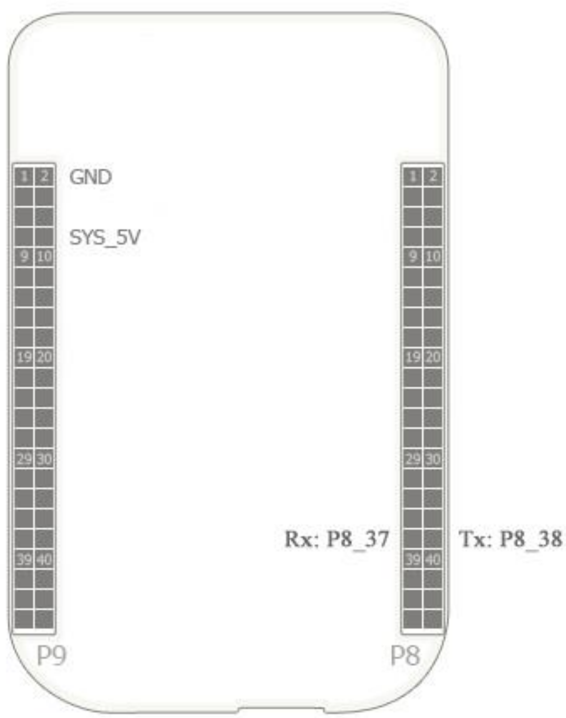

Figure 5 - Bluetooth module pinout

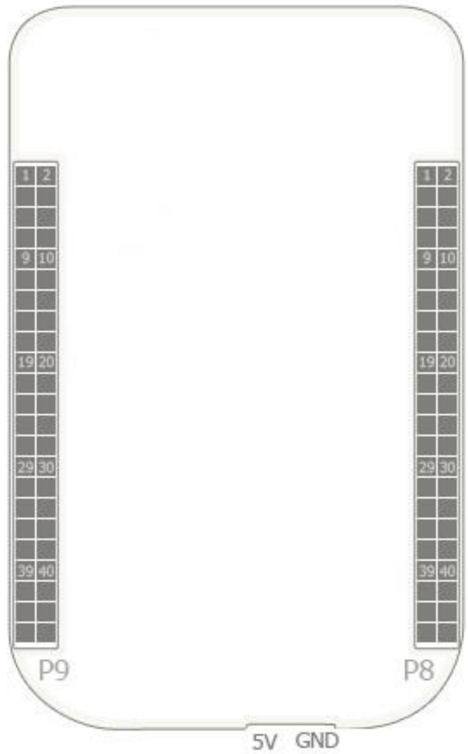

Figure 6 - Power circuit pinout (via power jack)

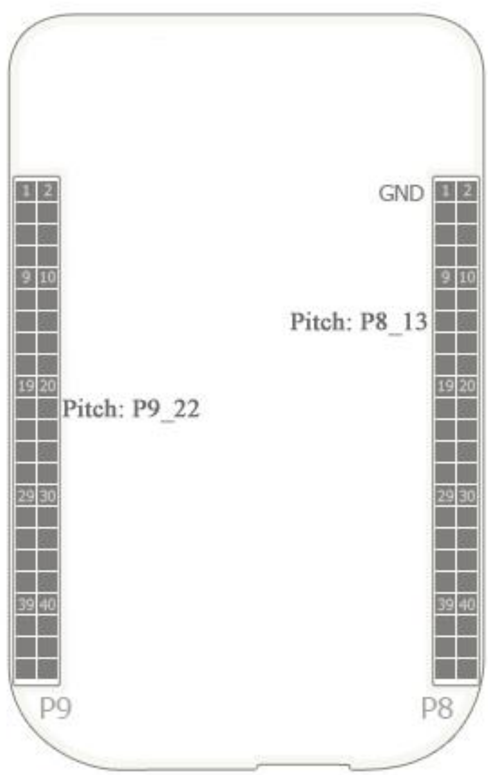

Figure 7 - Servo PWM pinout

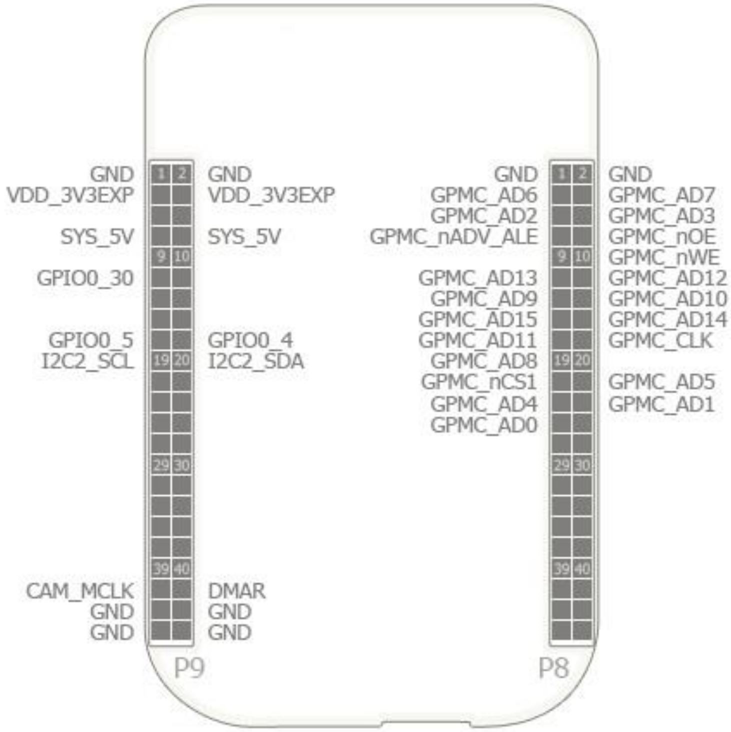

Figure 8 - Camera Cape pinout

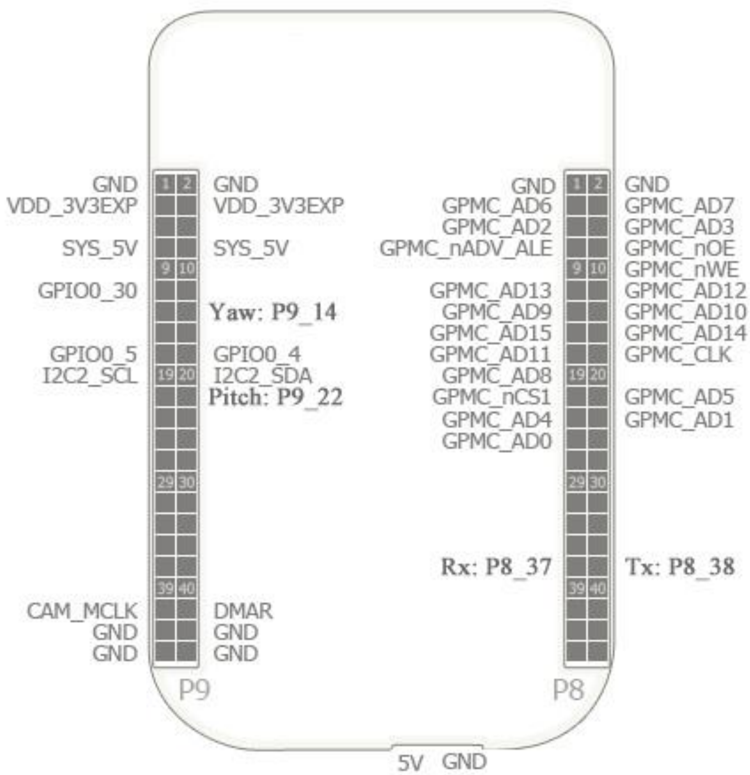

Figure 9 - Composite pinout diagram

[MT,ID]

3.2. Microprocessor Platform

The BeagleBone Black development board (with internal microprocessor and processing power) is used as the microprocessor platform to host a hub between the digital camera, servo actuators, embedded camera, and Bluetooth module. The BeagleBone has sufficient GPIO pins as well as processing power to handle the tasks needed to manage this system, which was an important consideration in its selection as the project's main processor. The BeagleBone boasts a 1GHz processor with 500 MB of RAM [12] which is within ideal range for streaming mid-to-low quality video feeds. For live-streaming either the embedded camera or the viewfinder of the attached camera, having a faster clock is better for sending more packets over Bluetooth to the mobile application. As for rival development boards, options in lieu of developing a custom board included using either an Arduino or a Raspberry Pi. The Arduino does not have a fast enough clock speed or enough RAM for buffering the streaming data to be useful in this task. The Raspberry Pi is more comparable to the BeagleBone, but while a Raspberry Pi 2 has a 900 MHz processor and 1 GB of RAM, the Raspberry Pi 2 has an increased amount of bulk for unnecessary ports that would unnecessarily end up increasing the size of the build. In addition, the BeagleBone Black has a TI DSP chip allowing for the H.264 encoding to go even faster.

Power is delivered to the BeagleBone board at 5V +/- 0.25V using a typical DC power jack connected to a battery and voltage regulation circuit. The digital camera is connected to the BeagleBone board using a USB cable which connects to the BeagleBone's USB host port. The embedded camera is connected to the BeagleBone using a camera cape (aka "shield"; attachment hardware that plugs into the BeagleBone I/O ports) and the servos are connected to the BeagleBone's PWM ports using typical wire connectors with pin heads.

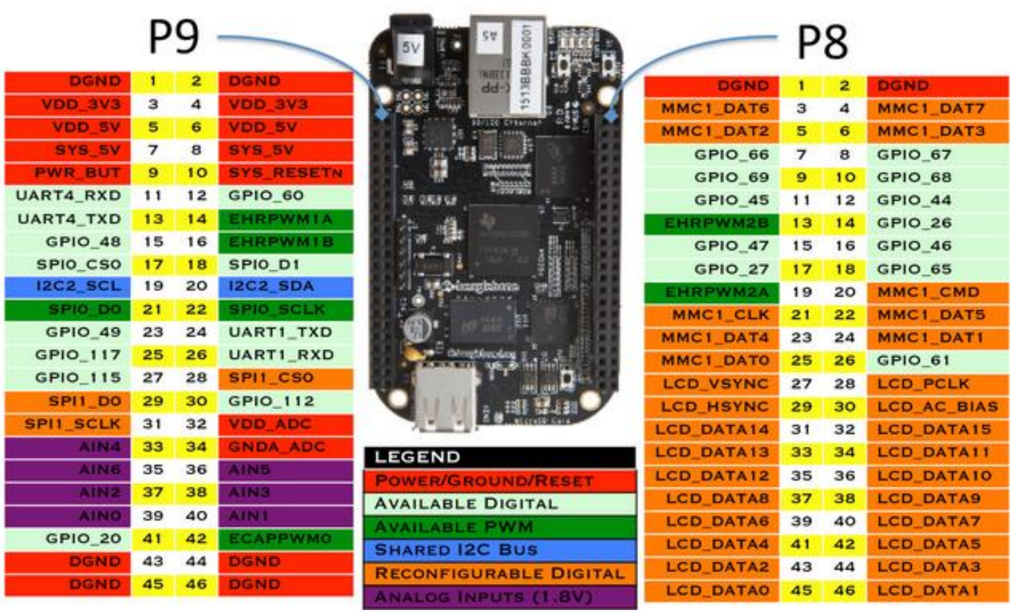

Figure 10 - Pinout Diagram for the BeagleBone Black Development Board

[MT, ID]

3.3. Wireless Communication

Wireless communication is a significant aspect of the Titan system, which uses the wireless link with a mobile device to transmit a camera image to it as well as receive user commands. This wireless link is established specifically between the app on the mobile device and the Beaglebone Black board. While the Beaglebone board does not host a wireless module of its own, an external wireless module may be connected to its GPIO ports to enable wireless capabilities. Many wireless modules operate with 5V or 3.3V supply rails, both of which are included on the Beaglebone board. Circuitry needed to condition the electronical signals of the wireless module are included within the hardware peripherals of the wireless module to ensure the smoothest operation achievable.

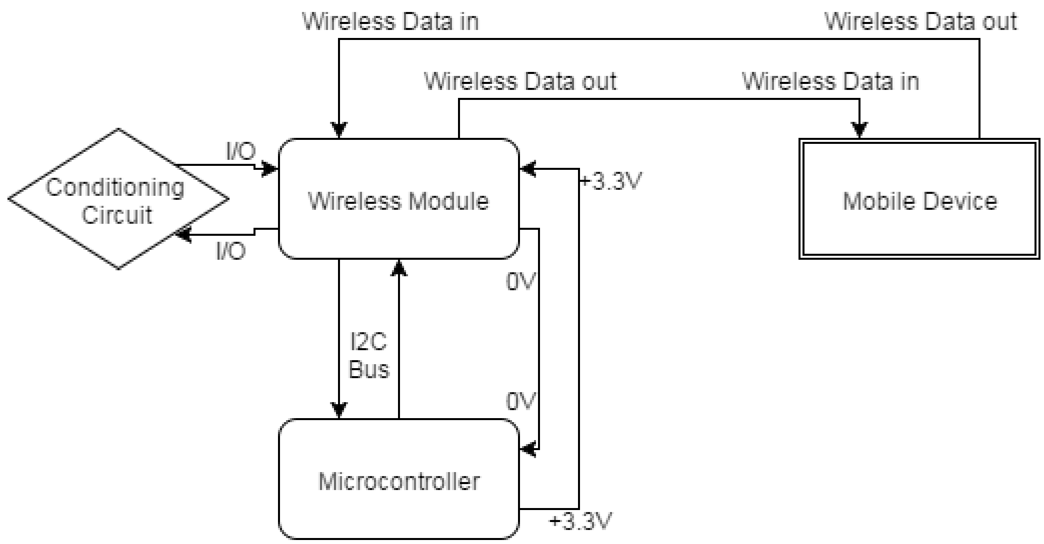

Figure 11 - Level 2 Block Diagram for Wireless Control Elements

Module	Wireless Module
Inputs	• Data via wireless connection • Microprocessor data • Signal conditioning peripherals • Power
Outputs	• Data via wireless connection • Microprocessor data • Signal conditioning peripherals
Functionality	• Streams video and commands to/from mobile app

Table 13 - Level 2 Block Diagram for Wireless Control Elements Inputs and Outputs

For wireless communication, the Remote Camera Control Rig needs a low-power wireless module in order to maximize battery life while enabling the wireless image transmission. Two common wireless transmission technologies stand out for this job: WiFi Direct and Bluetooth. WiFi Direct offers a much greater data transmission rate that can handle higher resolution or faster frame rate, though this comes at the cost of power and transmission range. Additionally, Wifi Direct requires the user to disconnect from their current local Wifi network, which is highly undesirable for most tablet and smartphone users. Considering Bluetooth, then, it is feasible to transmit a sufficient image/video feed data rate while reducing power consumption, increasing range, and being more user friendly than WiFi Direct. A possible Bluetooth solution appears to be Microchip's RN4020 Bluetooth module (Figure 13), which has a transmission rate of up to 1Mbps with an output power of only 7dBm (for a range of 100m). This module features a low current consumption of 16mA sending or receiving at an operating voltage of 3.3V. It communicates over I^2C protocol with an operating temperature range of -30°C ~ 85°C, indicating a suitable match for our wireless requirements. An alternative solution is the RN52 Bluetooth 3.0 Class 2 Bluetooth Classic module (Figure 7), which may be used instead of the RN4020 to enable a greater transmission rate (up to 3Mbps) at the cost of increased power consumption (30mA) and decreased transmission range (4dBm for a distance of 10m). Another solution is the RN-42 bluetooth module, which is sold with a breakout board called BlueSMiRF Silver by Sparkfun. This module is a class 2 bluetooth module with a range of approximately 18m, robust frequency hopping, operating voltage of 3.3-6v, and easy integration due to the breakout board's simple compatibility. The module chosen to be used in the Titan prototype is the RN-42 BlueSMiRF breakout board due to its high data rate ability, long transmission range, and ease-of-integration due to its dedicated breakout board.

Features

- Fully qualified Bluetooth 2.1/2.0/1.2/1.1 module
- Bluetooth v2.0+EDR support
- Available with on board chip antenna (RN-42) and without antenna (RN-42-N)
- Postage stamp sized form factor, 13.4mm x 25.8 mm x 2mm (RN-42) and 13.4mm x 20 mm x 2 mm (RN-42-N)
- Low power *(26uA sleep, 3mA connected, 30mA transmit)*
- UART (SPP or HCI) and USB (HCI only) data connection interfaces.
- Sustained SPP data rates - 240Kbps (slave), 300Kbps (master)
- HCI data rates - 1.5Mbps sustained, 3.0Mbps burst in HCI mode
- Embedded Bluetooth stack profiles included *(requires no host stack)*: GAP, SDP, RFCOMM and L2CAP protocols, with SPP and DUN profile support.
- Bluetooth SIG certified
- Castellated SMT pads for easy and reliable PCB mounting
- Certifications: FCC, ICS, CE
- Environmentally friendly, RoHS compliant

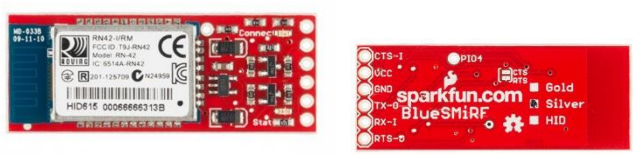

Figure 12 - Datasheet specs for the RN-42 bluetooth module

Specification	Description
Standard	Bluetooth 4.1
Frequency Band	2.4 ~ 2.48 GHz
Modulation Method	GMSK
Maximum Data Rate	1 Mbps
Antenna	PCB
Interface	UART, PIO, AIO, SPI
Operation Range	100 meters
Sensitivity	-92.5 dBm at 0.1% BER
RF TX Power	+7 dBm (avg), +8.5 dBm (peak)
Temperature (operating)	-30°C to +85°C
Temperature (storage)	-40°C to +85°C
Humidity	10% ~ 90% non-condensing

Figure 13 - Microchip's RN4020 BLE module with data overview

Specification	Description
Standard	Bluetooth® 3.0, class 2
Frequency Band	2.4 ~ 2.48 GHz
Modulation Method	GFSK, PI/4-DQPSK, 8 DPSK
Maximum Data Rate	3 Mbps
RF Input Impedance	50 ohms
Interface	UART, GPIO, AIO, USB, I2S, S/PDIF, speaker, microphone
Operation Range	10 meters (33 feet)
Sensitivity	-85 dBm at 0.1 % BER
RF TX Power	4 dBm

Figure 14 - Microchip's datasheet specs for the RN52 BT Classic module

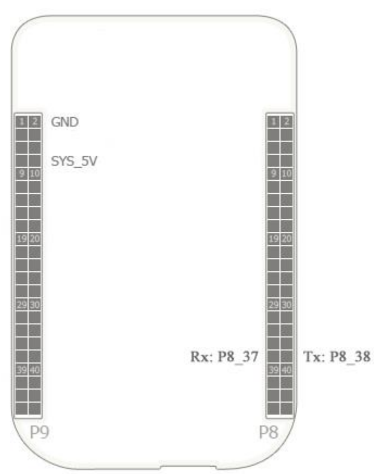

Figure 15 - Bluetooth Module pinout on Beaglebone for the RN-42 BlueSMiRF board

The H.264 encoding standard is commonly used for modern video transmission. This encoding format can be done on the BeagleBone by means of FFMPEG [13]. This can then be decoded on the mobile app, as android supports H.264 decoding [14]. This compresses the photo/video feed to be small enough to be sent over bluetooth. Based on the camera used in the Titan system, the compression ratio can be changed so that it can send either the video from the embedded or attached camera. The expression for data to be streamed for the video is shown as $Transmission\ data\ in\ bps = [\ Image\ Width * Image\ Height * Frame\ Rate * Motion\ Rank * 0.07]$. This is the bitrate equation for H.264 encoding [15]. The motion rank is how much motion there is in the frame. There will be no motion unless the system is moving; as such, a motion factor of 1 or 2 may be used. 1 means minimal motion, which is may be fine; motion factor 2 means some motion. Motion factor 2 is expected to be used as the motion rank to overestimate the amount needed for the project. Assuming 720p and 10fps, the equation is [1280 * 720 * 10 * 2 * .07] = 1,290,240 bits per second, or 1.3 megabits per second. Bluetooth Classic has a bandwidth range of 2-3 Mbps, which provides more than enough bandwidth for the transmission feed.

[MT,ID]

3.4. Camera Sensing

The Titan system uses two digital camera options so that the user can rely on using the system to aim their camera even if the camera itself doesn't support the USB digital control library. The libgphoto digital control library, however, is much more powerful than an embedded camera in terms of the amount and ability of camera control commands and can offer a more accurate view of what the camera "sees", so both techniques are to be used in the system. The integrated camera can ideal be obtained as a "camera cape" for the BeagleBone microprocessor board to maximize on cohesion between the two devices and streamline the video feed processing. Alternatively, a webcam may be used with the system via USB link. The "libgphoto" digital camera control library is used within the programning in the BeagleBone board to interpret and translate commands to and from the external digital camera to act as a liaison between the digital camera and the BeagleBone operating system. The external digital camera is to be powered by its own means while the on-board camera is powered by means of the Titan system.

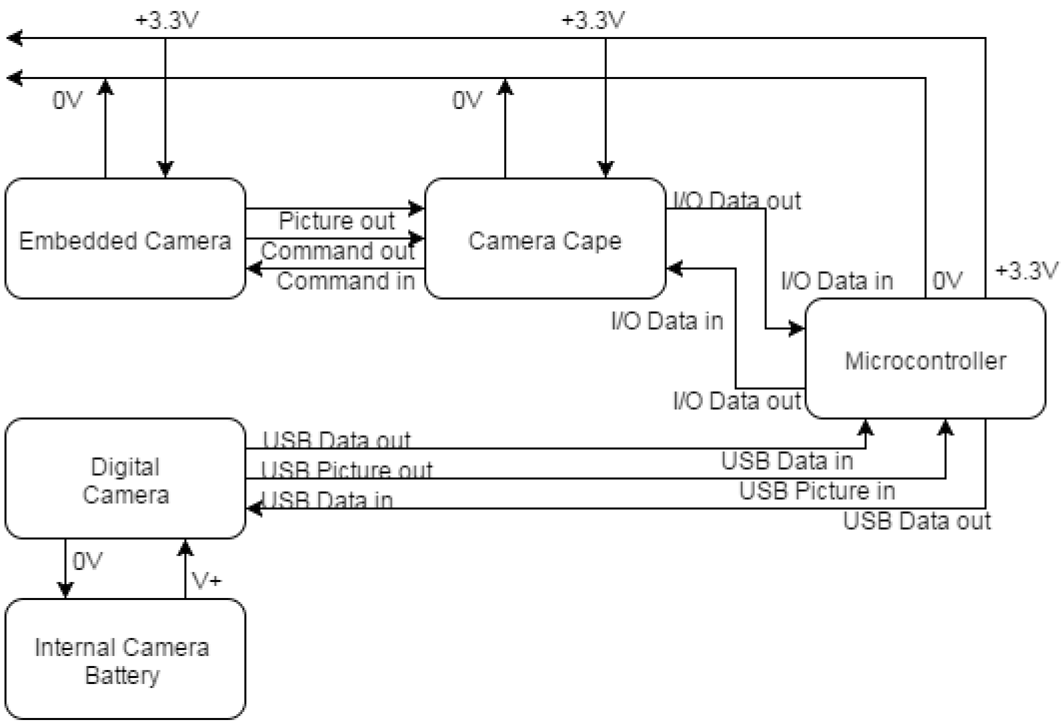

Figure 16 - Level 2 Block Diagram for Sensing Elements

Module	Digital Cameras
Inputs	• Light • Microprocessor commands • Power
Outputs	• Visual sensor data • Microprocessor command responses
Functionality	• Streams video and commands to/from microprocessor

Table 14 - Level 2 Block Diagram for Sensing Elements Inputs and Outputs

[MT]

3.4.1. External Digital Camera

3.4.1.1. Overview

When the completed Titan system is all set up, a key aspect is having an external digital camera that is compatible with the Titan system software. The user must be aware that only compatible cameras can have their shutters and settings controlled digitally (though scores of digital camera models are compatible as such). The library that will be used with the camera rig system is called "libgphoto". This library gives a list all possible cameras that can be controlled using the libgphoto software library. The more digital operations of the camera that can be controlled, the more ideally Titan will work to its full potential. A backup camera control method is needed in order to include control of other cameras that do not support the libgphoto library. This is where the embedded camera comes into play. This is a digital camera that comes with the

Titan system that the user will always have the option to control. The embedded camera is mounted in a position very close in proximity to the user's own external digital so that the user knows that their camera is seeing roughly the same image the embedded one is seeing.

[OK, MT]

3.4.1.2. Camera Compatibility

Having the best controllable aspects of the camera will optimize the entire system to its full capability. For the Titan system, full capability means that the libgphoto library will give the user the ability to control most or all of the settings and actions of the camera such as viewfinder, quality, image size, ISO, white balance, photo effect, zoom, assist light, ExpComp, flash mode, aperture, focus points, shutter speed, Metering Mode, AF distance, and/or focus locking. The libgphoto library is widely used all over the world and across many different camera companies and models, ensuring widespread availability. It supports over hundreds of cameras that are known and used by most people who would be interested in the Titan system. The camera brands, some of the most successful in the world, include Canon and Nikon. A good example would be the Canon PowerShot SX110IS. It is a very commonly used camera which lets the user tap into all of its controllable aspects (mentioned above), most importantly the viewfinder. The user's phone would send wireless packets to the microprocessor with the use of the libgphoto library in order to control all the aspects of the camera. If the user's camera is not fully supported by the libgphoto library (i.e. it supports only partial or no digital operations control) then the embedded camera can be used as a viewfinder to help aim the external camera regardless.

Figure 17 - Canon PowerShot SX110IS (left) and typical webcam (right)

[OK]

3.4.2. Embedded Camera

3.4.2.1. Overview

An embedded camera sensor module is attached to the BeagleBone microprocessor, which is part of the entire Titan system. It is possible for the embedded camera to be accessible to the user at all times. This means that the operator could use this camera to take pictures if they are without one themselves, though the main purpose for this camera is for the user to visually control cameras that are not supported by the library (using the embedded camera's viewfinder and controlling the servos accordingly). Once the user set up camera shot locations with the embedded camera, they will know that their personal camera is roughly looking at the same approximate image. Once ready to take the picture, the user can just control the shutter via smartphone to snap the picture (if supported by that camera model). Many embedded camera sensor modules are already designed to fit onto a BeagleBone board using a “cape” attachment board. Using a cape with ribbon cable connectors instead of vertical stacking pins is advantageous to positioning the camera close to the external camera. There needs to be good movement and adjustment of the camera’s position in order to be placed close to the user’s camera.

[OK]

3.4.2.2. HD Camera Cape

The ideal embedded camera cape that connects to the Titan system is the “HD Camera Cape for the Beaglebone Black” by RadiumBoards (Figure 19). This is a standard camera sensor module broken out specifically for Beaglebone purposes. The HD Camera Cape provides a high resolution portable camera solution for the BeagleBone Black platform. The entire required pin-outs are directly connected to the Beaglebone via pin headers. There will be a total of 9 pins connected between the expansion board and the Beaglebone, none of which interfere with the pins needed for TITAN’s other functions. The embedded camera operates at the same voltage (3.3V or 5V) as the Beaglebone so there is no need to adjust for its own power levels.

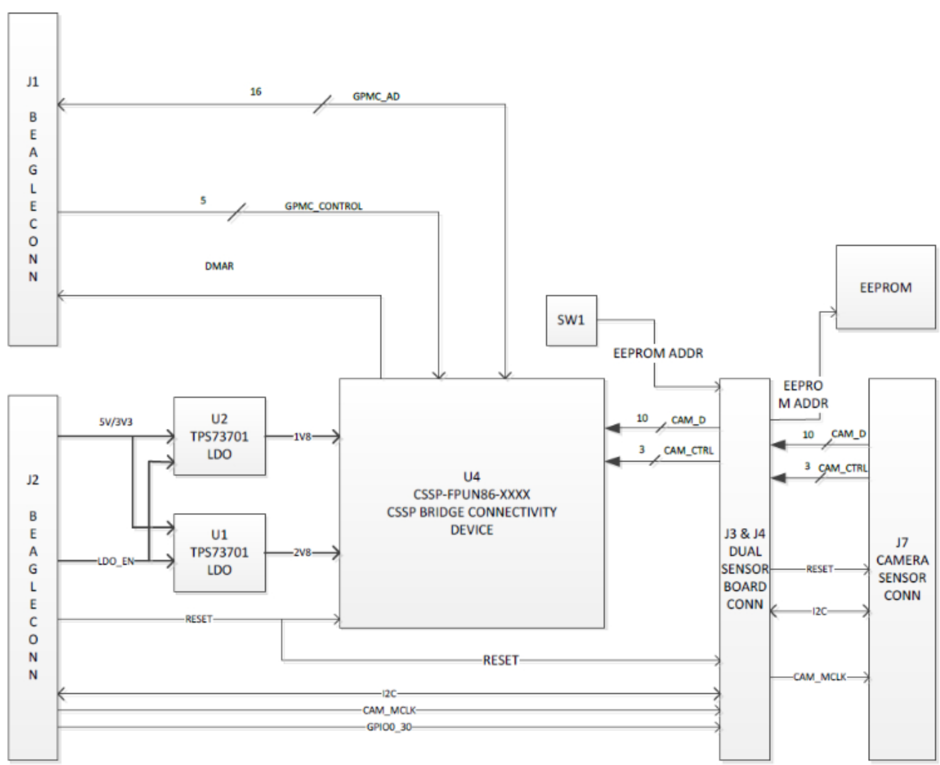

Figure 18 - Embedded Camera Block Diagram

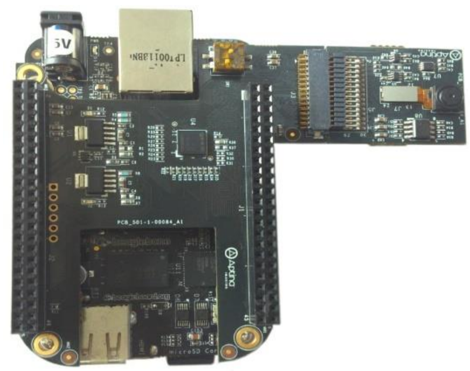

Figure 19 – HD Camera Cape without ribbon cable

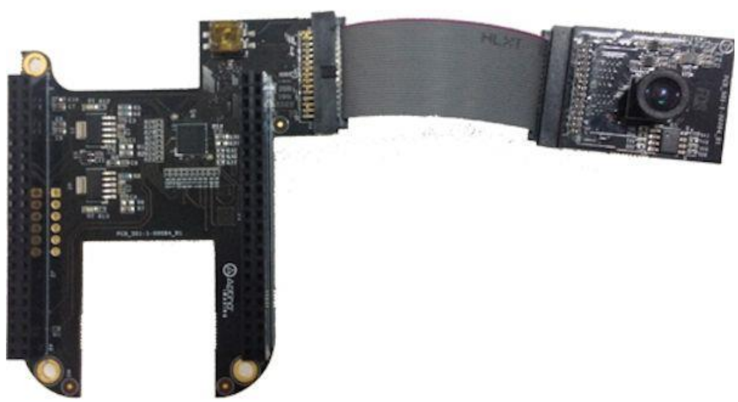

Figure 20 – HD Camera Cape with ribbon cable

The entire camera cape module can be divided into two sections; one of which is the expansion board, which is the bigger board on the left side that directly connects to the Beaglebone [16]. This board contains the data management circuitry. The right side where the 1.6Mp camera is located is called the sensor board which contains the camera sensor module [17]. It is able to take very high resolution picture with very low noise/interference. The expansion board contains the CSSP Bridge Connectivity Device which is the liaison between the cape and the Beaglebone. It receives the image from the sensor board and transfers it to the Beaglebone using the general purpose pinout interface. The expansion and sensor board are connected via 30-pin board to board via 2.5-inch ribbon cable. The entire camera cape is stacked right on top of the Beaglebone.

The default length of the ribbon cable provided with the HD camera cape is 2.5 inches, which is proven to be insufficiently long enough for free-range servo motion. In order to have full range of movement for the servos with the embedded camera attached, a longer cable must be obtained. A replacement ribbon cable sold by SamTec comes in 5.5in and 8.5in lengths, the latter of which is more than enough for full range servo motion. It is possible that the video feed quality may suffer due to the extended length, though typically such signal quality degradation occurs at much greater lengths than those offered by these cable lengths.

The HD camera cape includes a software CD with a kernel patch that allows the current version of the kernel on the BeagleBone to be updated for optimized performance with the camera cape (such is the case if the Beaglebone is installed with Debian instead of Angstrom).

The resolution of the HD camera cape can be changed in order to get a smoother output with minimal introduction of performance lag. The ideal video feed output is to be at maximum resolution, though in same cases adjustment may be needed to tune the smoothness of the system's performance by reducing resolution.

Hardware Specifications	• Image capture up to 1280x980 resolution at 10fps (DMA) • 720p HD Video Capture at 30fps • Superior low-light performance • Ultra low-power • Progressive scan with Electronic Rolling Shutter (ERS) • Automatic image correction and enhancement • Adaptive Polynomial lens shading correction • Supports Angstrom Linux Operating Systems and Android Operating Systems
Software Specifications	• Beagle Bone Black distribution plus GIT
Trade-Off Analysis	• Lowest Power, Highest Image Quality
Development Tools	• Compatible with all BeagleBone tools and software
Component Selection	• TI Sitarra processor • Aptina image sensor

Table 15 - Camera Specifications

[OK]

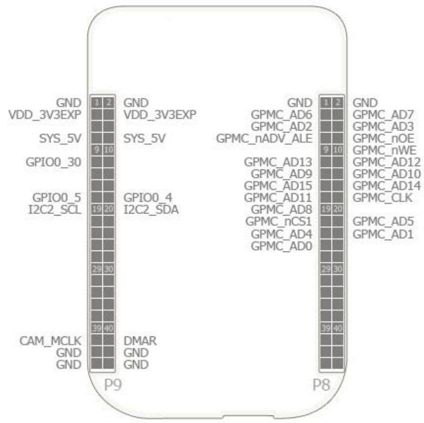

Figure 21 - Camera Cape Pinout of Beaglebone Black

[OK]

3.4.2.3. Embedded Web Camera

An alternative option to using the RadiumBoards HD Camera Cape attachment is to use a typical USB web camera. The essential concept is the same as the HD camera cape except that the webcam must be connected to the Beaglebone via USB instead of as a GPIO attachment. The only difference in mechanical design is that a USB hub must be added to the TITAN module since the Beaglebone only has one USB host port and the external digital camera must also be connected to the Beaglebone via USB. The Beaglebone Black board and its developer community provide very strong software support for the use of USB webcams; in this regard, coding the Beaglebone to work with a webcam instead of the HD camera Cape is almost equally simple, if not more. The particular webcam model chosen for the project prototype is the C615 Logitech web camera with HD video recording.

Figure 22 –Logitech C615 webcam

3.5. Actuation

The orientation of the Remote Camera Control Rig may be directly adjusted by means of actuators driven by the microprocessor. The most suitable type of actuators for this application have been determined to be servos, namely the common HS-422 model, due to their relatively low cost, lightweight design, sufficient torque strength, and market availability. Stepper motors have been considered for this application, but their drastically greater weight and unwieldiness was a bigger factor relative to the design constraints than the benefits they offer. Various servo models may be selected to accommodate different torque needs, though for the prototype (which is a lightweight, hobbyist design) the HS-422 and similar servos are certainly strong enough to move a typical point-and-shoot camera. In order to prevent potential electrical loading effects on the power rail of the BeagleBone board, the servos may be powered separately using a separate segment of the power conditioning circuit that also feeds the BeagleBone board. The position of the servos is controlled using digital pulse-width modulation (PWM) pulses from the microprocessor board. The BeagleBone Black board has dedicated PWM pin hardware and a library for sending PWM signals which is to be used when the microprocessor (via the wireless module) receives a command that instructs it to change the position of the servos.

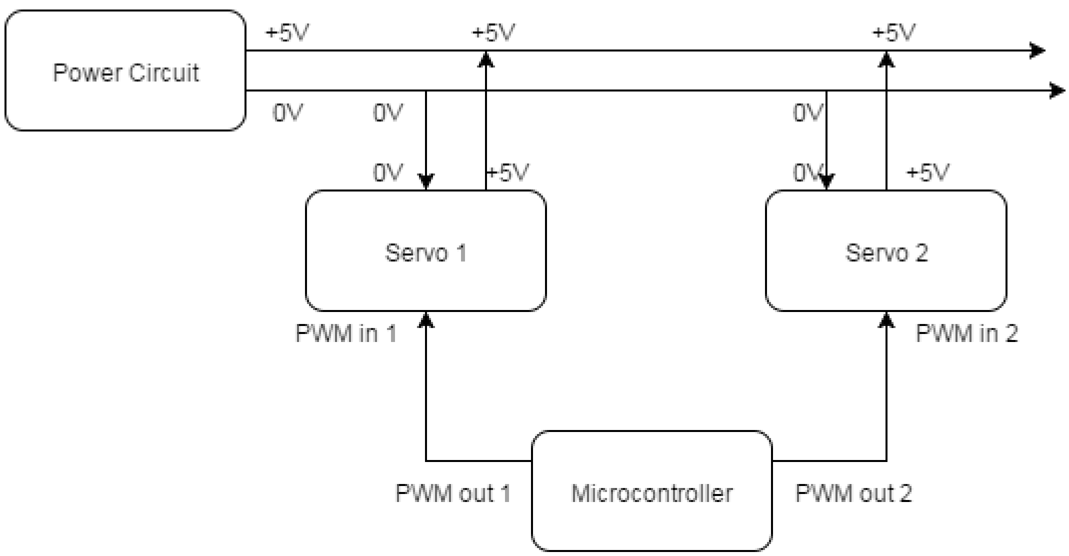

Figure 23 - Block Diagram for Actuation Elements

Module	Actuators
Inputs	• Power • PWM signal
Outputs	• Physical position
Functionality	• Actuates physical orientation of camera

Table 16 - Block Diagram for Actuation Elements Inputs and Outputs

The HS-422 servo model is designed to hold a torque of 57 Oz-in. With a typical highly-equipped DSLR weight of approximately 48.7 Oz at an expected distance of approximately 1 inch from the camera base to the base of the servo, the expected torque required is at least 48.7 Oz-in where [Torque = Distance * Weight] with [Torque = 1in * 48.7Oz]. This required torque of 48.7 Oz-in is less than the HS-422's nominal torque of 57 Oz-in, indicating a suitable strength of the selected servo model.

In order to properly calibrate the servo position for a given position command, the servos themselves must be characterized by their positions at various PWM signals. The notation for the orientation of the servos is denoted as shown in [Figure 13]. [Table 17] gives the calibration limits of the servos in each of their possible direction of movement (the limits are defined as the software position in degrees at which each servo maintains its given position without any visible or auditory signs of strain).

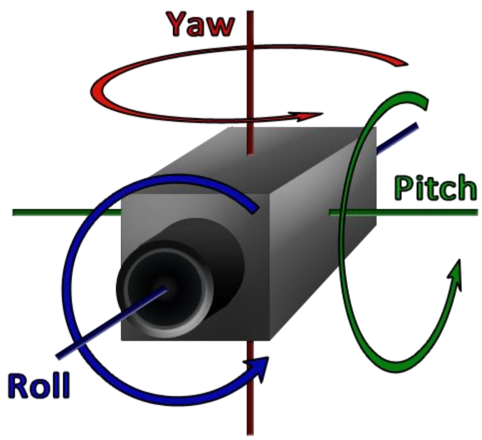

Figure 24 - Servo orientation direction definitions

Servo Characterization under Camera Load	Software Position (degrees)	
Pitch Center:	65	
Yaw Center:	83	
Pitch Max:	86	(up)
Pitch Min:	39	(down)
Yaw Max:	170	(right)
Yaw Min:	11	(left)

Table 17 - Servo characterization results

[MT]

3.6. Software Design

3.6.1. Overview

The user's mobile device wirelessly connects with the Titan camera system via Bluetooth. The BeagleBone streams the image/video feed from either the embedded camera or the attached camera, opening a data pipe between it and the app. The app then reads data from this pipe and displays it on the screen for the user to see. The basic data flow of this configuration is seen in Figure 25 and Figure 26.

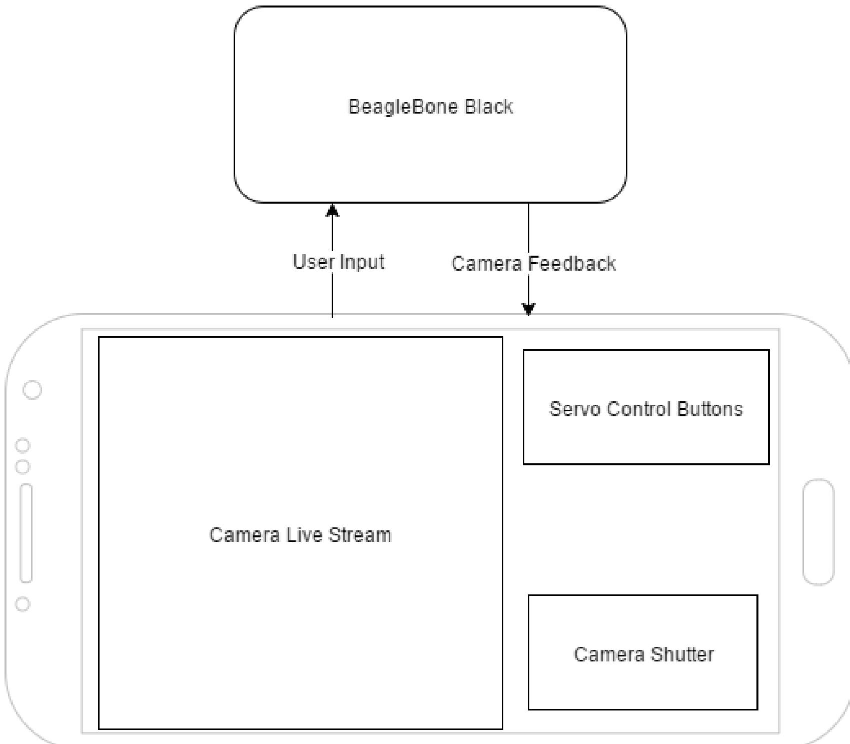

Figure 25- Level 1 Graphic User Interface Input/Output Diagram

Module	Graphic User Interface
Inputs	• Wireless microprocessor connection status • Video feed • User touch
Outputs	• Wireless microprocessor connection commands
Functionality	• Shows user video feed, wirelessly sends user commands to microprocessor

Table 18 - Input/Output list for GUI Interface

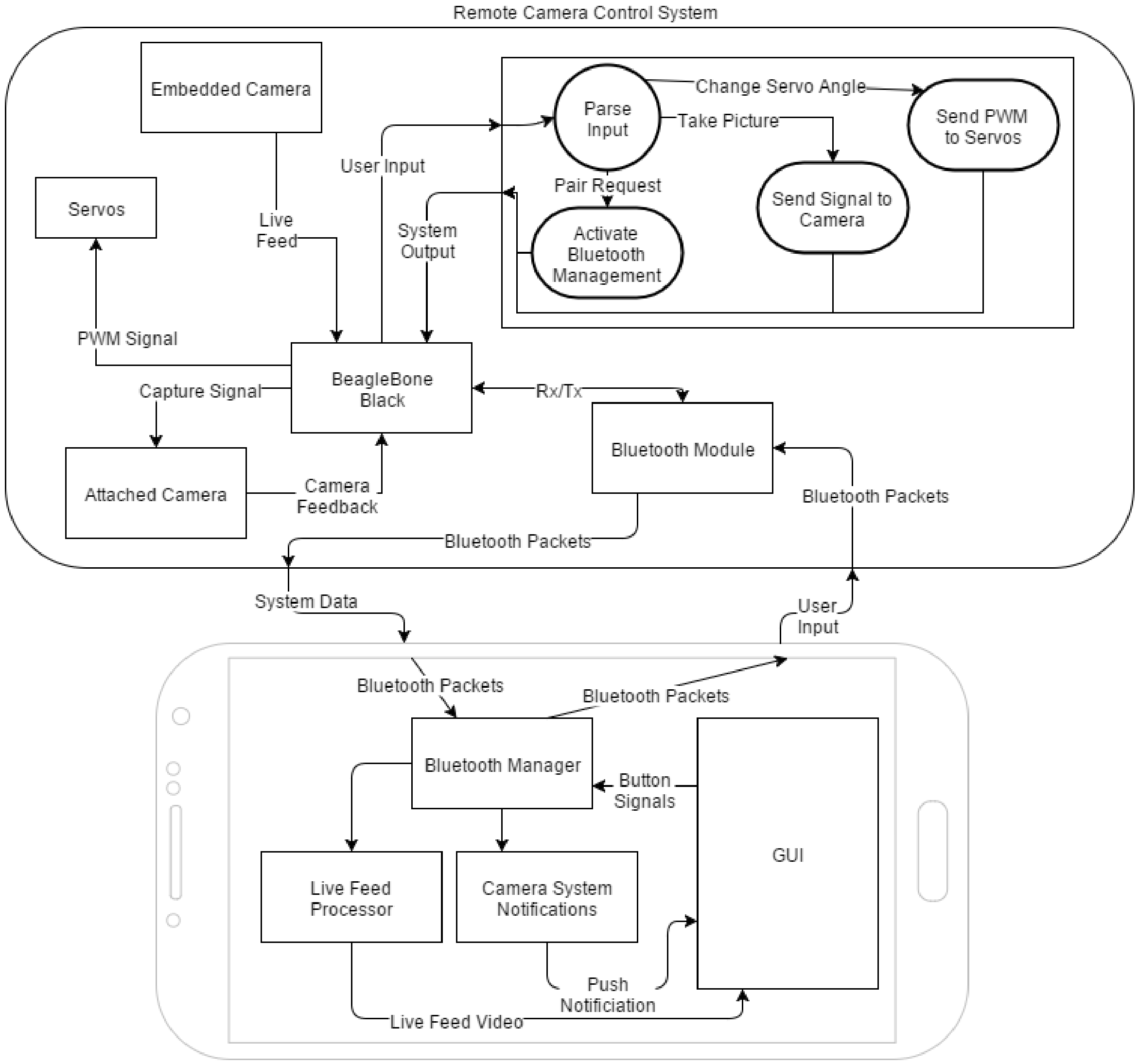

Figure 26 – Level 2 Discrete System Data Flow Block Diagram

Module	Remote Camera Rig
Inputs	• Wireless Communication • Camera Input • Power (5V)
Outputs	• Video Feed Over Wireless Communication • Digital Camera Commands • Mechanical movement
Functionality	• Streams video to mobile app, orientation controlled by mobile app

Table 19 - Discrete System Data Flow Block Diagram Inputs and Outputs

3.6.2. Mobile App

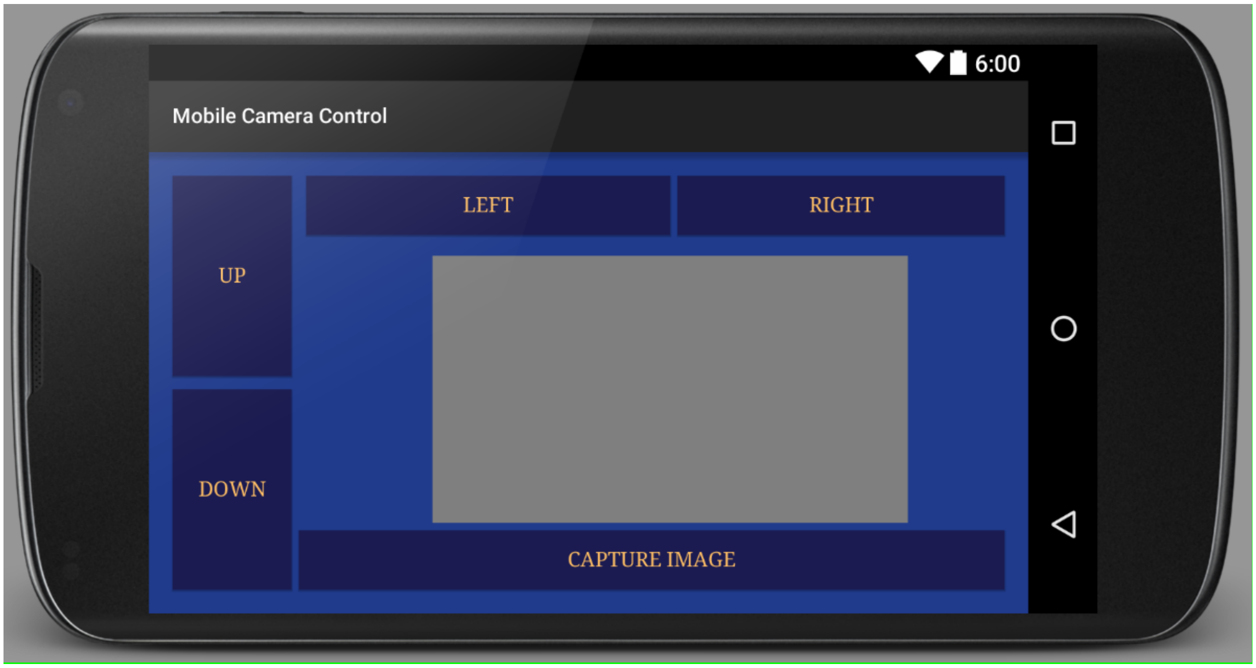

Figure 27 - Android Studio build of mobile app with on-screen video feed

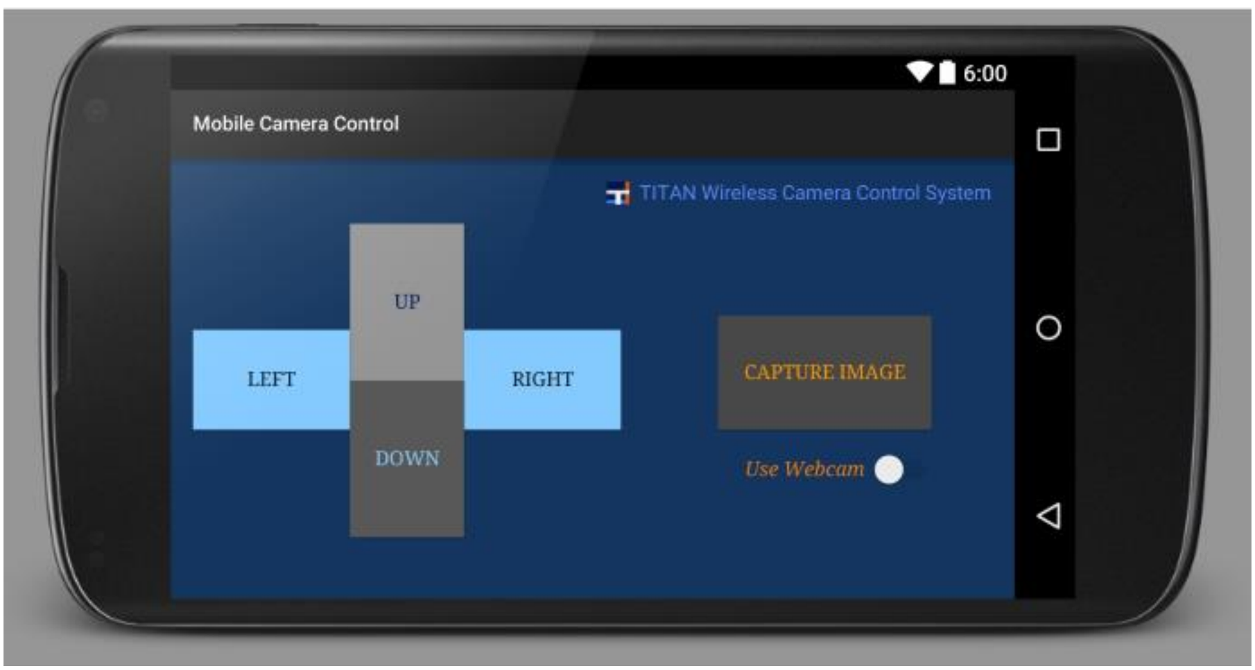

Figure 28 - Android Studio build of mobile app without on-screen video feed

The Mobile Application is the driving force of the system's usability. This app is simple, as it is mainly for user input and displaying of output. This application is written in Java, as it is deployed on the Android operating system. The application allows users to change the angle at which the camera on the tripod is facing as well as remotely capture images from the attached camera. The application itself is driven by Android Fragments, which are partial activities that can be swapped in and out. There are three fragments that encompass the app: The Main Screen, which has the video feed, the servo controls, and camera shutter activation; the Bluetooth Menu, which work with creating the link between the camera and device, as well as running as the background Bluetooth manager for the application; and Application Settings, where persisting application parameters can be set and saved across sessions. The user can switch between fragments at any time by using the navigation drawer, which can be accessed either by swiping a finger from the left-most edge of the screen to the right or by means of the Action Bar. For TITAN's prototype demonstration, the app may be modified to pass the video feed to an external monitor display rather than the GUI screen so that everyone at the presentation can see the live video feed without having to pass the mobile device to every single participant.

Figure 29 - Example Android Action Bar

3.6.2.1. Main Screen Fragment

Module	Main Screen Fragment
Inputs	Servo Control Buttons: • Vertical (Up/Down) Buttons • Horizontal (Left/Right) Buttons Remote Shutter Activation Button
Outputs	Video Feed from Camera Control Module
Functionality	Allows the user to interact with TITAN and display the live video feed

Table 20 - Main Screen Fragment Functional Requirements

The Main Screen is the fragment that will "see" the most use, as it is the main GUI for controlling the Camera Control Module. This is the fragment that the application will automatically load on startup. This fragment is meant to be used in the landscape orientation. The video feed will be as large as the resolution allows. There are buttons for vertical and horizontal servo control as well as for the shutter activation and switching between embedded camera and external camera video feeds. Figure 27 shows a design for the Main Screen fragment, which reflects the information stated in the functional requirements table (Table 20).

3.6.2.2. Bluetooth Menu Fragment

Module	Bluetooth Menu Fragment
Inputs	User Inputs: Module Selection Bluetooth Inputs: • Video Feed Packets • Module Status Packets • Alert Packets
Outputs	Bluetooth Output: • User Input Packets
Functionality	Allow the user to pair the app to the Camera Control Module and run as the Bluetooth Manager in the background

Table 21 - Bluetooth Menu Fragment Functional Requirements

The Bluetooth Menu fragment appears as a simple menu that allows the user to select the Camera Control Module to which the app will connect. In the background, this fragment serves as the Bluetooth manager for the app. This class takes in Bluetooth packets as it receives them and processes them based on the type of packet received. Video Feed packets are received through the Serial Port Profile, or SPP. This emulates a serial connection between the app and the Camera Control Module. The video feed comes as compressed video packets and the Bluetooth manager puts the packet into the buffer that the Main Screen is using to show the live feed. Module Status Packets are processed by simply extracting the coded message. This message is just to show whether or not the Camera Control Module was able to complete the previous request. Finally, Alert Packets alert the user via a push notification after the message has been decoded from the packet.

3.6.2.3. Settings Fragment

Module	Settings Fragment
Inputs	User Configurations
Outputs	GUI: • Display Configurations Device Storage: • Configuration File
Functionality	Allows user to set persistent application settings

Table 22 - Settings Fragment Functional Requirements

Finally, the Settings Fragment stores application persistent settings to a configuration file and allows the user to change the settings at any time. On app startup, settings from this file are stored to local variables for use in the run time of the mobile application.

[ID]

3.6.3. BeagleBone Software

The BeagleBone Black is the brains of the camera system. It receives data from the app, parses the input, and processes the image/command data to be sent between the app and the camera. The inputs from the app are control signals, telling the servos to move or the camera's shutter to activate. The BeagleBone has a library that allows for the communication with the attached camera via USB. The embedded camera, if a camera cape, is attached to the BeagleBone's GPIO pins and communicates using these I/O pins through serial communication. If the embedded camera is a webcam, the device may be connected using a USB link. The BeagleBone will decide which feed to send to the user based on the following algorithm: if there is a point-and-shoot camera attached via USB (and a check verifies that it is compatible with the libgphoto2 digital command library) with which the BeagleBone can obtain the data from the viewfinder, send that feed; otherwise, send the embedded camera feed. The BeagleBone operating system is custom written to satisfy the needs of the system. It features capabilities to pair the system via Bluetooth to a mobile device using the companion application, to send a live video stream once connected, and to control the attached camera and servos. The OS balances the transmission and receiving lines to maintain connection with the mobile application, while still sending its user pertinent information.When the BeagleBone receives a signal to change the pitch or yaw of the system, the BeagleBone calculates the change in angle and deliver the corresponding PWM signals to the servo motors in order to obtain the desired viewing angle. If the BeagleBone obtains a signal to activate the shutter, it sends a command over the USB line to the attached camera to capture the image.

The Camera Control Module operates on a basic finite state machine that utilizes multithreaded code to optimize processor time. The two basic threads are the User Control Thread and the Video Feed Thread; the User Control Thread handles command packets sent to the module from the app and satisfies the requests given, while the Video Feed Thread handles the video feed. This code is written in C++ and will be executed on device startup.

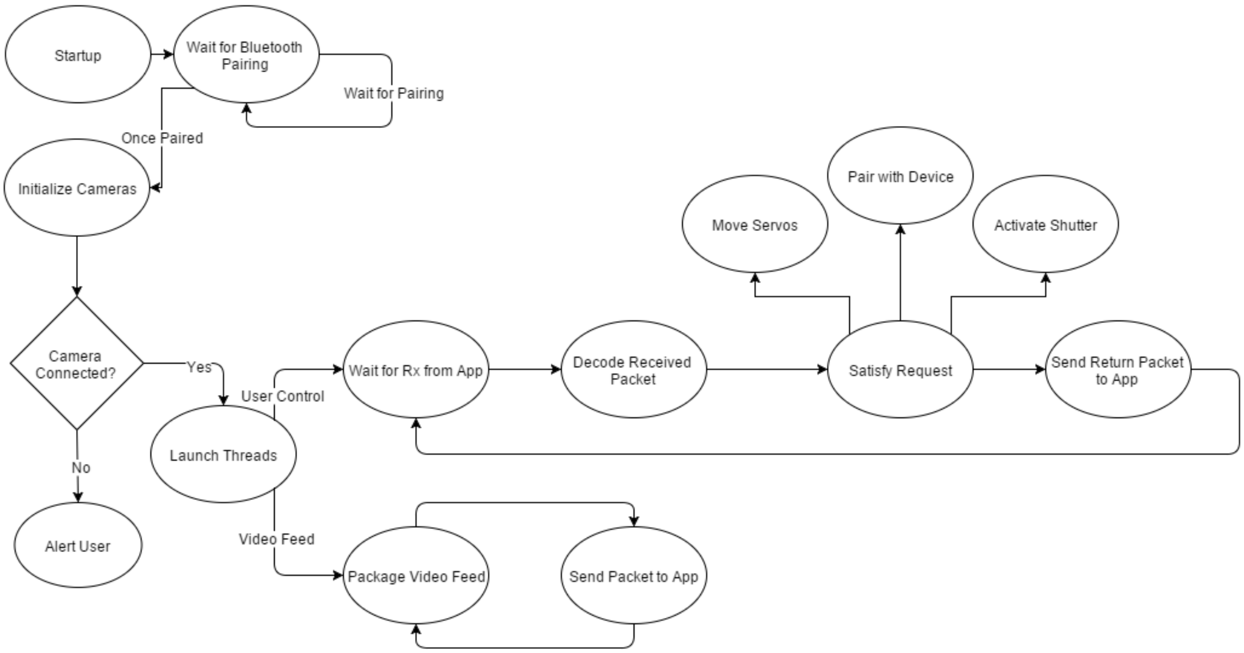

Figure 30 - Finite State Machine for Camera Control Module Operating System: This diagram details the OS's fundamental operation.

The Titan Camera System operates under the finite state machine depicted in Figure 30. Upon module startup, the operating system begins Bluetooth communications. The module waits until it is paired with a mobile device before continuing to initialize both the embedded and attached cameras. If the module starts up and no camera is attached, it will alert the user via an alert packet; after this packet is sent, the startup routine will continue as if it has been initialized. After the cameras are initialized, the module is ready to begin operation. The two branches of operation are the User Control and Video Feed, both of which will run concurrently. Both threads contain code to handle the events of an attached camera disconnect/connect.

```
// Wait for Bluetooth Initialization
while(!initializeBT(Bluetooth_PIN));
// Initialize Cameras
initializeEC();
initializeAC();
// Initialize Threads
thread UserLoop = new thread();
thread VideoFeed = new thread();
// Activate threads and Loop
UserLoop.join();
VideoFeed.join();
```

Figure 31 - Operating System Pseudocode: This is the basic code that will drive the Camera Control Module.

The code structure for the OS utilizes threads for the two branches of the loops. This benefits the system overall because this allows the two to work in tandem. Each of the two threads loops infinitely until power is disconnected. For the most part, these two threads will never interact nor interfere with the other's operation. However, the Bluetooth manager will be used by both. As such, a mutex is used with the Bluetooth manager so that the two threads do not interfere with each other.

```
// Wait for Rx
while(!receivedBT());
// Get Bluetooth Packet
std::string payload = BTManager.getPacket();
// Decode packet
packetType type = decode(payload);
// Satisfy Request
switch(type)
{
    case Servo:
        moveServos(payload);
        break;
    case Camera:
        captureImage();
    default:
        // Handle odd packet
}
// Prepare System Response
std::string response = prepareSystemResponse();
// Send response
while(!BTManager.lockMutex());
BTManager.sendPacket(response);
BTManager.unlockMutex();
```

Figure 32 - User Control Thread Pseudocode: Details the operation of the code that will handle user commands.

The User Control is the part of the module with which the user interfaces. Once the module receives a Bluetooth command packet, it will decode the request and attempt to satisfy it. The main requests that would be satisfied are servo movement, activating the shutter of the attached camera, and pairing with a device. After completing the request, a system response is generated and packaged. After this response packet is sent back to the user, the module will once again wait for an incoming Bluetooth packet. Figure 32 - User Control Thread Pseudocode: Details the operation of the code that will handle user commands.is the pseudocode that handles information that comes from the mobile application. This thread does exactly what is depicted in Figure 30 - Finite State Machine for Camera Control Module Operating System: This diagram details the OS's fundamental operation.30. Utilizing some a few classes that will be made to handle the Bluetooth, Servos, and Camera, this thread parses command packets from the mobile application and perform whatever is requested of the system. The system then generates a response containing information on the task that has been completed or not and the system status (battery level, etc.) at that point in time. This status packet is then sent back to the mobile application to confirm that the job was done or not and alert the user as necessary.

```
// Check if we are using the Attached or Embedded Camera
if(usingAttached())
{
    useAttachedFeed();
}
else
{
    useEmbeddedFeed();
}
```

Figure 33 - Video Feed Thread: Describes the basic operation of the thread that controls the video feed.

In Figure 33 - Video Feed Thread: Describes the basic operation of the thread that controls the video feed.3, the pseudocode describing the operation of the video feed thread is given. This thread is not nearly as complex or complicated as the User Control thread. This thread checks to see which camera is being used at the time and then uses the individual camera classes' video feed function which is tailored to suit each process. This feed is set up as a Serial Port Profile, SPP, which allows the constant streaming of data across the Bluetooth Connection. This is all done in the backend by the Bluetooth manager class. An SPP emulates a serial connection between two devices allowing for the continuous feed.

As described above, the module is driven by a multithreaded OS that allows the module to make full use of all its resources by allowing the User Control, a thread that is only operating when the user actually requests a service, and the Video Feed, a thread that is repeatedly performing the same instructions, to operate in tandem. The Bluetooth Manager has a mutex that synchronizes the threads and prevents any race conditions that might interfere with basic operation of the module.

[ID]

3.6.3.1. Camera Control Module Class Definitions

3.6.3.1.1. BTManager Class

Module	Bluetooth Manager Class
Inputs	Packets to be Sent: • Video Feed Packets • Module Status Packets • Alerts
Outputs	Received Packets from Mobile Application
Functionality	Allows the Camera Control Module to interact with Mobile Application by sending and receiving packets via Bluetooth

Table 23 - BTManager Class Functional Requirements

The Bluetooth Manager, or BTManager shown in pseudocode, is the class in the Camera Control Module that handles all Bluetooth transmission and reception. This class is used by both of the threads; as such, it has resource synchronization by means of a mutex. This locks the Bluetooth Manager from being used by another thread until the thread currently using it unlocks it. Since the video feed is using SPP and the other packets are just normal packets, there are two different functions within this class for sending packets: one for the video feed and one for the normal packets. These functions send their respective packets in the way that is befitting of the packet. This code is appropriately written with Android Bluetooth Standards in mind when it comes to matters such as MTU.

[ID]

3.6.3.1.2. Servo Class

Module	Servo Class
Inputs	Angles for horizontal and vertical movement
Outputs	Servo Movement
Functionality	Allows for the movement of the servos

Table 24 - Servo Class Functional Requirements

The Servo class is the backend for servo movement in the Camera Control Module. The main functionality is in turning inputted angles into physical movement by adjusting the duty cycle of the servo motor. There is a function call that takes a raw payload from a Bluetooth input packet and extracts the desired angles from it. After the angle is extracted, there is a call to move the servos. In order to move the servo motors, the duty cycle of the motor must be changed. The following equation has been created from testing to calculate the duty cycle from an inputted angle:

$$duty = 100 - \left(\left(\frac{angle}{180}\right) * duty_{span} + duty_{min}\right)$$

Equation 1 - Duty Equation: Turns an inputted angle into the respective duty cycle.

This equation transforms the angle as a floating point number into the duty cycle to be used by the motors. $duty_{span}$ is the difference between the maximum and minimum duty times in milliseconds. $duty_{min}$ is the minimum duty time. Through testing, $duty_{min}$ has been found to be 2; and, $duty_{max}$ is 11. As such, $duty_{span}$ is 9.

[ID]

3.6.3.1.3. Camera Class

Module	Camera Class
Inputs	Embedded Camera: • None Attached Camera: • Capture Signal

Outputs	Embedded Camera: • Video Feed Attached Camera: • If applicable, video feed
Functionality	Abstraction of the two types of cameras. Each camera will be an object of this class and will have functionality to follow suit

Table 25 - Camera Class Functional Requirements

The Camera class is the abstraction of the physical connection to the embedded and attached cameras in the Beaglebone code. The embedded camera will intentionally only be used for the live video feed, while the attached external digital camera will be used for capturing either photos or a live video feed. When the external camera is initialized after it is connected, the OS obtains information from the camera and decides based on a list stored on the module if the camera can be used for live feed purposes. This is dependent on whether or not the camera is supported by the libgphoto2 library. If the camera is not supported, it can only be used to for remote shutter activation purposes. The fact of whether or not the camera is supported will be sorted in a member variable of the attached camera object and in the OS itself. For the video feed, the external camera will always be used over the embedded camera, in the case both are able to be used. If only the embedded camera can be used for the feed, it will naturally be used as the source of the live video feed. The live video feed is processed in the H.264 encoding method using FFMPEG on the Camera Control Module; the Mobile Application unwraps the feed once it receives the packet. By using this encoding, it is possible to compress the video feed to be sent over Bluetooth.

[ID]

3.7. Power Supply Circuit

3.7.1. Overview

The power supply circuit is the hardware that provides the regulated operating voltage on which the Titan system operates, which includes the Beaglebone board and servo motors. Figure 34 outlines the level 1 block diagram for the power system.

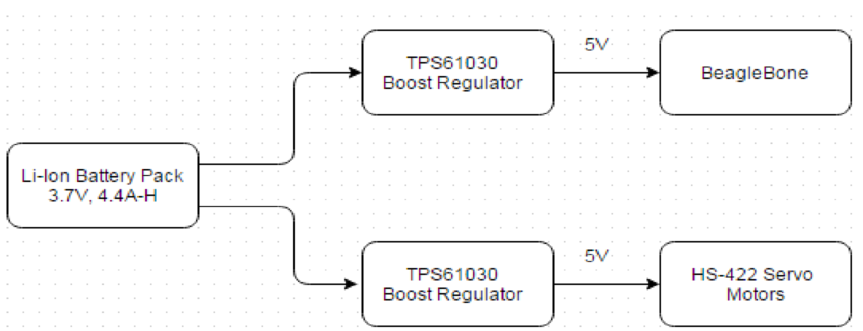

Figure 34- Power Supply Level 1 Block Diagram

Module	Power Supply
Input	• 3.7V, 4.4AH Li-Ion Battery Pack.
Output	• Two 5V regulated rails.
Functionality	• Steps the battery voltage up to the 5V system operating voltage.

Table 26 - Power Supply Inputs and Outputs

The entire project is designed to run off a dual Li-Ion, rechargeable battery pack that feeds the various subsystems that require power. The two main subsystems that need their own power supply are the BeagleBone master controller and the servo motors. Each is fed separately in order to prevent noise from the motors interfering with the power supply for the Beaglebone. The supply voltage for both the BeagleBone and the HS-422 servomotors is 5V, so the boost regulators will be designed using the same filtering components.

The first stage of the power supply is the battery input; the battery pack selected is based the need for a decently long run time when in mobile use as well as spatial constraints. It is desirable by the end user that the product has a good battery life and is compact. In order to size out the correct battery, a few calculations are made to determine the battery life under the maximum load of the system. The current draw of each subsystem is estimated and outlined below.

- BeagleBone Black Master Controller: Average current of 300mA at idle, 400mA benchmark running. [18]
- RN4020 Bluetooth Module: 16mA when transmitter and receiver are active.
- HS-422 Servo Motors: 180mA at no load operating.
- BeagleBone Camera Cape: TBD, estimation of 200mA will be used.

A few things to note about the above values are that the servos are not expected to be constantly running even when the entire system is powered on, though the BeagleBone board will be constantly running. Under the worst case scenario, it is assumed that the motors are constantly running unloaded as well as the board and all of its peripherals. The expected battery life is calculated below.

$$\text{Total Current Draw} \approx 400\text{mA} + 16\text{mA} + 2(180\text{mA}) + 200\text{mA} = 976\text{ mA}$$

$$Battery\ Life(Hours) = \frac{Battery\ Capacity\ (AH)}{System\ Current\ Draw\ (A)}$$

The battery that is to be used is rated for 3.7V at 4400mA-H [22], thus the expected battery life is calculated to be:

$$\text{Battery Life} \approx 4.5\text{ Hours}$$

The actual expected battery life will exceed 4.5 hours (which is the full-load operation battery life), which meets the requirement for the project (good battery life). The physical dimensions of the battery (69mm x 37mm x 18mm) [22] also meet our desired requirements for mobility; the battery can be easily stored in a 3-D printed box that will also house the power circuit PCB and BeagleBone. Another important feature of the battery selected is the on-board protection system, which monitors voltage level and cuts off the supply of current at a threshold voltage in order to protect and extend the battery's rechargeable capability. The protection circuitry also keeps the battery voltage from going too high during recharging and cuts the supply of power from the battery before they are completely dead at 2.5V (past the voltage threshold of recharging). In order to recharge the battery pack when depleted, a LiIon/LiPoly constant-voltage/constant-current charger is used which is selected based on the specification that the batteries should be charged at a rate of 2A or less. [21][22]

The next stage of the power system is where the input voltage is stepped up to the operating voltages of the board and motors. The battery can only provide a nominal 3.7V - in order to step up the voltage, a boost converter is determined to be the best solution. Figure 35 shows a boost converter during the different phases of its operation.

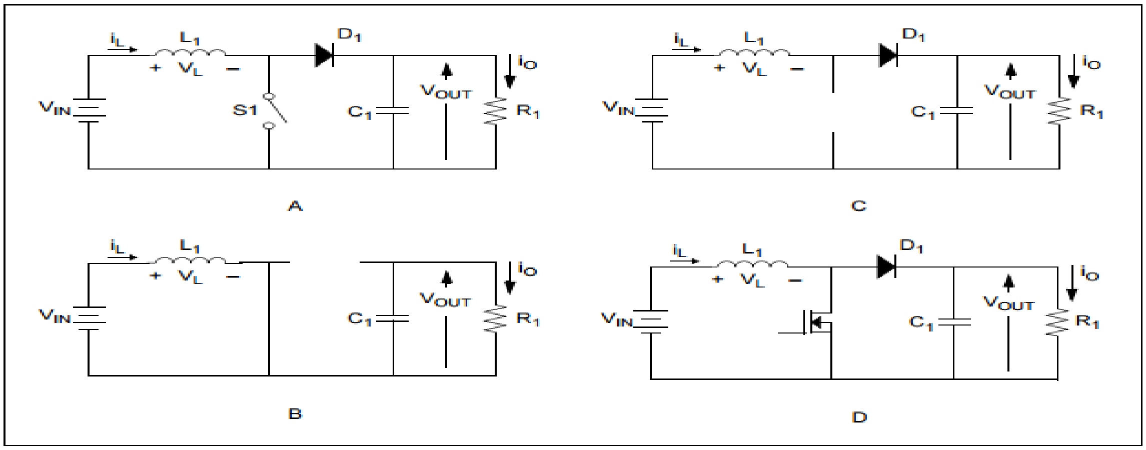

Figure 35 - Simple Boost Converter Example

In figure 35-B, the MOSFET is switched on for time DT, where D is the duty ratio and T is the period of the cycle, and the diode is off because it is in the reverse biased state. Current will build in the inductor during this time. In figure 35-C, the MOSFET switches off for time T-DT, the diode will turn on and the energy stored in the inductor will transfer to the load through the diode. The boost converter is capable of stepping up the input voltage based on the conversion ratio

$$\frac{Vout}{Vin} = \frac{1}{1-D}$$, where D is the duty ratio, which is always less than 1.

The TPS61030 Boost Converter by Texas Instrument will be implemented to supply power to the BeagleBone master controller and the HS-422 servomotors. The reason a switching regulator is used as opposed to a linear regulator is because of the need for efficiency, linear regulators are significantly less efficient than switching regulators. The table below outlines some of the specifications of the TPS61030 boost IC. [19]

Input Voltage	Minimum: 1.8V, Maximum: 5.5V
Output Voltage	Minimum: 1.8V, Maximum: 5.5V

Switch Current	Maximum: 4.5A at 5V output voltage.

Table 27 - TPS61030 Electrical Specifications

An output current vs. efficiency graph provided by the datasheet illustrates that when the output voltage is 5V, the efficiency is above 90% over the output current range of 100mA to 1A, the curve is specified for a battery voltage of 3.3V which is just a little under the nominal 3.7V output voltage of the battery. [19] It can be concluded that based on an estimated maximum system current draw of 976mA, the power supply will be above 90% efficient.

Figure 36 shows the circuit layout with the TPS63061 [19]. The switches and the switching control circuits are inside the chip, the external components make up the filter circuit. The values for filter's components needs to be calculated to satisfy certain output conditions such as voltage ripple, current ripple etc. Table 22 explains the pinouts of the regulator IC and their functionality.

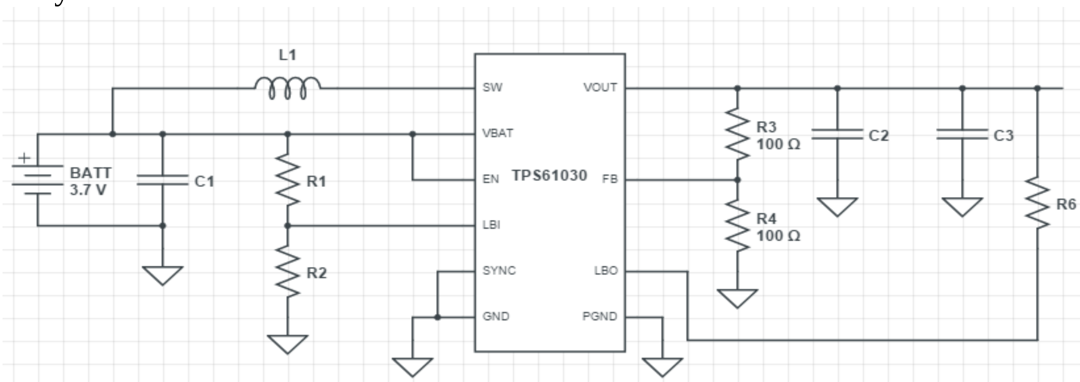

Figure 36 - TPS61030 Boost IC and Filter Components

SW	Boost and rectifying switch input.
VBAT	Battery input pin.
EN	Device enable pin, this pin should be set to VBAT to enable and GND to disable.
LBI	Low-battery input pin, this is to monitor the battery voltage. When the battery voltage drops below drops below a user-set threshold voltage an error flag is generated.
SYNC	If this pin is set low, it enables power save mode which improves efficiency at lighter loads otherwise the pin is set to VBAT and power save mode is disabled.
VOUT	Regulated voltage output.
FB	Feedback pin for setting and maintaining the desired output voltage.

LBO	The error flag from the LBI pin is generated at this pin, this pin will go active low when the battery voltage goes below the set value.
GND	Control/logic ground.
PGND	Power ground, in this case the power ground and logic ground will be the same.

Table 28 - TPS61030 Pinout and Functionality

The filter components of the power supply are designed based on design criteria such as output voltage, output voltage ripple, and inductor current ripple. The follow sections will explain how the filter and feedback circuits were designed.

[SD]

3.7.2. Programming the Output Voltage

In order to set the output voltage, resistors R3 and R4 are used to set the FB pin to the reference voltage of the IC. The internal reference voltage at the FB is 0.5V, based on the desired output voltage of 5V the resistors can be calculated using the following equation. [19]

$$R3 = R4\left(\frac{Vo}{Vfb} - 1\right) = 1.6M\Omega$$

The datasheet recommends that R4 should be in the range of 200kΩ, [19] based on available resistor values R4 will be 180kΩ which makes R3 1.6MΩ. The reason for such a high divider resistance is because the current through the feedback network should be 100 times greater than the typical 0.01µA current into the FB pin.

[SD]

3.7.3. Programming the LBO/LBI Threshold Voltage

The voltage divider R1 and R2 is used to set the desired low-battery voltage. For the batteries chosen for this project, the battery will be fully depleted at 2.5V. In order to prevent damage to the battery, the low-battery voltage will be set 3V which means the error flag will be generated at the LBI pin when the battery voltage reaches 3V. In order to do this, R1 and R2 should be selected to set the LBI to 0.5V which is the internal reference. The following equation is used to set the LBI voltage. [19]

$$R1 = R2\left(\frac{Vbat_{low}}{Vfb} - 1\right) = 2.15M\Omega$$

The data sheet recommends that R2 should be in the range of 500kΩ, [19] using standard resistor values R2 will be set to 430kΩ which makes R1 equal to 2.15MΩ which will be rounded to 2.2MΩ since that's a standard resistor value.

[SD]

3.7.4. Inductor Selection

The inductor value is selected based on the estimated max current through the inductor during the charging cycle as well as the desired inductor current ripple. The maximum current through the inductor is calculated using the following equation.

$$I_L = Iout\left(\frac{Vout}{Vbat \times 0.8}\right) = 3.125A$$

The absolute maximum output current will not exceed 1.5A and the minimum battery voltage is 3V so based on these values the maximum current through the inductor is 3.125A. The data sheet specifies that the maximum inductor current should not exceed the maximum rated switch current of 4.5A. [19] The average inductor current is calculated using the average battery voltage of 3.7V and the above equation, it is calculated to be 2.2A. The inductance value can be calculated using the following equation using a ripple current of 10%, a switching frequency of 600 KHz and the nominal 3.7V battery voltage.

$$L1 = \frac{Vbat(Vout - Vbat)}{\Delta I_L \times f \times Vout} = 7.9\mu H$$

The calculated inductance is 7.9μH, for a typical 5V output voltage application a 6.8μH inductor is recommended by the datasheet which is close enough to the calculated value for it to be acceptable.

[SD]

3.7.5. Input/Output Capacitor Selection

The input capacitor C1 is to improve the transient behavior of the circuit and the datasheet recommends a firm 10μF capacitor at the input. [19] The output capacitors are used to condition the output voltage ripple, they provide current to the output during the time that the switch is off and the inductor is charging. The minimum output capacitance C3 can be calculated using the following equation.

$$C3min = \frac{Iout(Vout - Vbat)}{f \times \Delta V \times Vout} = 86.6\mu F$$

The Beaglebone requires a well-regulated 5V input ±0.25V, thus the voltage ripple should satisfy this condition, the servomotors are not as strict on the input voltage requirement thus can use the same value. Specifying the voltage ripple to be 10mV, the minimum capacitance required neglecting the ESR of the capacitor is calculated to be 86.6μF. Taking into account the ESR of the aluminum C3 capacitor, which is 23mΩ according to Digikey, [20] the additional voltage ripple is calculates as follows.

$$\Delta V_{ESR} = Iout \times Resr = 23mV$$

In an effort to reduce the additional voltage ripple across the ESR of the C3 capacitor, they are placed in parallel at the output to reduce the resistance. The C2 capacitor is specified to be 2.2μF. [19]

To conclude, since both the Beaglebone and the servomotors require a 5V input, the power supply will be designed the same for both to reduce complexity and to avoid having to do two different designs for essentially the same thing.

3.8. PCB Design and Implementation

In order to reduce the overall size and increase the performance of the power supply, it is decided that a printed circuit board (PCB) is the best route to take in order to realize the circuit. Surface mount components take up a fraction of the space of through-hole components, and there are various performance considerations that are taken into account when choosing surface mount over through-hole. The PCB is designed using EagleCAD, a relatively easy-to-use board layout software that is free for use to students.

Devices (or parts) in EagleCAD are comprised of two pieces: the symbol and the package. The symbol is a representation of the part's electrical characteristics, which is used in the schematic; this is similar to symbols used in simulations programs such as pSpice. The package is the part's physical footprint on the PCB; the package captures the part's dimensions and pad sizes. The first step in the power supply's PCB design is laying out the circuit schematic and making sure it passes the electrical rule check built into EagleCAD. From the schematic the layout is generated using the packages assigned to the symbol used in the schematic.

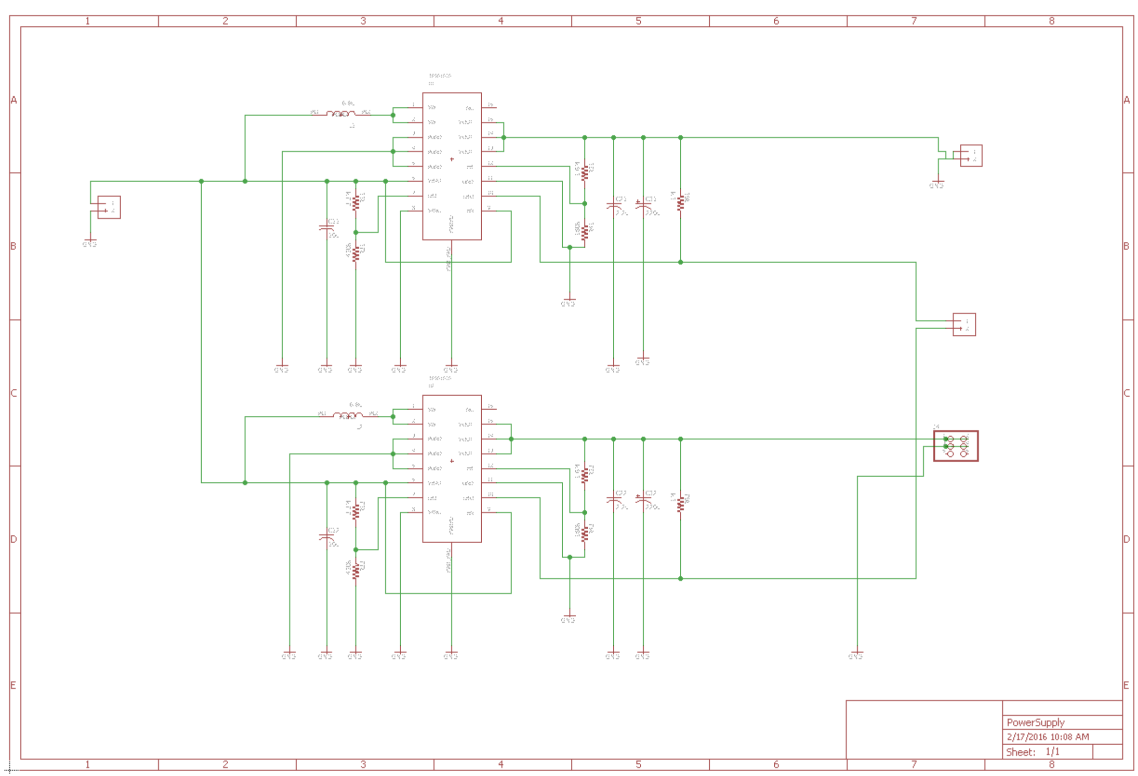

Figure 37 - EagleCAD Schematic for Power Supply

The schematic depicted in Figure 37 represents the boost circuit. Its component values are based on the calculated values during the initial design outline in sections 3.7.2-5. IC U1 and its filter components are for the BeagleBone's supply of power, while IC U2 and its filter components are for the servo-motors. The interface for the input J1 and BeagleBone output J2 use terminal blocks due to the fact that they are easy to interface with and they are relatively inexpensive to purchase. The output for the servo-motors J4 uses male pins because the servo motors use female pin connectors as inputs. Since the input to the BeagleBone is a barrel jack connection, a barrel jack connector cable can be used to connect terminal block J2 to the BeagleBone's 5V DC power input. The middle terminal block J3 is the low battery output (LBO) for both converters; one LBO is routed to one connection in the terminal block and the other to the second connection. Each converter is configured to bring that pin active low when the battery drops below the desired voltage of 3V. It is expected that the battery will not need to be charged often due to its large charge capacity and low current draw from the system, but the option to charge it while within the TITAN module is available regardless.

The package size/dimensions for all the resistors are 0805 as well as capacitors C11/2 and C21/2 - this is due to the fact that 0805 parts are common in EagleCAD and they are easy to solder for prototyping. The library part for the inductors may be created using the physical dimensions of the part provided by the datasheet so that the footprint on the board would match the actual part when soldered on to provide a clean electrical connection. Figure 38 shows the package and symbol that are created in this way.

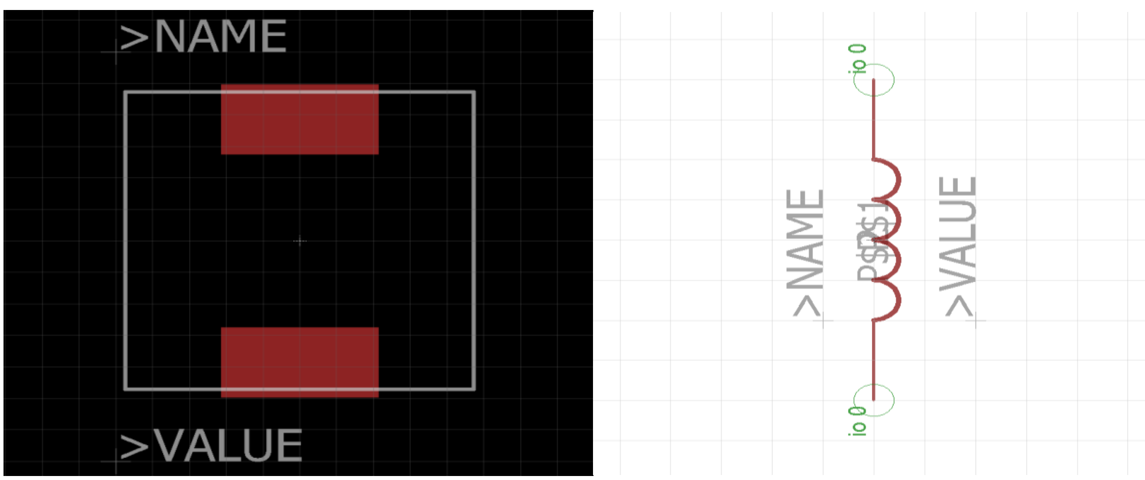

Figure 38 - Custom Eagle Library: Inductor Package and Symbol

This process is repeated for the TPS61030 TI boost converter IC because there is no exact library for the part. The package for the IC is a 16-pin TSSOP which is a standard package, the difference being that the IC package has a power pad underneath as well as some of the dimensions of the IC package are different than the standard TSSOP16 package provided in EagleCAD. The TSSOP16 package provided in EagleCAD may be modified by adding the power pad with the dimensions provided in the datasheet as well as adjusting the pin widths in order to match the physical part. The final custom created device for the boost IC is shown in figure 39.

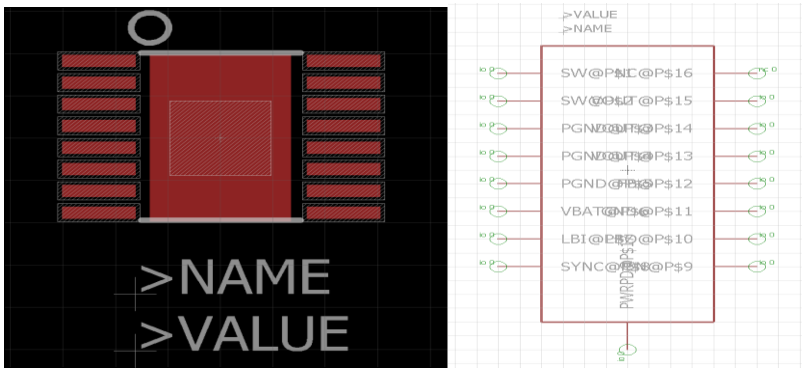

Figure 39 - Custom Eagle Library: TPS61030 Boost Converter IC Package and Symbol

As with all switching power supplies, the layout is an important step in the design, especially at high peak currents and high switching frequencies. If the PCB is not carefully laid out the circuit could show stability issues as well as electromagnetic interference (EMI) problems, these potential issues are factored into the layout design for this board. The final layout for the PCB is shown in figure 40

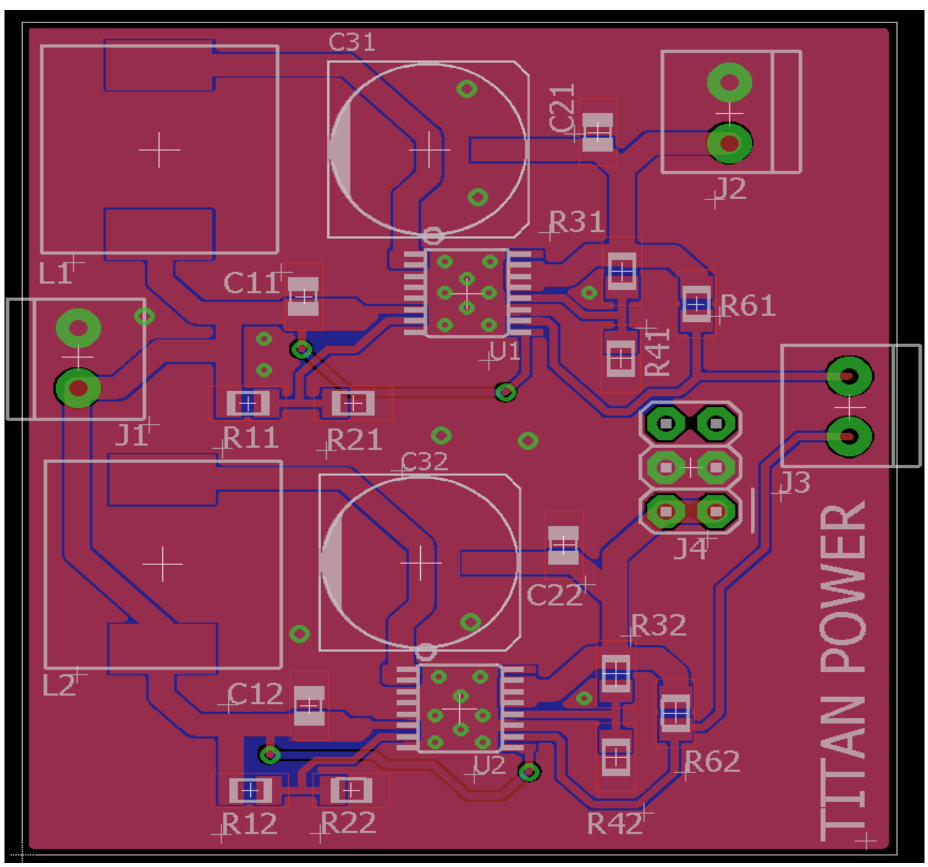

Figure 40 - Eagle Layout for Power Supply

The traces for the PCB are as short as possible in order to avoid introducing unwanted resistances and inductances into the circuit, which could throw off performance and accuracy. This is especially important for the feedback pins because of the need for high accuracy in order to regulate the output voltage. The resistors chosen for the feedback network have a tolerance of 0.1% and are placed as close as possible to the feedback pin so that the IC see's the desired 500mV reference voltage. Higher precision resistors are more readily available in surface mount packages as compared to through-hole thus justifying the choice of surface mount over through-hole. Also, the input inductor and aluminum output capacitor are placed as close to the IC as possible to reduce trace length, these two filter components have a large impact on the desired performance of the boost converter.

The traces for the main current path (input and output) are designed to be thicker than the standard trace size as they carry the most current. Increasing the trace width on these paths improves heat dissipation and puts less demand on the components thus increasing the performance of the circuit. The circuit uses two grounds, the power ground and the control ground which are separated to avoid ground shifting problems which occurs when there is superposition of power ground current and control ground current. The power pad's under the IC's as well as the power ground pins are connected to the ground plane fill of the PCB, the control ground pins are connected to the power pad using very short and thin traces. Even though the two grounds are electrically connected they are considered separated due to the fact they are connected to the power pad's under the IC's using short, thin traces which minimizes the loop thus reducing chances for power ground current to interfere with the control signal.

The purpose of the boost converter PCB is to step the 3.7V battery voltage up to the 5V operating voltage of the system. The resistor feedback network is what ultimately dictates what the output voltage will be. The designed value for resistors R41 and R42 was 180kΩ which yielded an output voltage of 4.8V, slightly lower than expected. This can be fixed by modifying these resistor values, a 160kΩ resistor yielded an output voltage of 5.4V and a 169kΩ resistor yielded 5.2V which is close enough to the desired 5V. The output waveform for the boost converter using a 169kΩ resistor in the feedback network is shown in figure 41

Figure 41 - Boost Converter PCB Output

Because the circuits for both the BeagleBone and the servo-motors are exactly the same, the outputs are identical. It can be seen that the output voltage is well regulated and has a small ripple of about 16mV with an average output of 5.19V. Figure 41 shows the output when the power supply is unloaded but once put under load, the power supply delivered enough power to operate all of Titan's subsystems.

The entire power supply, including the battery, the recharger IC, and the boost converter PCB, integrate with the rest of the Titan system by fitting into a compartment within the body's housing, as seen in figure 42. Overall, the power supply operates as intended by supplying regulated 5V power to TITAN so that it can be used remotely and is compact enough to fit into the housing, thus satisfying the two most important design requirements. A finalized block diagram of Titan's power supply is shown in figure 43.

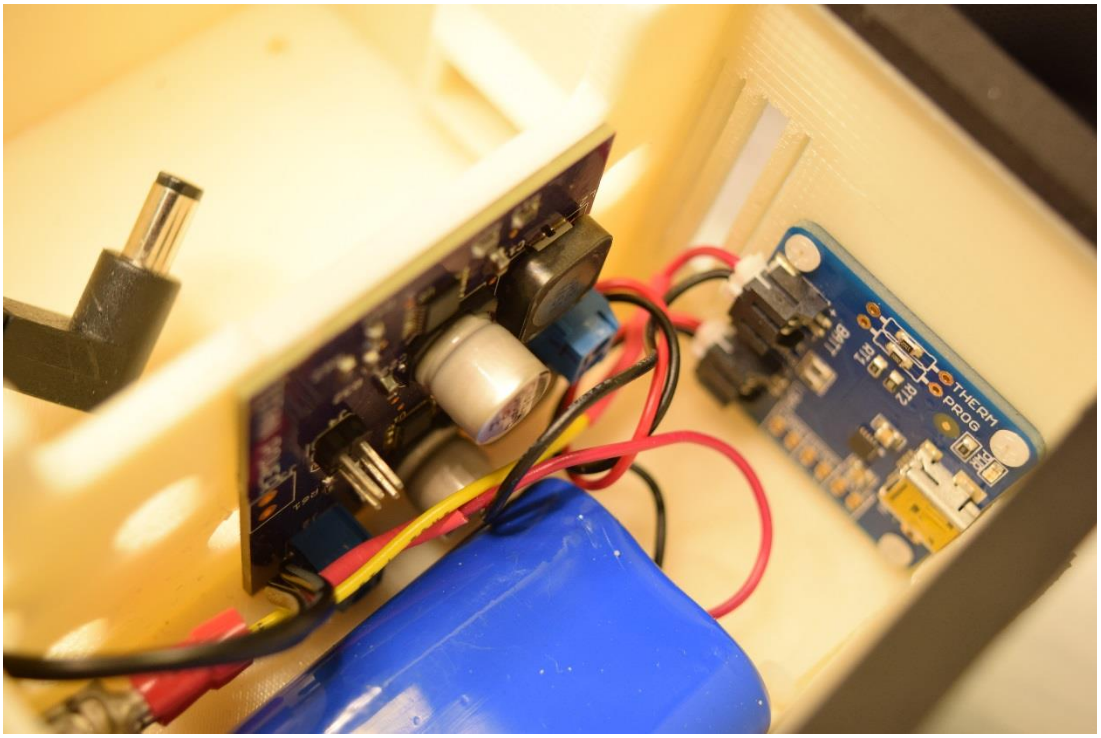

Figure 42 – The power circuit: 5V Boot IC (left), battery (bottom), and battery recharge board (right)

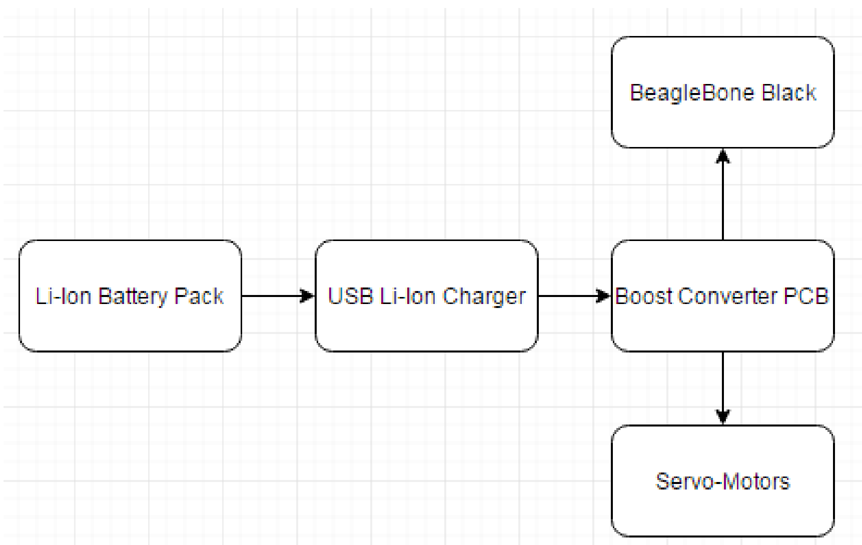

Figure 43 – Comprehensive Power Supply Block Diagram

[SD]

3.9. Mechanical Design and System Assembly

TITAN's construction is primarily characterized by the need to connect to a digital camera and tripod while sufficiently housing the system's components. The external camera is attached to a typical camera screw-mount bracket, which in turn is secured to a brace on top of a dual-axis servo mounting kit. The mounting kit consists of two servos which are mounted together to allow dual-axis rotation, with one servo mounted on top of the other. The bottom servo is locked into the TITAN housing case with its appropriate mounting hardware. The TITAN housing case itself holds all the TITAN system components, and includes a recess in its bottom side where a female tripod screw connector is secured, allowing the housing case to be screwed into any standard tripod mounting screw pad.

The TITAN housing module is designed to be lightweight and moderately rugged to allow the user to easily carry it by hand, backpack, or travel bag. The TITAN prototype module's housing case was chosen to be 3D printed in order to make it as small and lightweight as possible within practical constraints. The 3D-printed housing case holds the Beaglebone board with its attached embedded camera, Bluetooth module, system battery, the power regulator board, and battery recharge board. The housing module is separated into two main pieces - the body and the lid. The lid is designed for the servo to securely mount into it and allow the servo cables into the body. The body itself is specially shaped to hold all the system components within a minimum area while still offering ample room for hand-placement and minor hardware modifications. The lid, padded with foam gasket material, snaps onto the body using two mechanical clamps in order to ensure that potentially erratic servo movement will not cause the lid to fall off the body. The prototype body model also includes vents within its walls as a safe way to make sure the power circuit is not at risk of overheating. In the ideal system design, extensive heat testing will have been performed on the power circuit under various load conditions, and the system chassis will be modeled accordingly to balance overheating protection with weatherproofing.

Depending on which embedded camera is used with the system, the accommodating mounting hardware changes. The system is primarily designed for the HD Camera Cape configuration, so no changes are required to implement this configuration. For the webcam configuration, a USB hub is added to the outside of the module and the webcam is mounted to the front of the unit's top camera mounting bracket (instead of to the side of it, as the HD Camera Cape configuration is designed).

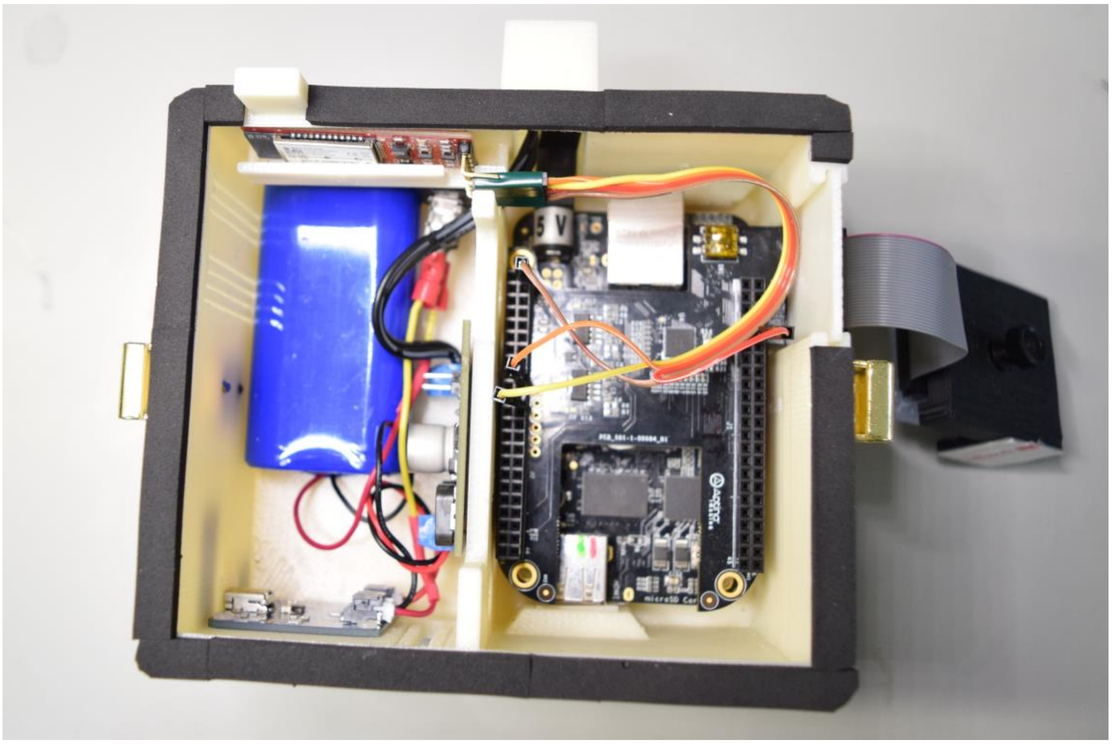

Figure 44 - Complete TITAN system with HD Camera Cape configuration (looking in from top, no lid)

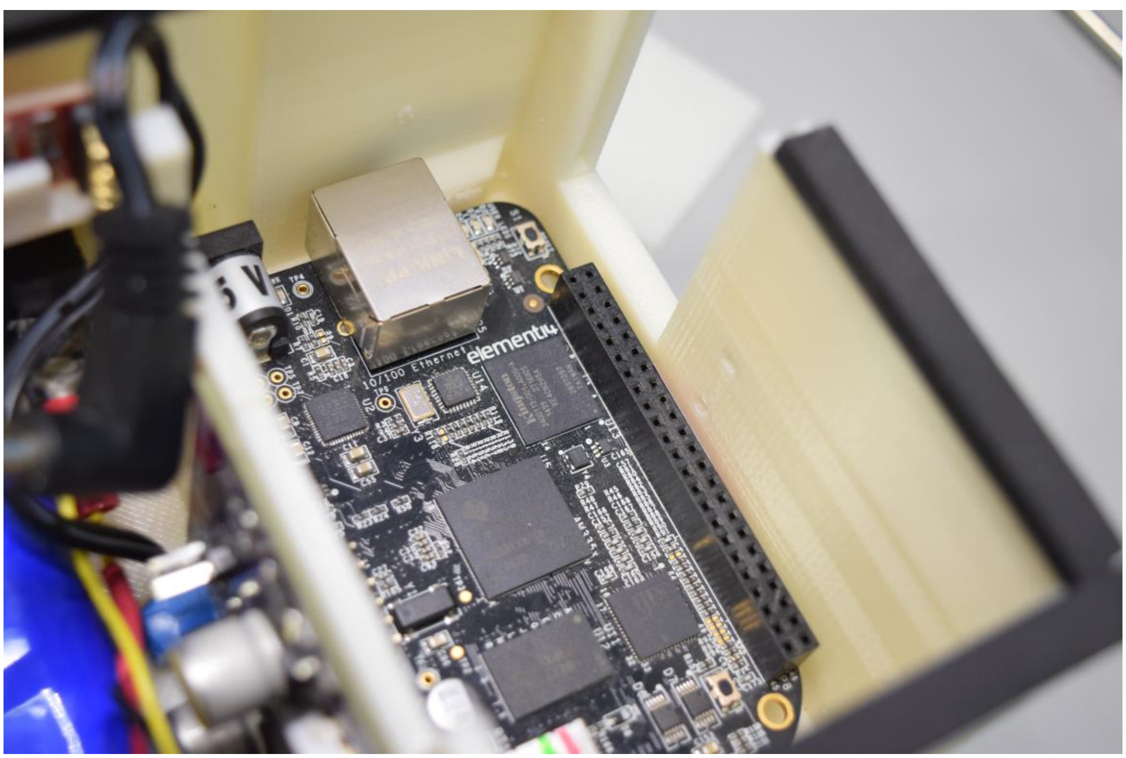

Figure 45 - Beaglebone Black without HD camera cape (which passes the ribbon cable through the "doorway" shown in the wall

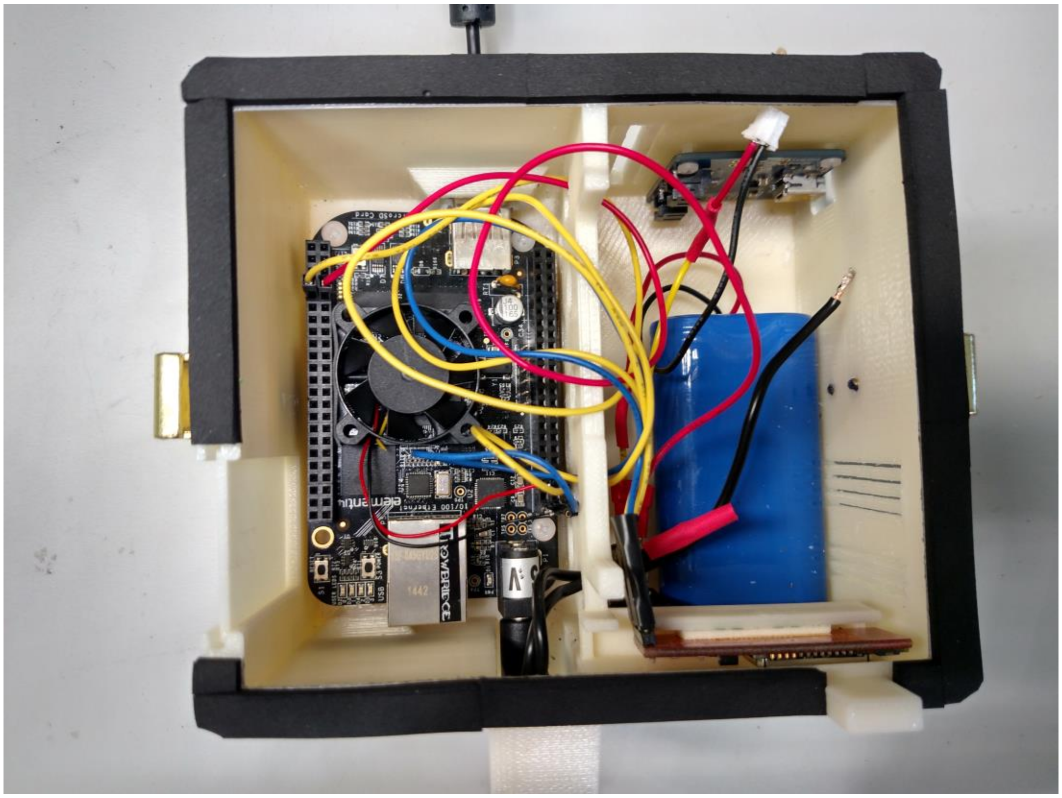

Figure 46 - Complete TITAN system with webcam configuration (with fan added to keep processor cool) (looking in from top, no lid)

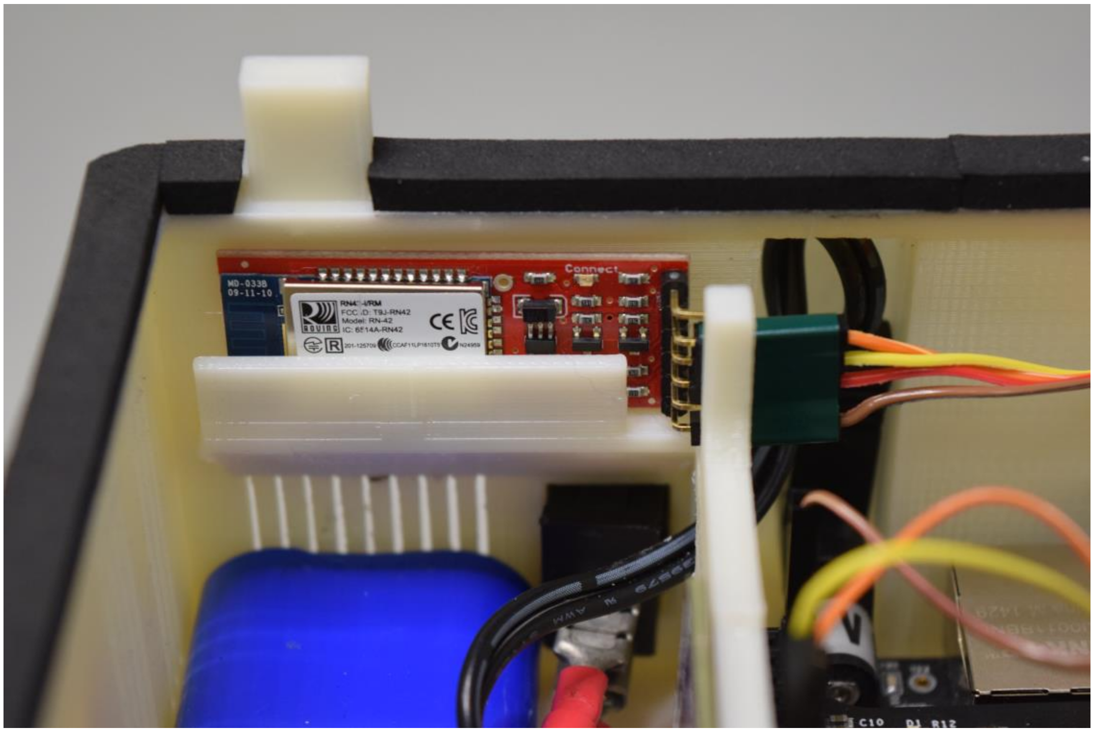

Figure 47 - Bluetooth module in place within the TITAN housing

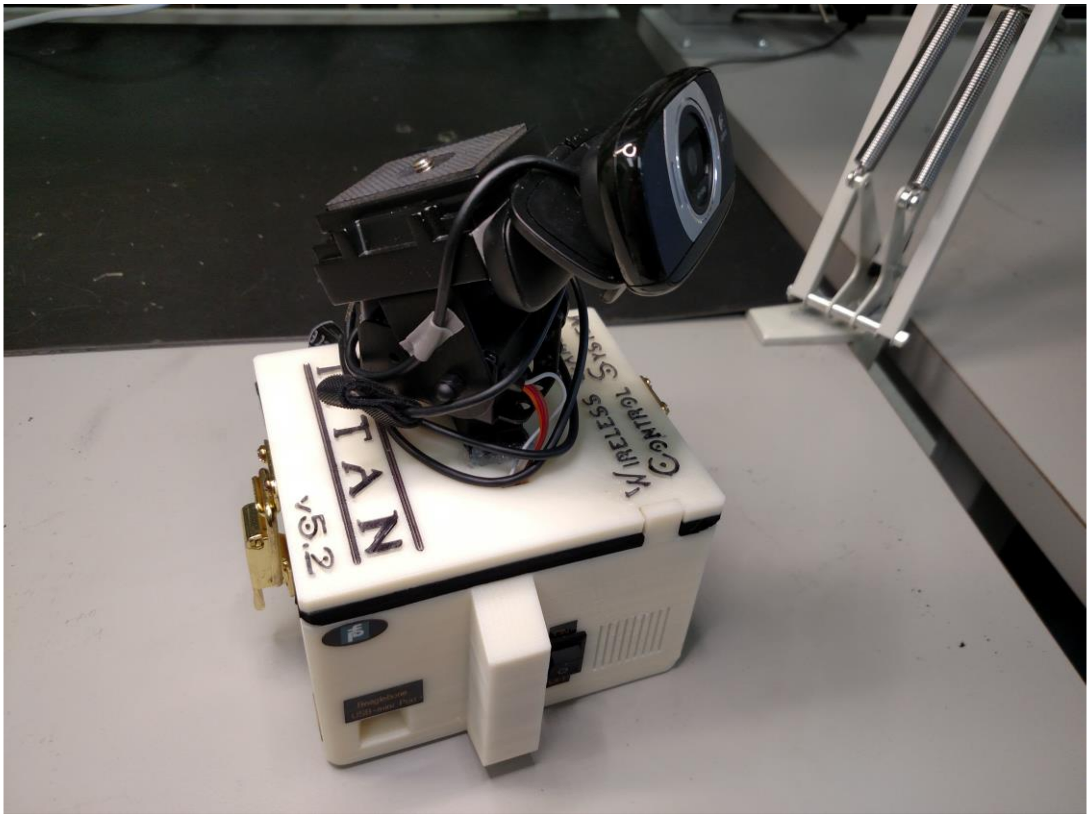

Figure 48 - Assembled TITAN system with webcam configuration (as used in the prototype demonstration)

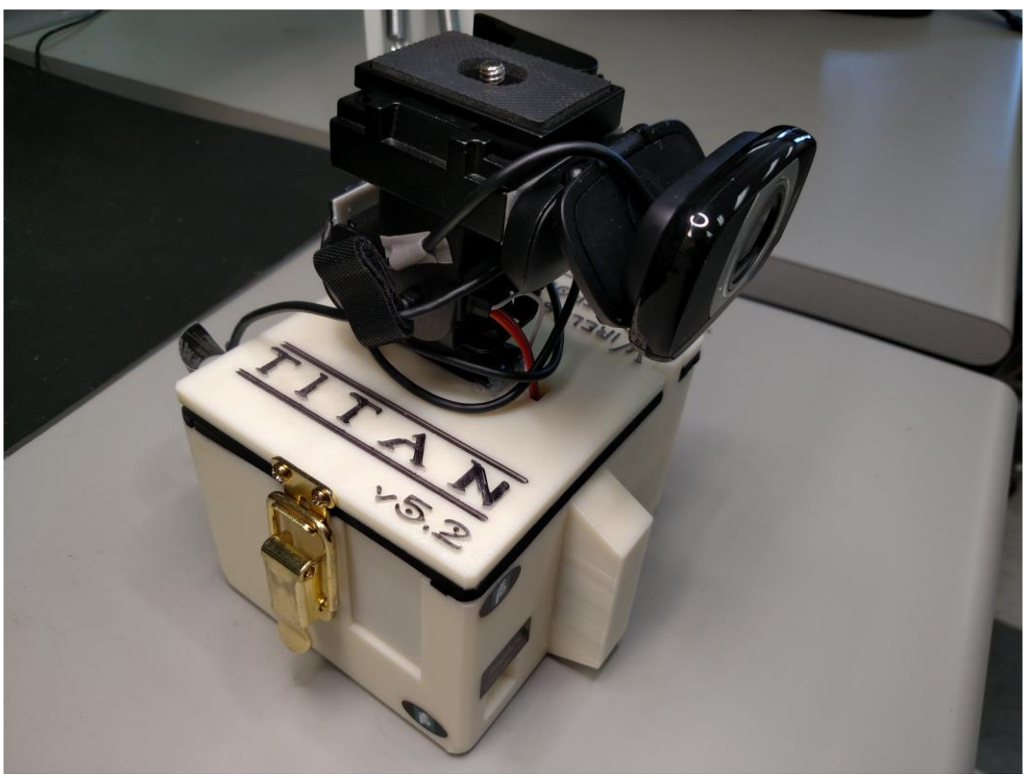

Figure 49 - Assembled TITAN system with webcam configuration (as used in the prototype demonstration)

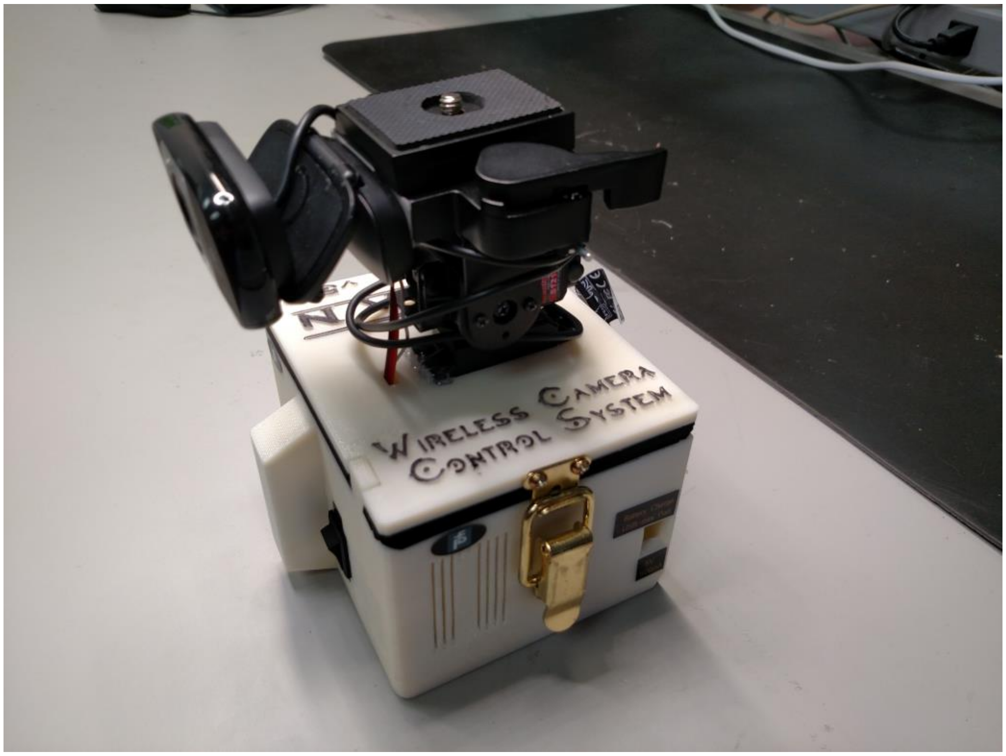

Figure 50 - Assembled TITAN system with webcam configuration (as used in the prototype demonstration)

Figure 51 - Tripod-style camera mount on the top of the TITAN system's servo components

Figure 52 - TITAN's lid with servo and webcam mounted

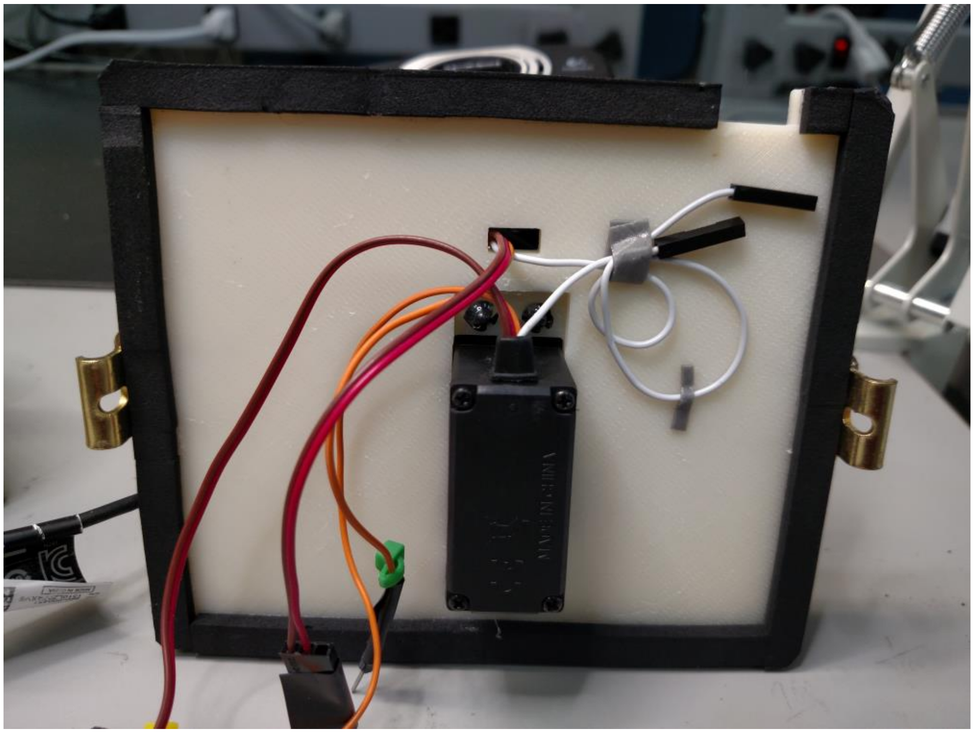

Figure 53 – The underside of TITAN's lid - the white servo wires are analog feedback lines for the servos which, with further development, could be used to more accurately track the position of the servos)

Figure 54 - The underside of the TITAN module's housing. Notice the air vents (top left), screw mount hardware (middle), and Velcro strip (bottom) which is used to attach a USB hub to the unit

Figure 55 - The USB-host side of the TITAN module

Figure 56 - The battery charger port side of the TITAN module

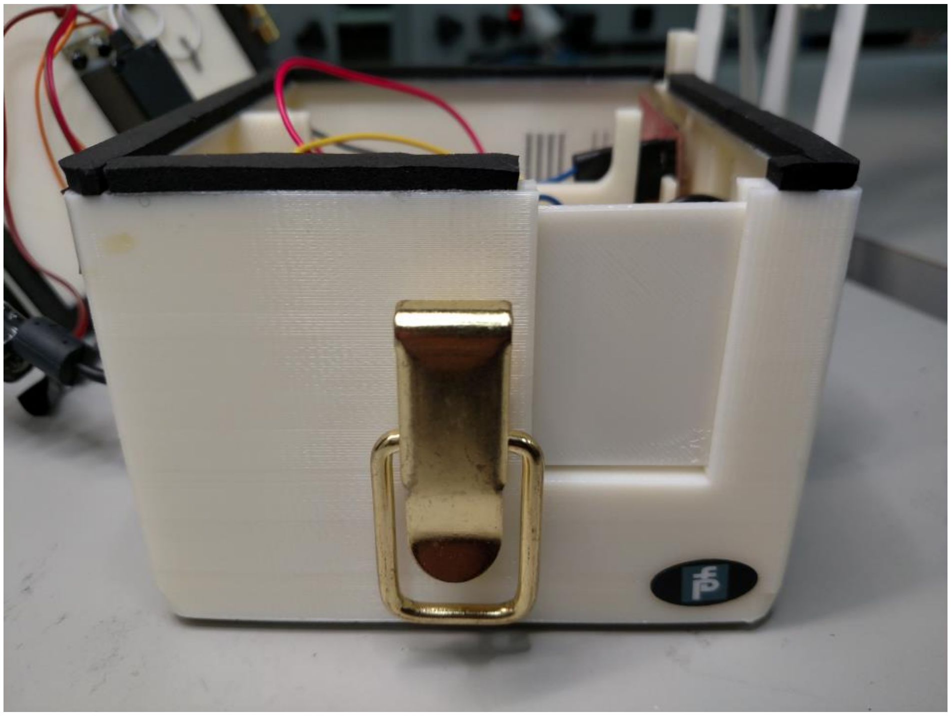

Figure 57 - The HD camera cape "doorway" side of the TITAN module

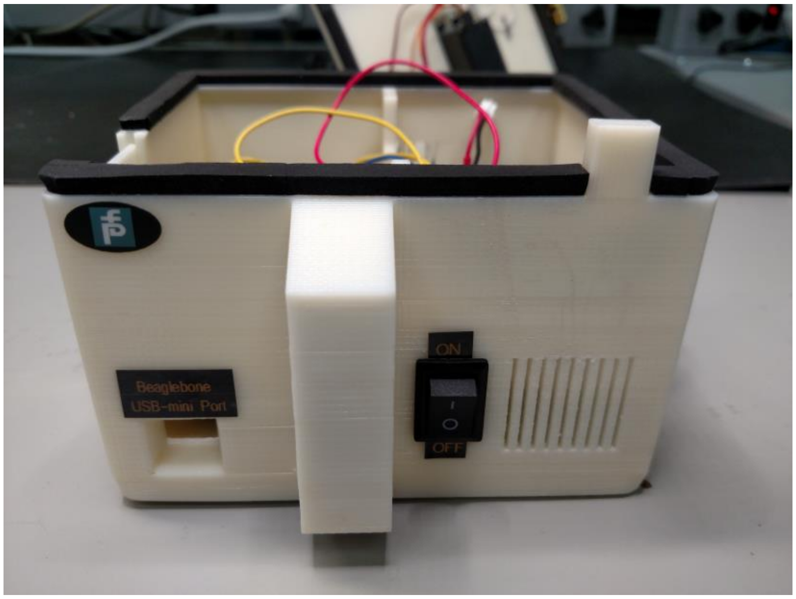

Figure 58 - The main control side of the TITAN module. The mini-USB port can be used to access the Beaglebone's software as needed

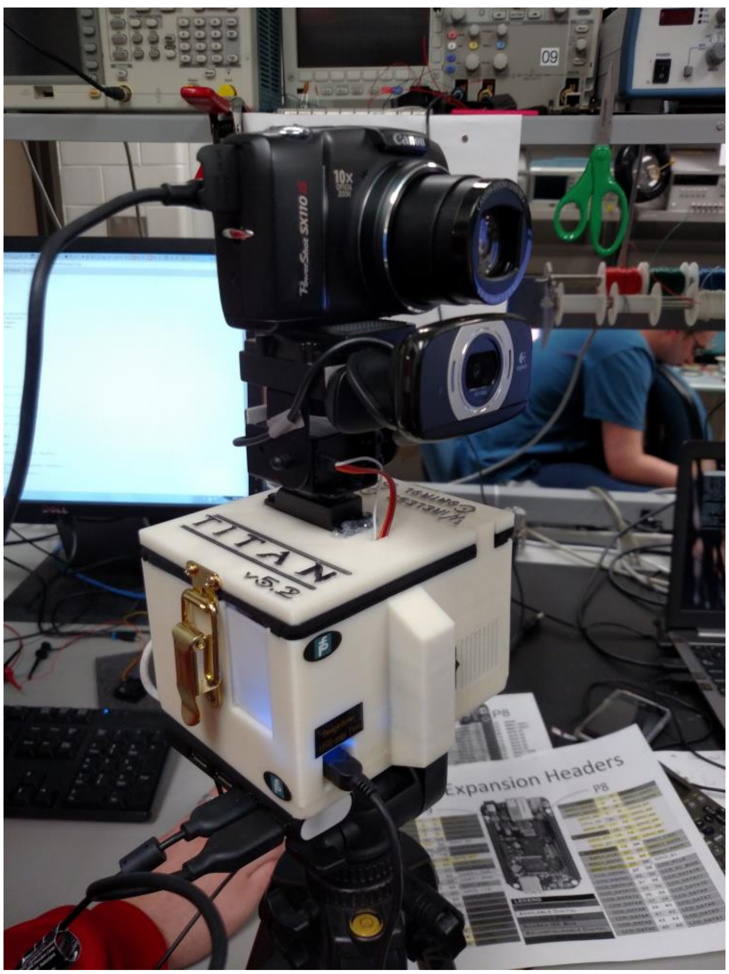

Figure 59 - Full prototype mock-up of TITAN system set up with tripod and external digital camera

Figure 60 - Full prototype mock-up of TITAN system set up with tripod and external digital camera

Figure 61 - Full presentation setup with prototype mock-up of TITAN system set up with tripod and external digital camera

4. Parts List

Qty.	Refdes	Part Num.	Description	Suggested Vendor	Vendor Part Num.	Catalog #/Page #/Website	Cost	Cost
1	-	-	BeagleBone Black RevC	Amazon	B00K7EEX2U	http://www.amazon.com/Be	49.09	49.09
1	-	-	1/4" screw adapter	Amazon	B00MLWO2RM	http://www.amazon.com/Fe	2.39	2.39
1	U1a	RN52-I/RM116	BT Classic Module	Digikey	RN52-I/RM116-ND	http://www.digikey.com/proc	17.2	17.20
1	U1b	RN4020-V/RM120	BLE moldule	Digikey	RN4020-V/RM120-ND	http://www.digikey.com/proc	8.83	8.83
1	-	-	Servo MountS	Robotshop	RB-Lyn-77	http://www.robotshop.com/e	9.95	9.95
2	-	-	Servos	Adafruit	1404	http://www.adafruit.com/proc	14.95	29.90
2	N1,N2	TPS61030PWPR	Boost Regulator IC	Digikey	296-14416-1-ND	http://www.digikey.com/proc	3.07	6.14
2	R1,R2	HVR2500001803FR500	Resistor	Digikey	PPCQF180KCT-ND	http://www.digikey.com/proc	0.47	0.94
2	R3,R4	HVR3700001604JR500	Resistor	Digikey	PPCHJ1.6MCT-ND	http://www.digikey.com/proc	0.6	1.20
2	R5,R6	HVR2500004303FR500	Resistor	Digikey	PPCQF430KCT-ND	http://www.digikey.com/proc	0.47	0.94
2	R7,R8	MRS25000C2204FRP00	Resistor	Digikey	PPC2.20MZCT-ND	http://www.digikey.com/proc	0.31	0.62
2	R9,R10	SFR2500001004FR500	Resistor	Digikey	PPC1.00MYCT-ND	http://www.digikey.com/produ	0.15	0.30
6	C1,C2,C3,C4,C5,C6	EEU-TP1V221L	Cap	Digikey	P14930-ND	http://www.digikey.com/proc	1	6.00
2	C7,C8	FK16X7R1E106K	Cap	Digikey	445-8351-ND	http://www.digikey.com/proc	0.63	1.26
2	C9,C10	FK24X7R1E225K	Cap	Digikey	445-8514-ND	http://www.digikey.com/proc	0.34	0.68
2	L1,L2	AIUR-06-6R8K	Inductor	Digikey	AIUR-06-6R8K-ND	https://www.digikey.com/pr	0.88	1.76
1	M1	PA0034	TSSOP 16 Breakout	Digikey	PA0034-ND	https://www.digikey.com/pr	4.19	4.19
1	-	354	Li-Ion Battery Pack	Adafruit	354	https://www.adafruit.com/pr	19.95	19.95
1	-	1995	USB battery Charger	Adafruit	1995	http://www.adafruit.com/proc	7.95	7.95
1	BL1,BL2	724	Terminal Blocks	Adafruit	724	https://www.adafruit.com/pr	2.95	2.95
1	U2,U3	2465	Boost/Recharger IC	Adafruit	2465	https://www.adafruit.com/pr	19.95	19.95
							Total	$192.19

Figure 62 - Comprehensive system parts list (using through-hole components)

Item #	Qty.	Refdes	Part Num.	Description	Suggested Vendor	Vendor Part Num.	Catalog #/Page #/Website	Cost	Cost
1	4	R4 R10	ERA-6AEB184V	RES SMD 180K OHM 0.1% 1/8W	Digikey	P180KDACT-ND	http://www.digikey.com/scripts/DkSearch/dksus.dll?Deta	0.63	2.52
2	4	R3 R9	1-1614959-2	RES SMD 1.6M OHM 0.1% 1/10W	Digikey	A103800CT-ND	http://www.digikey.com/scripts/DkSearch/dksus.dll?Deta	0.63	2.52
3	4	R2 R8	ERA-6AEB434V	RES SMD 430K OHM 0.1% 1/8W	Digikey	P430KDACT-ND	http://www.digikey.com/scripts/DkSearch/dksus.dll?Deta	0.63	2.52
4	10	R1 R7	RC0805FR-072M2L	RES SMD 2.2M OHM 1% 1/8W 08	Digikey	311-2.20MCRCT-ND	http://www.digikey.com/scripts/DkSearch/dksus.dll?Deta	0.024	0.24
5	4	C3 C6	UUD1H221MNL1GS	CAP ALUM 220UF 20% 50V SMD	Digikey	493-2308-1-ND	cripts/DkSearch/dksus.dll?Detail&itemSeq=189265920&	1.11	4.44
6	4	C1 C4	CC0805ZKY5V6BB106	CAP CER 10UF 10V Y5V 0805	Digikey	311-1355-1-ND	cripts/DkSearch/dksus.dll?Detail&itemSeq=189265915&	0.16	0.64
7	4	C2 C5	EMK212BJ225KG-T	CAP CER 2.2UF 16V X5R 0805	Digikey	587-1293-1-ND	cripts/DkSearch/dksus.dll?Detail&itemSeq=189265917&	0.2	0.80
8	4	L1 L2	CDRH124NP-6R8MC	(ED IND 6.8UH 4.9A 23 MOHM SI	Digikey	http://www.digikey.com/scripts/DkSearch/dksus.dll?Detail&itemSeq=189265914&uq=635902587432776916			
9	10	R6 R12	RC0805FR-071ML	RES SMD 1M OHM 1% 1/8W 0805	Digikey	311-1.00MCRCT-ND	cripts/DkSearch/dksus.dll?Detail&itemSeq=189265916&	0.021	0.21
10	1	BT1	WRL-12576	RKFUN BLUETOOTH MATE SILV	Digikey	1568-1265-ND	cripts/DkSearch/dksus.dll?Detail&itemSeq=189275762&uq	24.95	24.95
11	1	CABLE	CA-2191	BLE ASSY R/A 2.1MM 6' 18 AV	Digikey	CP-2191-ND	ww.digikey.com/product-detail/en/CA-2191/CP-2191-ND/	3.13	3.13
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								Total	$47.57

Figure 63 - Surface mount component bill of materials

Figure 62 shows the general bill of materials used for the project using through-hole electrical components. Figure 63 shows the bill of materials used for the updated SMD electrical components, which were ultimately used in the main demonstration of the TITAN prototype. Some component quantities are adjusted for price savings via quantity bundling rather than raw quantity needed. All components and parts ordered have been selected based primarily on acute need of each specific part and secondly by price savings according to each vendor and/or part model. [SD, MT]

5. Design Team Information

5.1. Samuel Davis, EE – Hardware Design

Team Role: Power and hardware development

Planned Senior Elective Classes: Analog IC Design, Power Electronics, Active Circuits, Wireless Communications, Digital Communications, Electromagnetic Compatibility

5.2. Ian Drake, CpE – Software Design

Team Role: Programming and app development

Planned Senior Elective Classes: Analog IC Design, Data Structures, VLSI Circuits and Systems, Electromagnetic Compatibility

5.3. Ognjen Krco, EE –Archivist

Team Role: Hardware development and research

Planned Senior Elective Classes: Modern Power Systems, Power Electronics, Digital Communications, VLSI Design, Active Circuits, Electromagnetic Compatibility

5.4. Matthew Trowbridge, EE –Team Lead

Team Role: Embedded hardware, mechanical design, and programming

Planned Senior Elective Classes: Embedded Systems, Analog IC Design, Electromagnetic Compatibility, Controls II, Active Circuits, VLSI Design

[MT, ID, SD, OK]

6. Conclusions and Recommendations

6.1. Design Considerations

The embedded design of this system is centered on the BeagleBone Black development board, while the mechanical design is designed to directly integrate with typical camera mounting hardware. The BeagleBone Black microprocessor board is chosen for many reasons, though primarily for its image processing abilities (as listed in Section 3.2). This system would work just as well using other platforms such as the Raspberry Pi 2 or Raspberry Pi 3, other BeagleBone models, or other capable microprocessors. Having selected the BeagleBone Black, however, many prototyping and expansion possibilities are available as part of the design and development stage of the project.

As expected, for all the tripods the system was tested on, there were no issues with the tripod falling off balance from servo movement or unit weight/shape. This implies that almost any tripod the user already owns can be integrated with the system with limited guarantee of operable stability (with the intention of the user being aware of the structural stability of his/her own tripod and/or camera mount).

For demonstration purposes, instead of streaming video/photos taken with the system to the user's mobile device, the video/photos may be sent to a large TV screen so that larger groups of people may see the result of TITAN's ability to control a camera without having to pass the mobile device to every single participant. For the prototype, a 1-amp fuse is also added to the battery's power supply line to prevent any unexpected current surges that may damage the system. Based on the demonstration of the prototype design, the TITAN module proved itself to be entirely capable of performing its intended tasks of camera control. Each component of the system has shown itself to perform as expected during the prototype demonstration, though some last-minute performance tweaking during the presentation mandated slight deviation from the original design.

6.2. Future Development

The libgphoto camera control library does not support every single digital camera. While it does support many digital cameras, it may not be possible to control every camera using it. Code for controlling unsupported cameras will be useful as future development to ensure as many cameras are supported by this system as possible. Ultimately, the ability to control cameras is also limited by the camera's manufacturer, who can limit the amount that the camera is able to be controlled by outside sources. For the sake of this project's scope of time and resources, only one supported camera model has been targeted as a demonstrative prototyping model. Various other servo models may be used as well to obtain greater values of achievable torque, allowing control of larger and heavier cameras. A more compact and higher quality embedded camera may be designed specifically for this device, and the Beaglebone Black board's cost may be dramatically cut by developing a custom microprocessor board with only the necessary functions and dimensions. Lastly, the TITAN case itself may be potentially designed to be even more compact and studier by redesigning it to minimize volume and using molding/casting or other fabrication techniques instead of 3D printing.

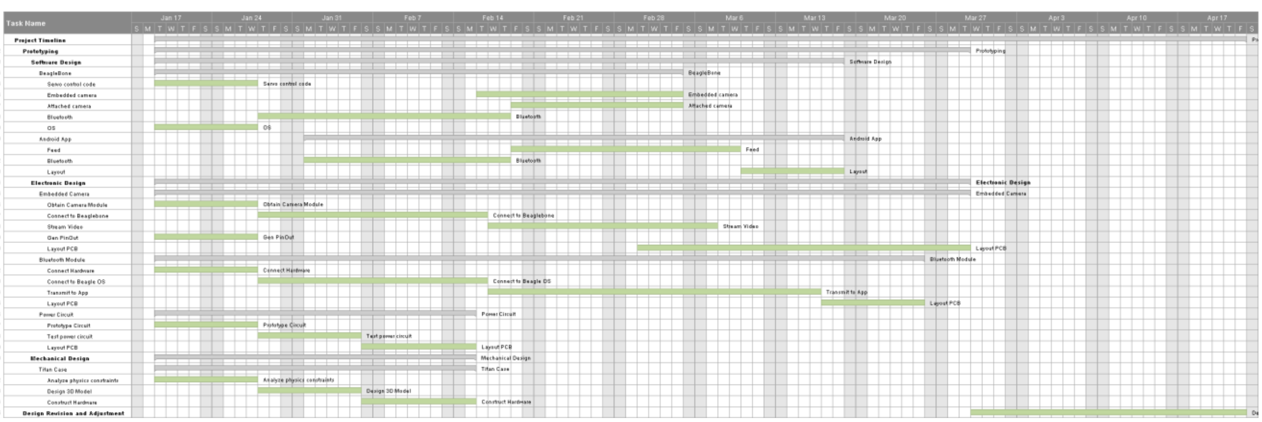

Figure 64 - Gantt Chart Project Plan for the Spring 2016 Semester

[MT]

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[MT, ID, SD, OK]

8. Appendices

8.1. Appendix A

This project as an advanced product is still a work in progress and certain aspects of its development are currently in prototypical/experimental stages. As such, there are aspects and modifications of the project which may differ in various ways from the original design; most of these cases have already been explained and outlined throughout the report, though instances may have been deemed to be too insignificant or irrelevant to be mentioned.

[MT]