

# Creating a Time Slicing Effect – GoPro Array Rig & Workflow

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A handwritten signature in black ink, appearing to read 'R. Figueroa', written in a cursive style.

# Creating a Time Slicing Effect – GoPro Array Rig & Workflow (May 2014)

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**Abstract** — Time Slicing or as we may know it as, “Bullet Time” is an effect most famously achieved in *The Matrix* (1999). The effect is achieved using a series of still cameras surrounding your subject. At the point of action, the cameras are set off simultaneously to capture that one point in time from various positions. *The Matrix* used this technique, but incorporated a laser targeting system to form a uniform curve in space of a given radius. When triggered, every camera would begin to capture the action at a high frame-rate as it was happening. This footage was then processed to interpolate between each camera at one point in time with heavy frame-to-frame interpolation.

My technique that will be provided for students in the School of Film and Animation at RIT is similar to that of *The Matrix*, but will not contain any large amount of intense computer interpolation between each image and will rely on a fixed rig of 14 GoPro Hero 3: Black Edition cameras rather than a laser generated curved path. The difference between my rig array and other similar GoPro arrays is the addition of an interchangeable curved and straight vertical element, giving artists a new perspective. This method will create a few interpolation artifacts when switching between cameras at a single point in time, but can be fixed using image interpolation algorithms for motion frames with both standard editing software or user created implementation. The important thing is to create the rig for capture and provide the workflow (both capture on post-production) so that the project can be improved on in the future.

## I. INTRODUCTION/OBJECTIVES

TODAY’S world is infatuated with capturing and sharing everything in their life with their family and friends. Most of the time these timeless moments are captured with our cell phone cameras. These All-in-One devices including a high-definition camera are a huge convenience because it takes away from having to carry that “one extra device” around.

In 2004 GoPro set out to accomplish the goal of this “capture and share” method, but by making you the star. The company wanted to be able to develop a camera system that could go anywhere with you and capture the moments that we only relive in our minds. GoPro’s revenue has doubled every year.

Starting in 2005 with over \$350,000 to over \$500 million in 2012. In a market dominated by the mobile device and its camera GoPro isn’t just surviving, it’s thriving.

The decision was made to mount multiple GoPro Hero 3 cameras on an aluminum crafted, curved bar rig. These cameras will be set to capture an object in motion at a high frame rate and then stitched together in post-production. This setup will simulate the effect of movement around the object while said object appears fixed, also known as the “Bullet Time Effect”.

These cameras are cheap enough, small enough, and light enough to simulate this effect for student use at the School of Film and Animation at RIT. In building this rig there are three main goals (and one extended goal being attempted) that must be accomplished for it to be reasonably used by other filmmakers.

- *Build the GoPro Array Rig.*
  - The final rig will be modular for easy breakdown and future additions. It will also be available for checkout at the RIT SoFA Cage.
- *Provide test footage for a demo reel.*
  - The rig will be tested vigorously with various genres of material. This reel will demonstrate both proof of concept and give students an understanding of what the rig can be used for.
- *Create a workflow for SoFA students at RIT to follow step-by-step.*
  - Both a hard and soft copy of the workflow will be provided to checkout at the School of Film and Animation Cage. This workflow will include all steps in both production and post-production. The production workflow will include how to build and setup the rig body as well as how to setup the cameras for capture. The post-production workflow will include how to export the footage and how to edit the footage in the provided software templates to achieve the bullet time effect.

These three objectives (GoPro array rig, test footage for a demo reel, and a workflow for students in SoFA at RIT to follow step-by-step) are the main goals in the development of this project. If these three goals were to be accomplished ahead of schedule, an extended goal would be the implementation of image interpolation to achieve a smoother transition between each of the cameras at a specific point in time.

This would be achieved using either the method provided by Ryan Connolly, an RIT Motion Picture Science Undergraduate Senior in 2013, with his thesis on *3D Multi-view User Interface* (May 2013), or the method outlined in Angel Tamariz Sánchez' Master Thesis, *Interpolation for Video Navigation* (October 2011). Connolly's method provides users with an image interpolation between two cameras in a static situation. Personally, I would be more inclined to attempt Sánchez' method for a high quality interpolation, but if time is limited, Connolly's method will suffice.

Sánchez' method used a "Watershed Algorithm" which essentially picks out and combines sections of pixel code values (sort of like a heat map) with a provided threshold. When taking the Watershed of both images they can then be superimposed onto one another. The first derivative of the two combined images is determined in Matlab, identifying the images "energy" or general edges. These edges are used to identify a correlation between the first and second image edges. This correlation is found using the "Auction Algorithm", outlined in Sánchez' thesis, to create the interpolated edges of the new inter-image. The Auction Algorithm combined with the Watershed Algorithm will create an image that can be mapped to the interpolated edges, section-by-section (rule of thirds) with the combined Watershed sections.

The technique being provided for the students in the School of Film and Animation (SoFA) at RIT would be similar to that of *The Matrix*, but will not contain any large amount of intense computer interpolation between each image and will rely on a fixed rig of cameras rather than a laser generated curved path. This method will create a few interpolation artifacts when switching between cameras at a single point in time, but can be fixed using either advance image interpolation algorithms for motion frames or built-in frame blending tools in post-production suite software. The important thing is to create the rig for capture and provide the workflow so that the project can possibly be improved on in the future. While the method in *The Matrix* in achieving the bullet time effect is the most ideal, the

average filmmaker doesn't have the Hollywood budget and time. The completion of this rig will enable students, to continue innovating in SoFA. It will allow filmmakers to test new shots, implement a whole new design workflow, and allow these artists to achieve a shot they didn't see possible before at RIT.

## II. BACKGROUND/THEORY

### A. Introduction to Time Slicing Theory

Time Slicing or as we may know it as, "Bullet Time" is an effect most famously achieved in *The Matrix* (1999). The term "Bullet Time" was then registered in 2005 to Warner Bros. after the success of the film in the video game *The Matrix Online*. The effect is achieved using a series of still cameras surrounding the desired subject. At the point of action, the cameras are set off simultaneously to capture that one point in time from various positions.

*The Matrix* used this technique, but incorporated a laser targeting system to arrange a uniform curve in space of a given radius. When triggered, every camera would begin to capture the action at a high frame-rate as it was happening. While these cameras were capturing the action they were also changing position around the laser drawn curve. This footage was then processed to interpolate between each camera at one point in time with heavy frame-to-frame interpolation. This ensured the bullet time effect would be smooth and prevent image artifacts when stepping through cameras.

In addition to these three main project goals, a camera characterization was performed to obtain a better understanding of what the GoPro Hero 3: Black Edition camera was doing under ideal shooting conditions. Both an understanding of what the camera is capable of and not capable of, is important to know before going onto any set. These tests included Noise, MTF, Dynamic Range/OECF, and Color Reproduction. Each test will be explained further in the experiment's background and procedure section.

*B. Technical Specifications/Camera Overview**1) Technical Details/Features (that will be used):**a) 12.40 Megapixel CMOS Sensor 1/2.3"**b) Video Resolution: 1920 x 1080 at 60fps*

(1) Sensor Size: 1/2.3" (6.17 x 4.55) mm

(2) Pixel Size: 1.55um

*c) ISO: Base 640**d) Shutter Speed: 1/60**e) 4:2:0 Chroma Sub-Sampling**f) Camera Picture Settings*

(1) GPH3 [ISO 640; WB AUTO; 1/60th; f/2.8; 1080p 59.94fps]

(2) GPH3 [ISO 640; WB AUTO-Protune; 1/60th; f/2.8; 1080p 59.94fps]

(3) GPH3 [ISO 640; WB 3000K-Protune; 1/60th; f/2.8; 1080p 59.94fps]

(4) GPH3 [ISO 640; WB 5500K-Protune; 1/60th; f/2.8; 1080p 59.94fps]

(5) GPH3 [ISO 640; WB 6500K-Protune; 1/60th; f/2.8; 1080p 59.94fps]

(6) GPH3 [ISO 640; WB RAW-Protune; 1/60th; f/2.8; 1080p 59.94fps]

*g) Encoding and Decoding Compression Variation*

(1) Encode: GoPro Cineform Compression (.mp4 file format)

(2) Decode as MPEG-4-AVC/H.264 Compression or GoPro Cineform Compression (.mov file format)

The GoPro Hero 3 has a unique wide-angle lens resulting in a wide field of view (FOV). This field of view can be manipulated by performing a digital crop. This is done by cropping the image formed on the sensor and then expanding it back out again to meet the resolution set by the user. The camera houses a 1/2.3" sensor and a fixed

f2.8, 2.8mm focal length lens. With this known, the hyperfocal distance of this system would be about 20-30cm. This means that 20-30cm to infinity would be the range of acceptable focus.

The Hero 3 Black Edition has the option to set the field of view to 170 degrees (Wide mode, uncropped), 127 degrees (Medium mode), and 90 degrees (Narrow mode). The 90-degree "Narrow mode" gives us the easiest FOV to build the rig's design around while also allowing us to add more cameras in the future without worrying about the cameras seeing each other from their crossing FOVs.

*C. Rig Build and Design Overview*

The idea for a "real world" time slicing effect would only be possible if a prototype was able to be made and tested. For this prototype to be feasible, many hours of planning took place to make sure that this rig would be as accurate and precisely made as possible to acquire desirable footage. The design was all contingent on the angle of the bent arm and the distance between cameras.

A group of second year mechanical engineering students from RIT agreed to work with me for both credit and the experience. We quickly started to work out the best way to go about this from the tools, the material, and the time management. It was determined after the first couple of meetings that this project was feasible with the tools and time available on the RIT campus. As the project began in the machine shop, there were continuous adjustments made to allow for ease of production and usage for the future users of the rig. There was an active decision made to keep extra space on the ends of the bar to allow for modifications and future additions to be made.

The GoPro Hero 3 Black Edition (GPH3) model is being used because they are currently the only (besides the brand new Hero 3+, as of October 2013) models that provide the option to manually control the white balance (via PROTUNE mode), while also fitting the budget. This is essential when trying to match each frame of footage between each camera in post-production.

The number of cameras being used was determined by a compromise between budget and quality. The more cameras lining the rig will result in an amplified and desirable effect for viewers. This is due to the lesser change at a constant distance throughout space around the subject. With a \$5,000 budget provided by the College of

Imaging Science at RIT a total of 14 camera bundles and 8GB MicroSD Class 10 memory cards were purchased.

The rig design will take into consideration that the cameras will be in their weatherproof casing. This will help eliminate worry of damaging the cameras and give the ability to shoot in a variety of conditions. The downside to this casing is that it does not allow entrance to the USB port on the side of the camera for power. We must solely rely on battery power when shooting.

When planning the design of the rig we must consider the dimensions of each individual GoPro. The dimensions of the GoPro Hero 3 camera with the weatherproof housing and original stand are (8.5cm x 8cm x 5cm) [H x W x D]. This would take the total length of the rig to about 72cm across without cameras spacing.

The array will utilize 14 GoPro Hero 3 Black Editions in total. The horizontal curve will house 9 cameras across with the center camera (5th camera in from the end, titled “OM”) in the direct center of the rig. The choice was made to make the point of camera center to be the point of the rig center instead of the lens center because the whole rig would then be offset. This is because the GoPro cameras have a lens center that is offset 6cm from the left, while facing you, in its provided weatherproof casing. The vertical section of the rig will house 5 additional cameras. The reasoning behind adding an additional camera to the vertical section was decided on the basis that students were interested in seeing how the vertical element on this rig would look, so it was decided to enhance the effect on the vertical section was made.



Figure 1: GoPro Hero 3 Front View Dimensions

This camera rig will be designed to have a set curvature so the 72cm would also not take the length due to curvature or camera spacing into consideration. The curve is essential to the design to simulate a smoother rotation around the subject. Instead of starting at one end of the rig and essentially capturing a moment in time and tracking away from the subject, the curvature allows for the subject to remain the focus of the effect. When developing the

curvature of the rig it must be understood that the angle of curvature cannot be too steep. This is to prevent the two cameras on each end from seeing each other in their field of view.

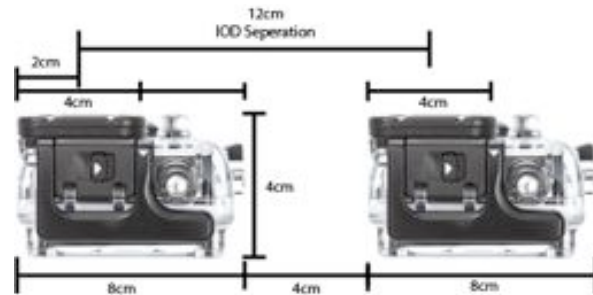


Figure 2: Side-by-Side Dimensions for Line Array

Understanding that each camera can be set to have a FOV of 90 degrees, we can use this angle to determine our overall arc angle of the rig without the two end cameras seeing each other with the understanding that in a perfect line, the cameras will only see each other if they are facing each other. Half the FOV angle can be used as our maximum angle of curvature because once that angle is reached the two end cameras will see each other. For this, 40 degrees will be used instead of 45 degrees because this allows for about 5 degrees of error within this maximum angle.

Knowing that we have a total of 9 cameras on the horizontal section of the rig, the problem can be split in half, using the middle camera as the starting point. This allows the other four cameras to pivot from this center camera in determining the angle in which the camera should sit. With a maximum angle of 40 degrees we can divide this by the 4 pivot points created by the separated cameras, wrapping around the arc. This would yield a 10-degree difference created by each camera; however, we do not want the angle to be this steep because we would be close to reaching the 45-degree absolute maximum. Dividing the previous 10-degree difference in half, a 5-degree difference between each separated camera is created, yielding a 20-degree arc.

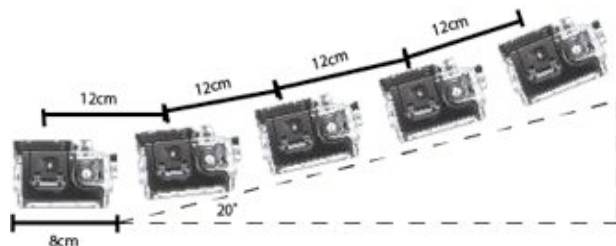


Figure 3: Arc Angle of Rig

With the current angle of curvature predetermined to be 20 degrees from horizontal on both ends of the rig, this allows for an addition of 8 cameras on each arm segment (addition of 24 total), a total of 38 cameras on the rig at one time with the same radius of curvature and camera spacing. The addition of these extra cameras would bring the rig's overall angle of curvature to a 40-degree angle, just barely reaching the 45-degree threshold where the FOVs from the two cameras on the end would cross. The mathematics attempt to also take into consideration a 70-degree overlapping camera FOV parallax, also known as the convergence angle ( $\alpha$ ) in optics; however, when both the 12cm IOD separation and the 20-degree curvature were implemented physically, the size and feel of the rig became more of how it was imagined.

There are distinct differences between the current GoPro array concepts and the design being implemented here. The addition of curvature to the typical line array model will add a new feel to the look of these other high-speed GoPro rigs. A vertical module, bearing the same 20-degree curvature will also be added to the center of the horizontal section. The final designed rig will resemble one of the grabbing claw games at retail stores, but the two bottom arms will be flat to the surface normal, and the third arm would be vertically perpendicular.

A handgrip system is also implemented alongside a standardized tripod mount for stable recording in all environments. These two mounted pole grips will be attached to the bottom for handheld use, but its main purpose is to be mounted on a typical RIT Cage provided tripod. Having the rig mounted during capture will result in fewer motion artifacts between each camera.

#### *D. Workflow Design Overview*

The workflow created consists of a step-by-step of the entire process. This includes a list of equipment needed, a setup of the cameras on the rig, a process of effective capture, a process of bringing the footage into post with correct organization (a template will be created to accommodate this specific workflow), a process on how to align cameras in the editing software to achieve the desired effect, and finally a process on optimized rendering and output methods. The workflow will include all this information in a document to then be provided to students (hardcopy and an electronic copy on the provided flashdrive) when checking out the rig at the RIT SoFA cage.

#### *E. Demo Reel Overview*

The demo reel will be made as if the product were being sold to RIT and its students. This will include both high action shots from sports and other interesting scenes to show off the basic capability of the system.

The current shot list includes:

- High diving (rig half in and half out of water)
- Gymnastics team flips
- Golf swings
- Cartwheel
- Cornstarch bouncing on speakers

#### *F. Camera Characterization Overview*

In addition to these three main project goals, a camera characterization was performed to obtain a better understanding of what the GoPro Hero 3: Black Edition camera was doing under ideal shooting conditions. These tests included Noise, MTF, Dynamic Range/OECF, and Color Reproduction.

##### *1) Noise*

Noise is defined as the random variation of brightness or color in an image caused by the imaging system itself or the variation in the number of photons sensed at a given exposure level. It is an effect of long shutter speeds, gain and well size. This is all done to correct exposure in low light situations.

Lack of noise is a key characteristic in an imaging system, but it is a constant battle between low noise levels and high low light sensitivity. It is an important aspect when choosing the ideal camera setup. A Macbeth chart shot with different camera modes will be used in this analysis. There are two methods that we will use to analyze noise. One will be between both the temporal and fixed noise characteristics of the camera. The other method will be a perceptual noise analysis based on standards set by Kodak for film grain noise evaluation.

Kodak released a standard that they would use for determining noise. A 50-micron aperture would be used when analyzing film. Humans are not sensitive enough spatially, to detect individual grains in the film, so the 50-micron aperture was chosen after psychophysical experiments. These experiments show that the 50-micron aperture would be ideal to us as the metric for a grain on the screen. This standard can be utilized today with digital systems when compared to film. HD film is approximately

21mm in width. The resolution of the test cameras is:

$$\begin{aligned} &1920 \text{ pixels in width.} \\ &\text{So the pixels/mm is:} \\ &\frac{1920}{21} = 91.4 \frac{\text{pixels}}{\text{mm}} \\ &\text{Convert that to microns and find the number} \\ &\text{of pixels in the 50 micron aperture:} \end{aligned}$$

$$\begin{aligned} 91.4 \frac{\text{pixels}}{\text{mm}} &= 0.0914 \frac{\text{pixels}}{\text{micron}} \\ 0.0914 \frac{\text{pixels}}{\text{micron}} &* 50 \text{microns} \\ &= 4.57 \text{pixels} \approx 5 \text{pixels} \end{aligned}$$

With this in mind, moving through each image in 5x5 pixel blocks, mimics the aperture size developed by Kodak and takes the end standard deviation.

Temporal and fixed noise will also be looked at for multiple images. Splitting these two aspects allows a determination of where the noise is coming from. Fixed noise is the dark current of the system and remains constant through multiple images. Temporal noise on the other hand is caused by read noise and interpolation.

$$\begin{aligned} \sigma_{\text{Temp}} &= \sqrt{\frac{N\sigma^2 \text{Diff}}{N-1}} \\ \sigma_{\text{Fixed}} &= \sqrt{\sigma^2 \text{Ave} - \frac{N\sigma^2 \text{Diff}}{N-1}} \\ \sigma^2_{\text{Total}} &= \sigma^2_{\text{Temp}} + \sigma^2_{\text{Fixed}} \end{aligned}$$

## 2) Modulation Transfer Function (MTF)

The Modulation Transfer Function (MTF) is a description of the camera system's spatial sensitivity. It shows how much detail the camera system can discern. To compare MTF and aliasing characteristics of the camera system an ISO 12233 chart will be shot. There are many things that influence the MTF including focus of the camera, the lens, compression techniques, and the size of the sensor. For this analysis the focus will be on the center and the left slanted edge and the frequency bars on the bottom. Comparing the center and left slant edges will show us how the Fisheye lens will degrade detail. Analysis in post-production is then done to compare the results. The Modulation Transfer Function is defined as:

$$\text{MTF} = \frac{\text{ModulationIn}}{\text{ModulationOut}}$$

Modulation is defined as the difference between two extremes on the edge. In this situation it is the difference between black and white on the ISO 12233 chart. The reason for the use of a slanted edge is because it acts as a slight stair step. Pixels in these cameras are square and in

turn cannot reproduce a uniform slanted edge. Analyzing the steps will tell us the spatial resolution of the system.

## 3) Dynamic Range/OECF

The dynamic range of a camera system refers to the range of exposures the system can register between the minimum exposure needed to produce a "usable" response and the maximum exposure the system can register, yet still collects "usable" data. This is commonly known as the range of stops of exposure a camera system can handle.

In 8-bit digital video cameras, the camera system converts these exposures to digital code values between 0 and 255. If the exposures are too high for the system the code values are forced to 255. If the exposures are too low for the system to detect, the code values are forced to 0. This is referred to as clipping on the high end and crushing on the low end. To test the dynamic range of the GoPro Hero 3: Black Edition, we will shoot an ISO 14524 OECF chart with each camera. Illuminance values of each patch on the chart will also be recorded for post-production analysis.

## 4) Color

The color reproduction of a camera system is essentially a subjective comparison between the two cameras of what looks best. Some images that look the best to the average consumer may not to a professional who must then manipulate the image later in post-production. This professional in a video workflow desires a flatter profile for easier and much more precise, color manipulation. This flatter profiler will help achieve the desired look of the image.

For a much more technical analysis, the Macbeth chart is used to compare the actual reflectance values off the patches. Chroma vs. Lightness arrow charts are used to determine color accuracy and analyze what the camera is doing. This will help explain if it is a fault of the camera or not. The Macbeth chart will be used under the same lighting conditions as the grey card from our noise analysis.

The modes being tested for comparison on the GoPro Hero 3: Black Edition include, AUTO, AUTO-T, 3000K-T, 5500K-T, 6500K-T, and RAW-T.

## III. METHODS/PROCEDURES

### A. The Build

In the machine shop located at RIT there were many different mechanical engineering practices involved to reach the end result. Initially, we had to bend a bar of 1/4" x 2" x 6' Multipurpose 6061 Aluminum in a metal roller to reach the twenty degree mark we were looking for. This took about six hours of work and fine adjustment, to get as

close as we could to the designed specification. After he initial horizontal arc was finalized we started machining 14 total L-shaped brackets (Multipurpose 6061: Aluminum 90 Degree Angle, 1/8" thick, 2" x 2" legs, 8' length) to hold each individual camera. These all had to be made identical, so that the angles were practically the same between each bracket, allowing for minimal differentiation between each of the cameras. The next challenge was to make sure that the vertical arm element was perfectly orthogonal to the base arc. This was crucial so that the vertical element would be directly in line with the base camera. After this was successfully accomplished, a tripod mount was built and fit (to the SoFA tripod mounts) so that it would match the angles of the horizontal arc and allow for solid connection between the rig and the tripod.

After all this was made and assembled, we added spacers (made from an Easy-to-Machine Polystyrene 1/2" Diameter, 8' Length Rod) behind each of the L-brackets. These spacers were accurately cut out to be the exact length (0.657") so that when each camera is tilted to rest on them, it would allow for a perfect ninety-degree angle perpendicular to the horizontal rig, for the mounted camera. Through the time of construction, there was an issue regarding whether or not the 3M-tape, located on the bottom of the camera mounts, would be strong and resilient enough over an extended period of time. It was decided to hard mount the camera mounts to each of the arc elements with threaded screws to ensure the cameras and mounts would not be either moving or falling off over the rig's lifetime.

Almost every machine in the shop was used in order to complete this rig. These include lathes, Bridgeport mills, grinders, metal benders, the drill press, automatic cut-off saws, files, and many other smaller tools. These were all needed to make sure that the rig would be as geometrically perfect as it needed to be to allow for the most accurate shots.

### *B. Assembly and RIT SoFA Cage Checkout*

Rig assembly was designed to be as easy as possible for students in SoFA. The rig comes packaged with 3 main cases:

- Rig and Handgrip case
- Camera and Toolbox case
- Batteries, Cables, and Chargers case

The screws connecting the vertical element to the horizontal arc are 3, 1/4" – 20 threaded machine screws with standard nuts attached. This base also holds the middle camera (CAM 0M) and plastic stopper. Both the screws and plastic stopper must be unscrewed before attaching the vertical element. Once the vertical element is in place, all four pieces must be placed on again (1/4" – 20 x3 and plastic stopper x1). To fasten the 1/4" – 20 machine screws securely, a wrench and corresponding Hex wrench is included in the provided toolbox at checkout. The rig's

handgrips, located in the Rig and Handgrip case, can also be attached and detached using the same provided machine screws, wrench, and Hex wrench.

Cameras are labeled both on the weatherproof casing and the camera itself. For organizational purposes they should be placed on the rig from the perspective of the user; "L" for left, "R" for right, "V" for vertical, and "M" for middle. The cameras on the horizontal arc should resemble the order: 4L, 3L, 2L, 1L, 0M, 1R, 2R, 3R, 4R from left to right. The cameras on the vertical element should resemble the order: 5V, 4V, 3V, 2V, 1V, and 0M from top to bottom. The cameras should be attached to the GoPro base mounts, already secured to the individual brackets and rested on the plastic stopper.

WiFi recording has been setup to work with these specific cameras. The GoPro WiFi remote is located in the provided cage toolbox. Once the cameras have been mounted the camera's WiFi signal must be turned on by selecting pressing the button on the left side of the camera (facing you). A blue light will begin flashing, indicating that the camera's WiFi is active. Do this for the 13 remaining cameras and then press the power button on the GoPro WiFi remote. The cameras will begin to turn on, one at a time. Once the remote indicates on its LCD screen that 14 cameras are connected, the cameras are all controllable. After using this remote now several times, I suggest taking a 5 second test shot before actually using it to shoot your scene. This allows all of the cameras to sync within 1 – 2 frames of each other after the first remote use. Cameras can also be powered down simultaneously using the GoPro WiFi Remote as well.

Active GoPro batteries with the WiFi in use last approximately 1 hour. To compensate for this poor battery life, the decision was made to purchase another set (14) GoPro batteries and dual battery charging systems (7) that will also be provided at cage checkout. These will be located in the Batteries, Cables, and Chargers case.

### *C. Camera Characterization Procedure*

#### *1) Noise*

For this test a MacBeth Chart and Kodak 18% Gray Card are captured. The baseline will be the camera's AUTO mode, lit to an f/2.8. To further test the systems we will compare changes in noise from the color modes from AUTO normal and all of the Protune modes.

Below is a diagram for the lighting setup for the Macbeth chart. Two 300W light should be on opposite sides and a light meter should be used to ensure that there is an even f/2.8 lighting. The lights should be adjusted spot or flood until the meter reads evenly. The camera, lights and Macbeth chart should be positioned the same height off the ground. Adjust the charts on a wall so that the chart fills up the field of view of the camera.



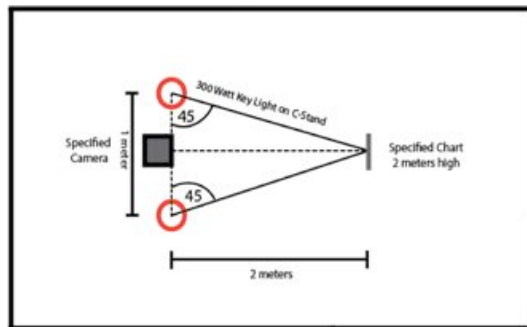


Figure 4: Lighting diagram for charts

The scene will be shot 6 times with varying camera modes.

Below are the shots and their settings/descriptions:

#### 1) Macbeth Chart and Kodak 18% Gray Card

a) GPH3 [ISO 640; WB AUTO; 1/60th; f/2.8; 1080p 59.94fps]

b) GPH3 [ISO 640; WB AUTO-Protune; 1/60th; f/2.8; 1080p 59.94fps]

c) GPH3 [ISO 640; WB 3000K-Protune; 1/60th; f/2.8; 1080p 59.94fps]

d) GPH3 [ISO 640; WB 5500K-Protune; 1/60th; f/2.8; 1080p 59.94fps]

e) GPH3 [ISO 640; WB 6500K-Protune; 1/60th; f/2.8; 1080p 59.94fps]

f) GPH3 [ISO 640; WB RAW-Protune; 1/60th; f/2.8; 1080p 59.94fps]

#### 2) Modulation Transfer Function (MTF)

The ISO12233 chart should be mounted on a wall. The camera should be brought up to the same height and leveled so that the edge of the frame lines up with the points of the arrows. In order to get an accurate reading the camera needs to be lined up as accurately as possible. Set up two 300W lights on opposite sides. The lighting diagram used in Figure 4 can also be used for this test.

The lights, camera and chart should all be at the same height. Use a light meter to ensure even lighting. The light meter should read 2.8 everywhere. Once you have the lights set up correctly, you need to check the base settings on the camera. Take about a 5 second shot with each camera mode:

#### 1) ISO12233 Chart

a) GPH3 [ISO 640; WB AUTO; 1/60th; f/2.8; 1080p 59.94fps]

b) GPH3 [ISO 640; WB AUTO-Protune; 1/60th; f/2.8; 1080p 59.94fps]

c) GPH3 [ISO 640; WB 3000K-Protune; 1/60th; f/2.8; 1080p 59.94fps]

d) GPH3 [ISO 640; WB 5500K-Protune; 1/60th; f/2.8; 1080p 59.94fps]

e) GPH3 [ISO 640; WB 6500K-Protune; 1/60th; f/2.8; 1080p 59.94fps]

f) GPH3 [ISO 640; WB RAW-Protune; 1/60th; f/2.8; 1080p 59.94fps]

#### 3) Dynamic Range/OECF

The ISO 14524 OECF Chart should be warmed up for 30 minutes before shooting and placed in a completely dark room (in Studio B) with no light spill. The camera should be at the same height as the OECF chart patches. Measure and record the luminance values for each OECF patch with a colorimeter. Take a 5 second shot with each camera mode listed below.

##### 1) ISO14524 OECF Chart

a) GPH3 [ISO 640; WB AUTO; 1/60th; f/2.8; 1080p 59.94fps]

b) GPH3 [ISO 640; WB AUTO-Protune; 1/60th; f/2.8; 1080p 59.94fps]

c) GPH3 [ISO 640; WB 3000K-Protune; 1/60th; f/2.8; 1080p 59.94fps]

d) GPH3 [ISO 640; WB RAW-Protune; 1/60th; f/2.8; 1080p 59.94fps]

#### 4) Color

For this test, just like in the Noise test, a MacBeth Chart is captured. The baseline will be the camera's AUTO mode, lit to an f/2.8. To further test the systems we will compare changes in noise from the color modes from AUTO normal and all of the Protune modes.

Below is a diagram for lighting setup for the Macbeth chart. Two 300W light should be on opposite sides and a light meter should be used to ensure that there is an even f/2.8 lighting. The lights should be adjusted spot or flood until the meter reads evenly. The camera, lights and

Macbeth chart should be positioned the same height off the ground. Adjust the Macbeth chart on a wall so that the chart fills up the field of view of the camera. The lighting diagram used in Figure 4 can also be used for this test.

#### 1) Macbeth Chart

- a) GPH3 [ISO 640; WB AUTO; 1/60th; f/2.8; 1080p 59.94fps]
- b) GPH3 [ISO 640; WB AUTO-Protune; 1/60th; f/2.8; 1080p 59.94fps]
- c) GPH3 [ISO 640; WB 3000K-Protune; 1/60th; f/2.8; 1080p 59.94fps]
- d) GPH3 [ISO 640; WB 5500K-Protune; 1/60th; f/2.8; 1080p 59.94fps]
- e) GPH3 [ISO 640; WB 6500K-Protune; 1/60th; f/2.8; 1080p 59.94fps]
- f) GPH3 [ISO 640; WB RAW-Protune; 1/60th; f/2.8; 1080p 59.94fps]

## IV. WORKFLOW DESIGN

### A. Data Management/GoPro Studio Workflow

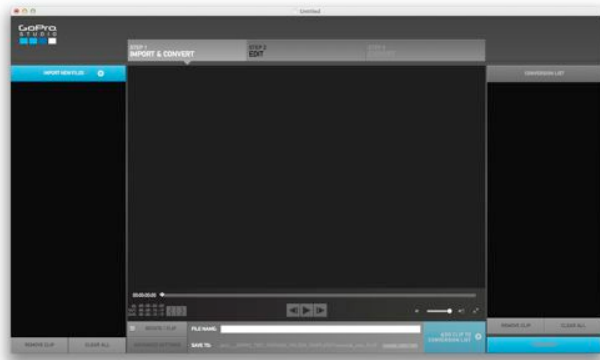


Figure 5: GoPro Studio Overview

- 1) GoPro studio must be installed first. This program not only allows for easy fisheye removal, but also installs the Cineform (Figure 5).
- 2) "NO\_NAME" GoPro Memory Card.
  - a. Copy over ONLY MP4 files to "FOLDER\_TEMP"
  - b. 1080p .MP4 Original → Flashdrive → "FOLDER\_TEMPLATE" → "Original Footage" → "0M..."

NOTE: Do not rename original clips.
- 3) Place each camera .MP4 in specific clip folder in "Original Footage" (Figure 6).

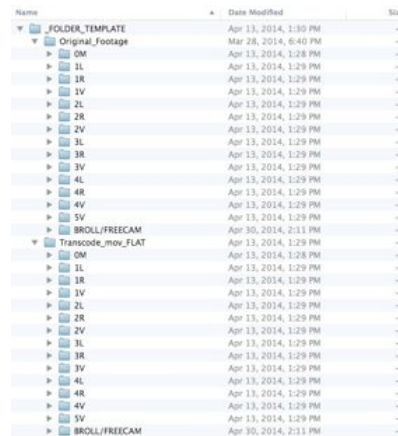


Figure 6: Finder; "FOLDER\_TEMPLATE" Overview

- 4) Open GoPro Studio software.
- 5) Import new files with the "IMPORT NEW FILES" button
- 6) Select "Original Footage" with all clips in sub folders.
- 7) On mid-bottom, select "Save to:"
- 8) Select "Transcode\_mov\_FLAT" to save all clips to.
- 9) Select all imported clips on the right with [cmd + A] on Mac.
- 10) Once all clips are selected, make sure the image size is;
  - a. Source (1920x1080)
  - b. Frame rate source (59.94p)
  - c. Quality: High
  - d. Select – Remove fisheye
  - e. Select – Remember settings for future clips
  - f. Click OK
  - g. With all clips still selected, Select - Add clips to conversion list
  - h. Once on the right side panel select all clips again and select "Convert"
- 11) Once converted select "Proceed to Step 2."
- 12) One by one, select each clip, click "1970s"
- 13) In the presets tab in the bottom right corner, select "none."
 

NOTE: You must select each clip individually, select "1970s" then "none" on presets. (This does not work for select all) If you do not pre-form this step, your output clips will have a significant increase in saturation and overall color shift.
- 14) Your exported clips are now located in the "Transcode\_mov\_FLAT" folder, outside of the individual camera folders.
  - a. Each clip will now have the camera ID prefix appended to the original clip name.
- 15) ex. GoPro1234 → 0M\_GoPro1234
  - a. Clips can now be dragged into their specific camera folders for organization without being changed by the GoPro Studio software.

NOTE: The average conversion rate ratio when converting the original GoPro .MP4 clips to the Flat .mov format is 10:1. In this case that means for every 1 gigabyte of information you are converting, that will be equal to about 10 gigabytes of information when Flattening the image through the GoPro Cineform conversion in the GoPro Studio software.

NOTE EXAMPLE: One of my test shots early on, I took about 90 seconds of video at 1080p, 60fps, Narrow FOV, AUTO WB. For all 14 cameras it totaled to be about 1.1GB in the .MP4 format encoded on the Class 10 8GB MicroSD card. When converting and flattening the image I reached roughly 120GB.

### B. Adobe Premiere Pro Workflow

- 1) Open “GoPro\_ARRAY\_RIG\_TEMPLATE”. Located on the “GOPRO\_RIT” flashdrive in the Adobe Premiere folder. (Figure 7)



Figure 7: Finder, “GOPRO\_RIT” flashdrive Overview

- 2) Save as... as your own project name.
- 3) Import camera media into specified folder under “Transcode\_mov\_FLAT”.
- 4) Drag all clips onto timeline from each camera folder onto their designated video track. (Onto the already created video sequence)
- 5) Cut each clip to length of cam 0M and sync all 14 cameras vertically via slate.
  - a. Place marker on each clip at slate – to be used for later.
- 6) Select camera at first desired position.
- 7) Under effect controls, select/enable “Time Re-mapping”.
- 8) Place key frame at the frame you wish to begin the effect.

- a. Arrow over one frame and set another key frame.
- 9) Place a key frame before the action where you wish to begin slow-motion on the starting camera (but still on the same selected clip).
  - 10) Place a key frame on the same clip after the effect where you wish the speed to return back to normal.
  - 11) Between the 1 and 2keys, drag the level to ~33% (30%-50%).
  - 12) Between keys 2 and 3, drag the level down all the way to 1%. This will effectively stop all the action between those two key frames (technically slowed to 1%, but visual looks paused)
  - 13) Between keys 3 and 4, drag the level down between 50% and 75% to create a smooth ramp-up.
  - 14) Leave the last key frames untouched so the action goes back to the normal speed. (Shown in Figure 8)



Figure 8: Adobe Premiere Pro CC – Time Remap Overview

### C. Adobe After Effects Workflow

- 1) With your last Adobe Premiere Pro project file open up Adobe After Effects.
- 2) Select the single shot you want to continue adding the bullet time effect to and copy all of the camera layers within that shot with [cmd + c].
- 3) In Adobe After Effects open up a new composition [cmd + n]
  - a. Make sure you have your composition frame rate set to the native 59.94fps Drop Frame of the GoPro media being used.
- 4) Paste the Adobe Premiere Pro content [cmd + v] into the layers timeline at bottom section of After Effects. This step should copy all of the media from the selection in Premiere Pro and any applied markers and key frames.
  - a. Line up all of the markers, key frames, and content just like how they were in Premiere Pro.
  - b. Ordering the cameras should be done at this step by dragging the layers at the bottom to the position desired. The top camera should be the camera you wish

- the see first. For example, if you wanted to start at CAM 4L and interpolate around the horizontal arc, order your clip in the order 4L, 3L, 2L, 1L, 0M, 1R, 2R, 3R, 4R from top to bottom.
- 5) Scrub to the location of the first frame where the first 1% Time Remapping key frame is located.
  - 6) Select all of the clips [cmd + a] and duplicate these clips within the timeline [cmd + d]
  - 7) Without clicking anywhere else and these duplicated layers selected, cut the media on these layers down to a single frame by holding the Option key and hitting the left bracket then right bracket keys. {Option + [} then {Option + ]}
  - 8) With these duplicated clips (and them all selected) a new composition has to be made with the duplicate clips within it. To do this, a Pre-Composition can be created by going to Layer → Pre-Compose [Shift + cmd + c] and clicking OK.
    - a. These duplicated clips are now within the single composition (default name, Pre-Comp 1)
  - 9) Go into the Pre-Composition setting [cmd + k] and change the duration of the composition to match the number of cameras you will be interpolating around, plus an additional frame.
    - a. Horizontal curve; 0;00;00;10
    - b. Vertical curve; 0;00;00;06
  - 10) Offset each of the individual frames by one to the right.
  - 11) Select all the clips and hit the T key to open up Opacity adjustments.
  - 12) Starting with the first frame, extend it out one more frame and adjust the opacity to about 40%.
  - 13) Place you scrub position at the point between both frames so that you can see both images overlapping on the monitor.
  - 14) Adjust the second image by clicking and dragging, to overlap the main subject you are pulling the effect on (or any stable markers in the scene) so that they line up correctly.
    - a. Continue doing this for the rest of the camera layers until they are all aligned.
  - 15) With the opacity back to 100% for all of the clips, selected all of the clips again and hit the R key to adjust the rotating of each frame. Choose a position in the frame where you believe that it is as horizontal to the scene as possible and use that as your reference.
  - 16) To compensate for some of your clips being out of the monitor frame from both the position and rotation adjustments, scaling must be applied. Select all of the clips again and hit the S key to bring up scaling options.
  - 17) Scale each clip up to the same amount, but just enough so that all of the frames are in the monitor frame.
    - a. NOTE: When shooting, stand further back that you would normally shoot to allow for less image scaling. As a base, I normally shot about double the distance I normally would have with a single camera.
    - b. NOTE: If you adjust the rotation or scale of either the first or the last camera, you must adjust both the scale and rotation of the first and last camera in your main composition to match each other.
  - 18) Back in the main composition, to clean things up, you can delete the all the camera layers from the timeline except for the Pre-Composition, the first camera, and the last camera.
  - 19) Trim the first camera layer to end when the Pre-Composition layer starts and trim the last camera layer to start when the Pre-Composition layer ends.
  - 20) Select all of the clips and enable Time-Remapping [Option + cmd + t]. You should now be able to see the key frames you made in the Premiere Pro project.
  - 21) Select the Pre-Composition layer and enable Pixel Motion Frame Blending.
    - a. Right click the Pre-Composition layer
    - b. Frame Blending dropdown menu
    - c. Select Pixel Motion
  - 22) NOTE THIS MINI LIST CAN ONLY BE DONE IF YOU HAVE THE TWIXTOR AE PLUG-IN
    - a. Apply Twixtor to the Pre-Composition layer and tweet these attributes
    - b. Color Source: Reference your Pre-Composition layer
    - c. Input Frame Rate: 59.940
    - d. Motion Vectors: Best
    - e. Image Prep: Contrast/Edge Enhance
    - f. Speed Perfect: 50%-75%
    - g. Frame Interp: Motion Weighted Blend
    - h. Smart Blend: Selected
  - 23) Select the last key frame associated with the Pre-Composition layer Time-Remapping and drag it to the duration you wish the effect to be.
  - 24) Select the key frames from the last camera from the end of the Pre-Composition layer on. Drag them over to start when the Pre-Composition layer ends so the last camera layer can pic back up. Your ending composition should look similar to Figure 9 below.



Figure 9: Adobe Premiere Pro CC – Time Remap Overview



## V. RESULTS & DISCUSSION

### A. System Design

The manufacturing process was crucial in the success of the envisioned project. Using the various tools throughout this process provided the opportunity to expand my learning experiences here at RIT. In addition, the closeness with the hands-on experience was fundamental in guaranteeing that this project would fulfill its expectations.

The entire system was designed around the ease of use for the producer and the end user, in that it can easily be broken down and packed away efficiently. Without this ease of assembly taken into account, the rig would not be a desirable tool for the RIT SoFA community. This project was able to develop a working, easy to use prototype, but also one that has the future user in mind (Figures 10, 11, 12, 13).



Figure 10: GoPro Rig Curved Vertical Element – No Cameras



Figure 11: GoPro Rig Curved Vertical Element – Cameras



Figure 12: GoPro Rig Straight Vertical Element – No Cameras



Figure 13: GoPro Rig Straight Vertical Element – Cameras

### B. Camera Characterization Analysis

#### 1) Noise

The noise calculations we've calculated for all the camera modes, including the Protune modes. It was a surprise to me that the Flat image overall had less noise in both fixed and temporal methods, with the exception of AUTO, 5500K-T, and RAW-T mode (Figure 14) with slightly higher fixed noise in the Flat image. My original expectations of these results were the exact opposite due to the encoding of the flat image from the original fisheye image.

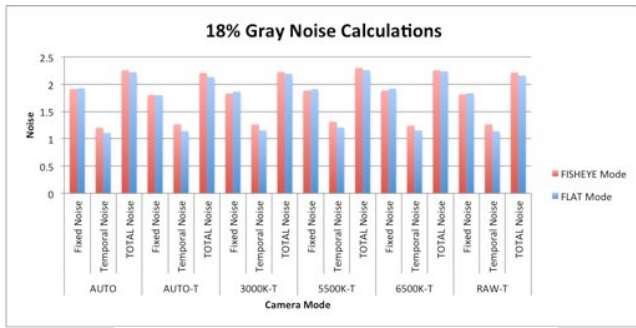


Figure 14: Gray Card Noise – Fisheye vs. Flat

The purpose of the 5x5 blocks, previously described, is to mimic the visual response of the observer averaging pixels. The standard deviation is calculated from the averages of these 5x5 blocks. This calculation was done over the red, green, and blue channels of the white, ~18% gray, and black patches located on the MacBeth chart. The results are very similar to those of the 18% Gray Noise Calculation results shown in Figure 12, but a clearer understand of how each color channel is reacting is shown.

The AUTO and AUTO-T modes are the most interesting to observe. Under the gray patch, the blue channel exceeds both the green and red channel by almost double, but only under the AUTO-T mode in the black patch does this same result occur. With the 5500K-T and the 6500K-T modes it makes sense again that the blue channel is much higher because it was compensating for the forced set white balance from the scene.

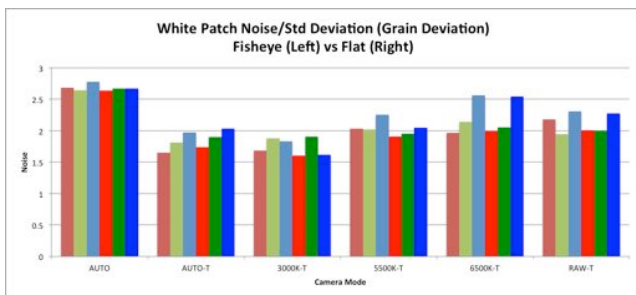


Figure 15: Noise RGB MacBeth chart White Patch – Fisheye vs. Flat

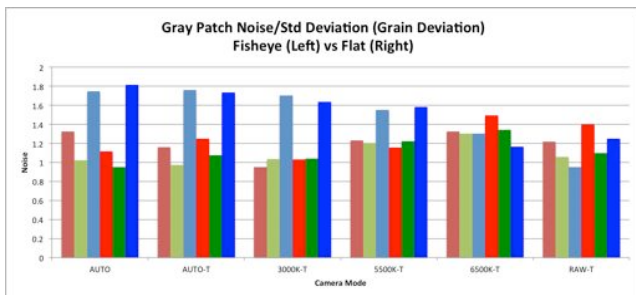


Figure 16: Noise RGB MacBeth chart Gray Patch – Fisheye vs. Flat

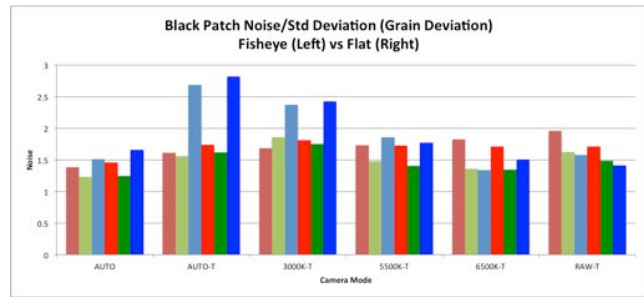


Figure 17: Noise RGB MacBeth chart Black Patch – Fisheye vs. Flat

2) Modulation Transfer Function (MTF)

The graphs in Figures 18, 19, 20, and 21 below show the MTF curves of camera system based on the test shots from the ISO12233 test chart.

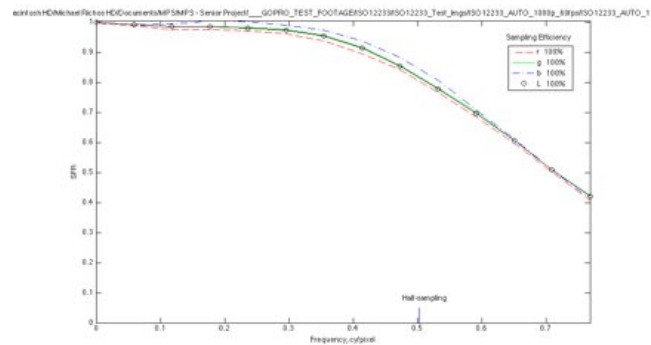


Figure 18: GPH3 MTF – Center Vertical ISO12233; AUTO; 1080p 60fps

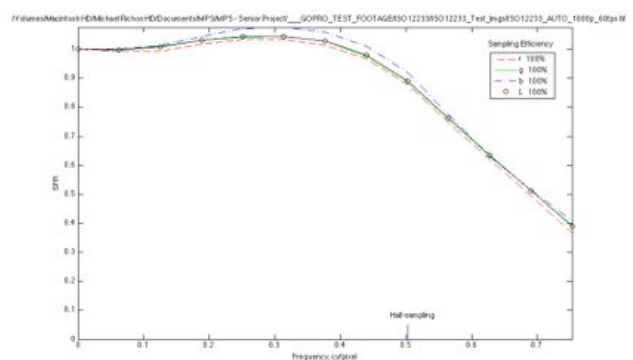


Figure 19: GPH3 MTF – Center Horizontal ISO12233; AUTO; 1080p 60fps

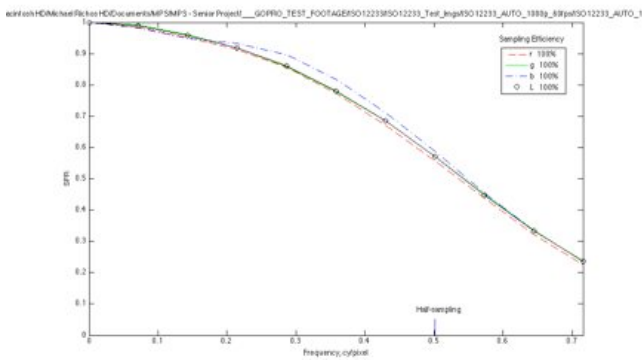


Figure 20: GPH3 MTF – Left Vertical ISO12233; AUTO; 1080p 60fps

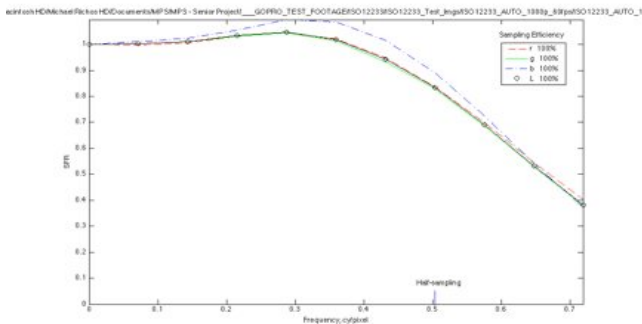


Figure 21: GPH3 MTF – Left Horizontal ISO12233; AUTO; 1080p 60fps

The MTF of the camera system introduces the problem of a potential difference between both the vertical to horizontal and center to edge readings. In both of the horizontal slant edge readings, a boost in contrast is applied near the middle region of frequencies; however this boost differs slightly between the center and left edge readings. The blue channel is boosted much higher than green or red, and also much higher near the top middle edge of the chart. This could be a result of GoPro’s fisheye lens implementation and its physical lens falloff.

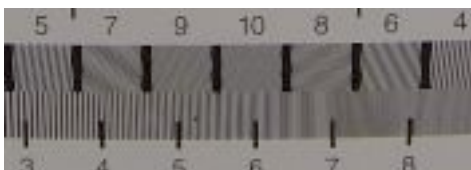


Figure 22: GPH3 MTF – Frequency Bars ISO12233; AUTO; 1080p 60fps

Aliasing artifacts are also very apparent, even when examining the lower regions of the frequency bars, referring to Figure 22. Again, this could be due to the signature fisheye lens of the GoPro camera systems, but should still be accounted for.

3) OECF

The graphs in Figures 24, 25, 26, and 27 show the OECF curves of camera system based on the test shots of the ISO 14524 OECF chart, all shot at normal exposure as well as

utilizing the luminance values measured from the chart.

We transformed the luminance values of the OECF patches into specific values of exposure that corresponded with the average pixel signal value of each patch captured by the camera systems. These exposure values were graphed with their respective signal values.

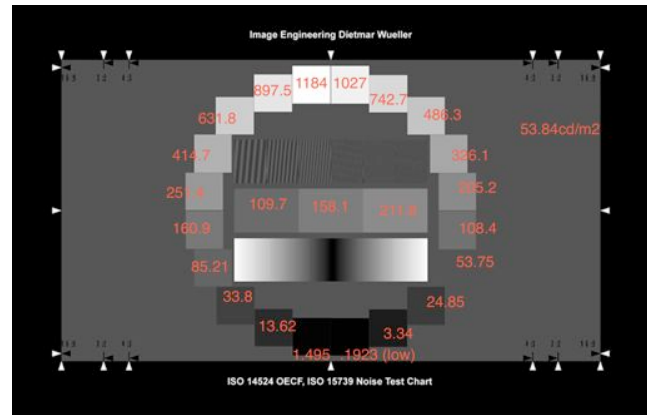


Figure 23: GPH3 ISO 14524 OECF Annotated Chart

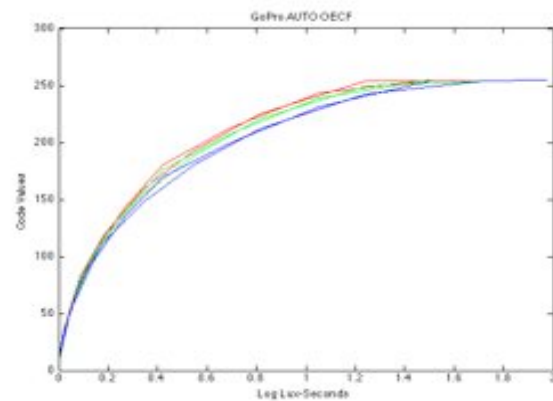


Figure 24: GPH3 ISO 14524 OECF; AUTO; 1080p 60fps

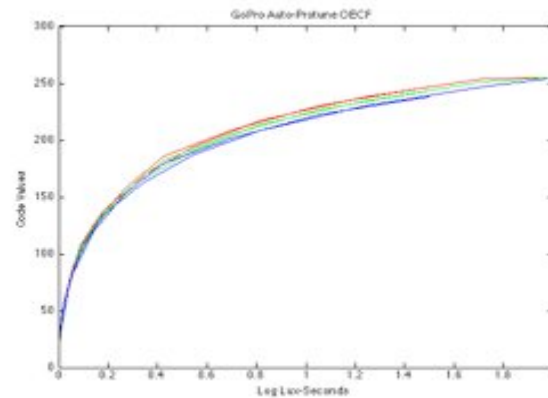


Figure 25: GPH3 ISO 14524 OECF; AUTO-T; 1080p 60fps

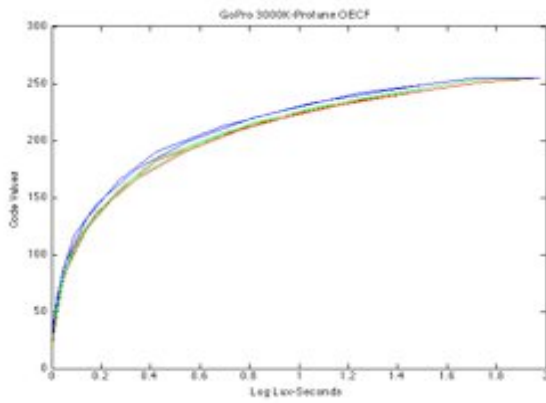


Figure 26: GPH3 ISO 14524 OECF; 3000K-T; 1080p 60fps

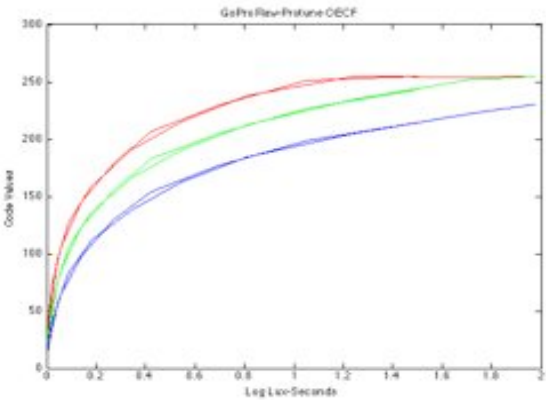


Figure 27: GPH3 ISO 14524 OECF; RAW-T; 1080p 60fps

Examining these figures closer, we can see that for the most part the camera systems are relatively alike in how they transcribe exposure values to signal code values except in RAW-Protune mode. AUTO mode looks as if its response is what we expected it to be by providing a decent contrast between low, mid, and high signal code values; however, within the AUTO mode OECF, the red and green channel looks as if they die off and clip much sooner than the blue channel. When coming from the AUTO-Protune mode to the straight AUTO mode, it is clearly visible that it attempts to replicate a flatter profile as the lower signal code values on the left have steep slope. As exposure increases the code value slope starts to become flatter. This slope allows for finer color adjustments in post-production.

The 3000K-Protune mode preforms this same theory, but allows for a shift in white balance for a 3000K Blackbody. Knowing the illuminant source of the ISO 14524 OECF chart to be Tungsten based, the result of having an increase in the blue channel and a decrease in the red channel to balance for this warmer source makes sense.

GoPro RAW-Protune, in relation to the other three camera modes, is not comparable. The purpose of this mode according to GoPro is to create a “flat” color profile for more accuracy and freedom when color-grading in post-production; however, what we are seeing here is the

appearance of a “flat” color profile. In normal RAW data implementation the data represented in the OECF curve should be linear, instead the profile representing “RAW” data in the GPH3 camera systems looks to flatten out their image to mimic the “RAW look”. Colorists and any other post-production editors should take note when grading their footage shot on this camera.

#### 4) Color Reproduction

Color Reproduction in the GoPro camera system can be measured both subjectively and objectively. The camera has several built in color modes when switching to Protune mode, but in this analysis the AUTO, AUTO-T (Protune), 3000K-T (Protune), 5500K-T (Protune), 6500K-T (Protune), and RAW-T (Protune) were used.

Just by looking at the figures below using a MacBeth chart, you can clearly see the differences when switching between the modes under the same lighting conditions. When comparing the differences between the AUTO and AUTO-T modes a large shift in lightness occurs. We see that a flatter look is achieved, but no hue shift is apparent when looking at the a\* b\* plot, just a shift in L\* and a slight shift in C\* making the patches appear less chromatic.

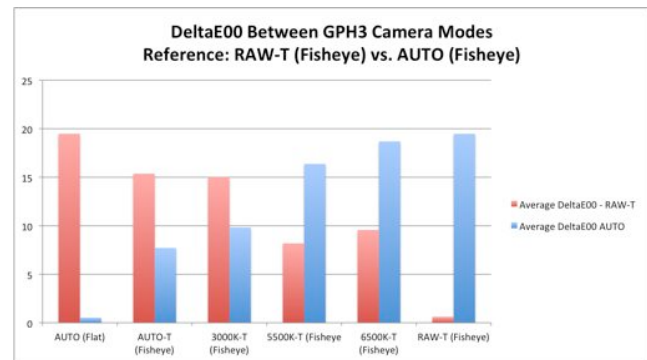


Figure 28: DeltaE00 Between Camera Modes

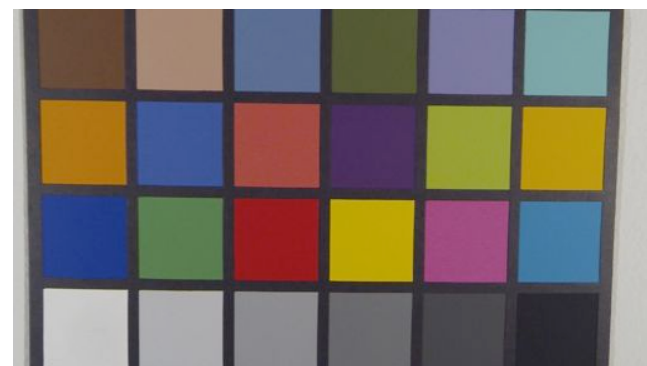


Figure 29: GPH3 AUTO color mode



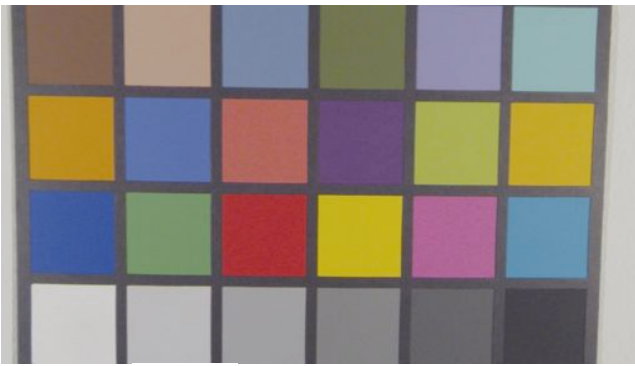


Figure 30: GPH3 AUTO-T color mode

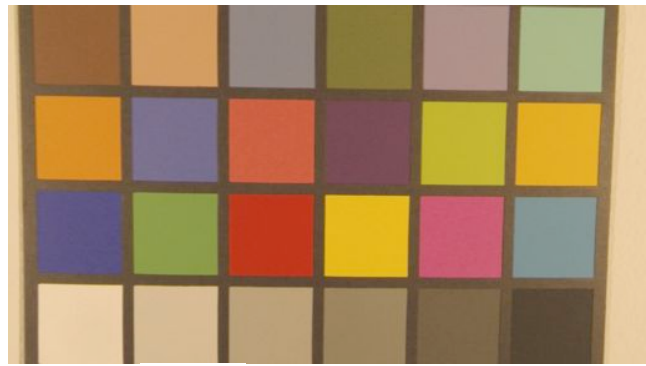


Figure 34: GPH3 5500K-T color mode

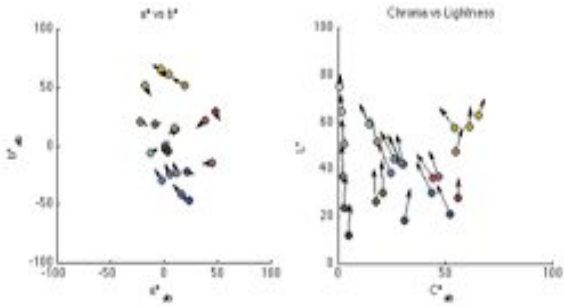


Figure 31: L\* versus C\* graph – Reference AUTO vs. AUTO-T

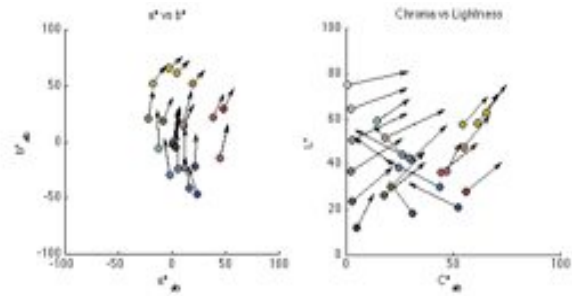


Figure 35: L\* versus C\* graph – Reference AUTO vs. 5500K-T

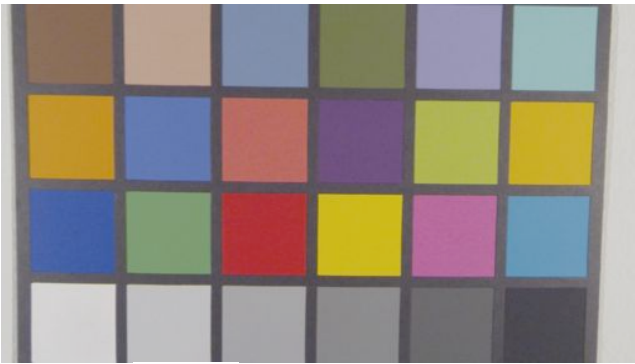


Figure 32: GPH3 3000K-T color mode



Figure 36: GPH3 6500K-T color mode

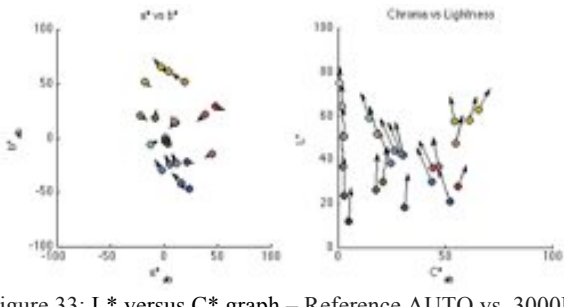


Figure 33: L\* versus C\* graph – Reference AUTO vs. 3000K-T

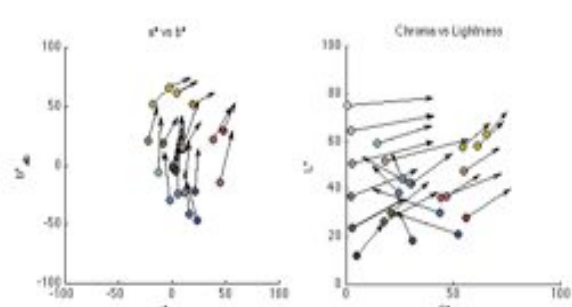


Figure 37: L\* versus C\* graph – Reference AUTO vs. 6500K-T



Figure 38: GPH3 RAW-T color mode

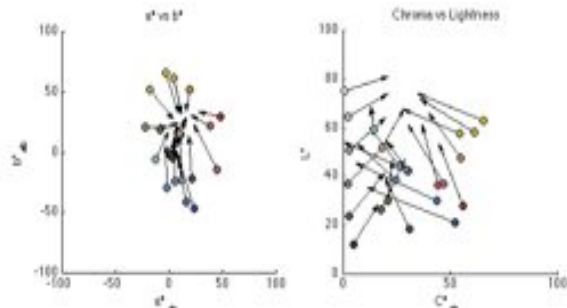


Figure 39: L\* versus C\* graph – Reference AUTO vs. RAW-T

A similar shift occurs with the 3000K-T mode when compared to AUTO mode; however, this shift is greater than that of the AUTO-T mode. Both the 5500K-T and 6500K-T modes show similar results when compared to the other modes. A larger hue shift occurs because of the forced white balance compensation. RAW-T mode is compared to AUTO mode to understand the appearance of a “flat” profile. When viewing the image patches an obvious hue shift is occurring because of tungsten based light source illuminating the MacBeth chart. Observing the Lab plot with AUTO as the reference, a larger shift in all the patches occurs in both regions. Colors are getting much more desaturated and less chromatic giving the appearance of a “flat” color profile, but going back quickly to our RAW-T OECF results we find this “flat” profile to not be the linear data we see in normal RAW data implemented in high end camera systems. Although the AUTO mode does provide an acceptable image in terms of color, any of the Protune options should be utilized if there are plans to color-grade the footage in post-production. These modes allow for more creativity to the colorist because it gives them more information to work with in a post-production workflow.

## VI. CONCLUSION

Moving forward with this project, there is still a lot of work that can be done to make it better and allow for different variations. The prospect for the addition of arc extensions in the future is a real possibility due to the open-ended arms used in construction. While this project did turn out very well and works just as it was designed, there are

things that could have been different that would strengthen the rig. For instance, most of the parts would have a smaller tolerance if they were made with an automated machine, instead of by hand. This would have cut down on slight differences between parts and could make the rig even more accurate.

With the time, resources, and personal at my disposal, this project turned out just as it was envisioned. This rig successfully shows that a mobile time-slicing rig with a working vertical element is feasible and can be implemented as a creative tool for the students within the School of Film and Animation at Rochester Institute of Technology.

## VII. RESOURCES

- [1] *Gopro hd hero 3 black edition technical specs.* (2013, October). Retrieved from <http://gopro.com/cameras/hd-hero3-black-edition>
- [2] Ashley, T. (2013, March 02). *Gopro 3 black: Hero or zero?* Retrieved from <http://tashley1.zenfolio.com/blog/2013/3/gopro-3-black-hero-or-zero>
- [3] Clade, D. (2013, November 12). *A fascinating look at how gopro became the best-selling camera in the world.* Retrieved from <http://petapixel.com/2013/11/12/fascinating-look-gopro-became-popular-camera-world/>
- [4] Pelz, J. (2013). *Vision and psychophysics: Class notes on convergence.* Unpublished raw data, College of Imaging Science, Rochester Institute of Technology, Rochester, NY.

VIII.APPENDIX

B. MacBeth Color Checker – RGB Patch Data

A. Noise – Gray Card Data

AUTO (Fisheye)		
Fixed Noise	Temporal Noise	TOTAL Noise
1.9098	1.2029	2.2571
AUTO (FLAT)		
Fixed Noise	Temporal Noise	TOTAL Noise
1.9241	1.1042	2.2184

AUTO-T (Fisheye)		
Fixed Noise	Temporal Noise	TOTAL Noise
1.8049	1.2647	2.2039
AUTO-T (FLAT)		
Fixed Noise	Temporal Noise	TOTAL Noise
1.7989	1.1407	2.1301

3000K-T (Fisheye)		
Fixed Noise	Temporal Noise	TOTAL Noise
1.8298	1.2632	2.2235
3000K-T (FLAT)		
Fixed Noise	Temporal Noise	TOTAL Noise
1.8635	1.1541	2.1919

5500K-T (Fisheye)		
Fixed Noise	Temporal Noise	TOTAL Noise
1.8847	1.3126	2.2967
5500K-T (FLAT)		
Fixed Noise	Temporal Noise	TOTAL Noise
1.9085	1.2062	2.2577

6500K-T (Fisheye)		
Fixed Noise	Temporal Noise	TOTAL Noise
1.8852	1.2414	2.2572
6500K-T (FLAT)		
Fixed Noise	Temporal Noise	TOTAL Noise
1.9187	1.1523	2.2381

RAW-T (Fisheye)		
Fixed Noise	Temporal Noise	TOTAL Noise
1.8152	1.2647	2.2123
RAW-T (FLAT)		
Fixed Noise	Temporal Noise	TOTAL Noise
1.8322	1.139	2.1574

AUTO (Fisheye) - White		
R	G	B
187.6354984	186.0494277	186.2503838
AUTO (Fisheye) - Gray		
R	G	B
88.05776062	87.02837595	90.9818429
AUTO (Fisheye) - Black		
R	G	B
33.5776501	31.79737731	38.55567738

AUTO-T (Fisheye) - White		
R	G	B
194.3188457	191.9416254	191.857287
AUTO-T (Fisheye) - Gray		
R	G	B
116.3105127	113.7883426	116.1176703
AUTO-T (Fisheye) - Black		
R	G	B
57.77597474	54.71325819	62.54576554

3000K-T (Fisheye) - White		
R	G	B
201.0578483	198.879172	199.2965221
3000K-T (Fisheye) - Gray		
R	G	B
122.6058068	120.4003772	123.1995965
3000K-T (Fisheye) - Black		
R	G	B
62.02605149	59.42515679	67.61370115

5500K-T (Fisheye) - White		
R	G	B
229.2025788	195.5498004	153.3497654
5500K-T (Fisheye) - Gray		
R	G	B
141.0712249	115.1171001	79.58817596
5500K-T (Fisheye) - Black		
R	G	B
72.20968379	57.61286786	43.82991974

<b>6500K-T (Fisheye) - White</b>		
<b>R</b>	<b>G</b>	<b>B</b>
232.5516425	187.5873865	126.001228
<b>6500K-T (Fisheye) - Gray</b>		
<b>R</b>	<b>G</b>	<b>B</b>
142.9221525	105.5381343	63.21477128
<b>6500K-T (Fisheye) - Black</b>		
<b>R</b>	<b>G</b>	<b>B</b>
73.49453971	53.72189816	35.85171703

<b>3000K-T (Flat) - White</b>		
<b>R</b>	<b>G</b>	<b>B</b>
200.2599009	198.6190957	198.6119907
<b>3000K-T (Flat) - Gray</b>		
<b>R</b>	<b>G</b>	<b>B</b>
121.5276523	120.2829262	121.7900531
<b>3000K-T (Flat) - Black</b>		
<b>R</b>	<b>G</b>	<b>B</b>
60.93513442	59.26327793	65.62554274

<b>6500K-T (Fisheye) - White</b>		
<b>R</b>	<b>G</b>	<b>B</b>
232.5516425	187.5873865	126.001228
<b>6500K-T (Fisheye) - Gray</b>		
<b>R</b>	<b>G</b>	<b>B</b>
142.9221525	105.5381343	63.21477128
<b>6500K-T (Fisheye) - Black</b>		
<b>R</b>	<b>G</b>	<b>B</b>
73.49453971	53.72189816	35.85171703

<b>5500K-T (Flat) - White</b>		
<b>R</b>	<b>G</b>	<b>B</b>
228.0470155	195.4187974	152.4885312
<b>5500K-T (Flat) - Gray</b>		
<b>R</b>	<b>G</b>	<b>B</b>
139.1844217	115.0710057	77.83759484
<b>5500K-T (Flat) - Black</b>		
<b>R</b>	<b>G</b>	<b>B</b>
71.41577124	57.61234156	42.34678304

<b>AUTO (Flat) - White</b>		
<b>R</b>	<b>G</b>	<b>B</b>
185.3452042	184.8104031	184.560414
<b>AUTO (Flat) - Gray</b>		
<b>R</b>	<b>G</b>	<b>B</b>
87.09692557	86.88316302	89.84562081
<b>AUTO (Flat) - Black</b>		
<b>R</b>	<b>G</b>	<b>B</b>
32.62957765	31.59471076	37.36669444

<b>6500K-T (Flat) - White</b>		
<b>R</b>	<b>G</b>	<b>B</b>
231.5054603	186.8328144	124.2362616
<b>6500K-T (Flat) - Gray</b>		
<b>R</b>	<b>G</b>	<b>B</b>
141.6244902	105.6044472	62.13723082
<b>6500K-T (Flat) - Black</b>		
<b>R</b>	<b>G</b>	<b>B</b>
72.48155783	53.40099118	34.42936713

<b>AUTO-T (Flat) - White</b>		
<b>R</b>	<b>G</b>	<b>B</b>
193.3906408	191.2902066	190.449147
<b>AUTO-T (Flat) - Gray</b>		
<b>R</b>	<b>G</b>	<b>B</b>
115.2442875	113.4680935	114.9521512
<b>AUTO-T (Flat) - Black</b>		
<b>R</b>	<b>G</b>	<b>B</b>
56.64690145	54.48646989	60.44098943

<b>RAW-T (Flat) - White</b>		
<b>R</b>	<b>G</b>	<b>B</b>
224.0797772	195.5077409	167.1447305
<b>RAW-T (Flat) - Gray</b>		
<b>R</b>	<b>G</b>	<b>B</b>
145.2321828	118.1766589	94.62440244
<b>RAW-T (Flat) - Black</b>		
<b>R</b>	<b>G</b>	<b>B</b>
81.14924784	58.86009386	45.36007193

*C. MacBeth Color Checker – Noise/Std Deviation (Grain Deviation)*

<b>AUTO (Fisheye) - White</b>		
<b>R</b>	<b>G</b>	<b>B</b>
2.684641751	2.647009922	2.780674561
<b>AUTO (Fisheye) - Gray</b>		
<b>R</b>	<b>G</b>	<b>B</b>
1.325750752	1.021206465	1.74432404
<b>AUTO (Fisheye) - Black</b>		
<b>R</b>	<b>G</b>	<b>B</b>
1.384753512	1.234013684	1.510408367

<b>AUTO-T (Fisheye) - White</b>		
<b>R</b>	<b>G</b>	<b>B</b>
1.648154931	1.811527883	1.972790907
<b>AUTO-T (Fisheye) - Gray</b>		
<b>R</b>	<b>G</b>	<b>B</b>
1.157891618	0.972422959	1.75908966
<b>AUTO-T (Fisheye) - Black</b>		
<b>R</b>	<b>G</b>	<b>B</b>
1.611298495	1.558908325	2.683924195

<b>3000K-T (Fisheye) - White</b>		
<b>R</b>	<b>G</b>	<b>B</b>
1.683018941	1.876440025	1.830979648
<b>3000K-T (Fisheye) - Gray</b>		
<b>R</b>	<b>G</b>	<b>B</b>
0.948129712	1.033493767	1.702825026
<b>3000K-T (Fisheye) - Black</b>		
<b>R</b>	<b>G</b>	<b>B</b>
1.682828809	1.861341061	2.372903528

<b>5500K-T (Fisheye) - White</b>		
<b>R</b>	<b>G</b>	<b>B</b>
2.03401904	2.021814686	2.254761537
<b>5500K-T (Fisheye) - Gray</b>		
<b>R</b>	<b>G</b>	<b>B</b>
1.232188143	1.204953228	1.549338157
<b>5500K-T (Fisheye) - Black</b>		
<b>R</b>	<b>G</b>	<b>B</b>
1.729605847	1.481378937	1.861205747

<b>6500K-T (Fisheye) - White</b>		
<b>R</b>	<b>G</b>	<b>B</b>
1.969193218	2.13951154	2.56236675
<b>6500K-T (Fisheye) - Gray</b>		
<b>R</b>	<b>G</b>	<b>B</b>
1.325290229	1.299354599	1.301676332
<b>6500K-T (Fisheye) - Black</b>		
<b>R</b>	<b>G</b>	<b>B</b>
1.827475743	1.356852401	1.340898289

<b>RAW-T (Fisheye) - White</b>		
<b>R</b>	<b>G</b>	<b>B</b>
2.180136959	1.943053605	2.310818592
<b>RAW-T (Fisheye) - Gray</b>		
<b>R</b>	<b>G</b>	<b>B</b>
1.215155528	1.055287529	0.951834263
<b>RAW-T (Fisheye) - Black</b>		
<b>R</b>	<b>G</b>	<b>B</b>
1.961068302	1.627269414	1.578530001

<b>AUTO (Flat) - White</b>		
<b>R</b>	<b>G</b>	<b>B</b>
2.635854738	2.673818702	2.669834143
<b>AUTO (Flat) - Gray</b>		
<b>R</b>	<b>G</b>	<b>B</b>
1.114529011	0.948303603	1.812626274
<b>AUTO (Flat) - Black</b>		
<b>R</b>	<b>G</b>	<b>B</b>
1.457304573	1.245862943	1.660555759

<b>AUTO-T (Flat) - White</b>		
<b>R</b>	<b>G</b>	<b>B</b>
1.738621873	1.899916962	2.034522169
<b>AUTO-T (Flat) - Gray</b>		
<b>R</b>	<b>G</b>	<b>B</b>
1.246937663	1.07667301	1.732686652
<b>AUTO-T (Flat) - Black</b>		
<b>R</b>	<b>G</b>	<b>B</b>
1.73952839	1.617855553	2.821908771

3000K-T (Flat) - White		
R	G	B
1.604860358	1.902882862	1.613974584
3000K-T (Flat) - Gray		
R	G	B
1.029301658	1.037420949	1.633880263
3000K-T (Flat) - Black		
R	G	B
1.811713492	1.749125929	2.42610674

5500K-T (Flat) - White		
R	G	B
1.905612721	1.952693101	2.044822475
5500K-T (Flat) - Gray		
R	G	B
1.154219108	1.220494032	1.580862845
5500K-T (Flat) - Black		
R	G	B
1.723580986	1.404362462	1.772279787

6500K-T (Flat) - White		
R	G	B
1.992652828	2.051268109	2.545294601
6500K-T (Flat) - Gray		
R	G	B
1.492304346	1.341660588	1.165518573
6500K-T (Flat) - Black		
R	G	B
1.710001367	1.343267625	1.502070433

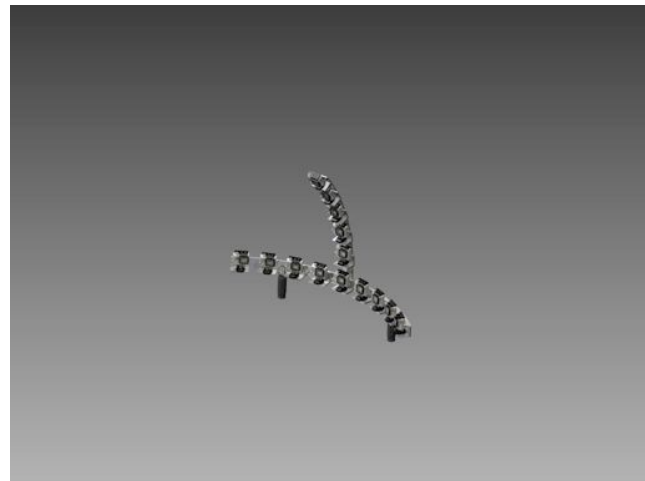
RAW-T (Flat) - White		
R	G	B
2.006859588	1.999136966	2.277457263
RAW-T (Flat) - Gray		
R	G	B
1.39889464	1.096826009	1.249162302
RAW-T (Flat) - Black		
R	G	B
1.715059673	1.484439388	1.409072573

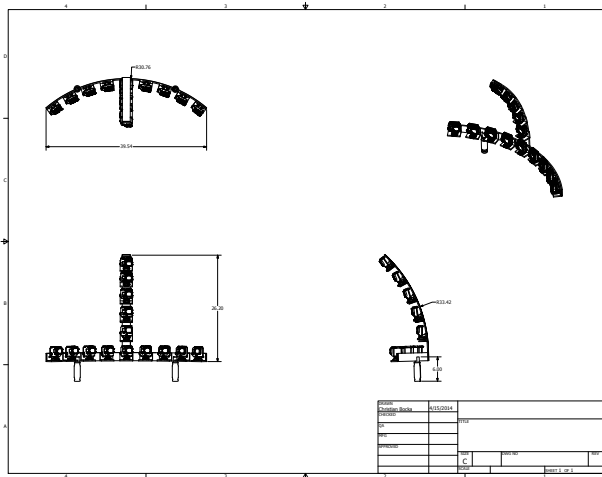
*D. MacBeth Color Checker – DeltaE00 Between GPH3 Camera Modes*

Camera Mode <i>Reference: RAW-T (Fisheye)</i>	Average DeltaE00 - RAW-T
AUTO (Fisheye)	19.4827
AUTO-T (Fisheye)	15.3636
3000K-T (Fisheye)	15.0118
5500K-T (Fisheye)	8.1819
6500K-T (Fisheye)	9.5676
RAW-T (Flat)	0.6131

Camera Mode <i>Reference: AUTO (Fisheye)</i>	Average DeltaE00 AUTO
AUTO (Flat)	0.5132
AUTO-T (Fisheye)	7.7079
3000K-T (Fisheye)	9.8244
5500K-T (Fisheye)	16.3678
6500K-T (Fisheye)	18.6887
RAW-T (Fisheye)	19.4723

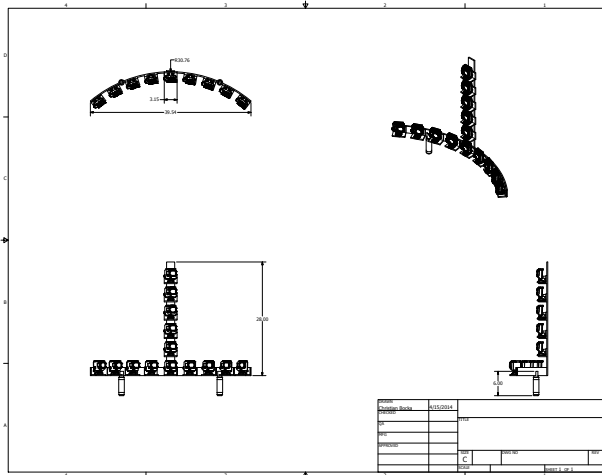
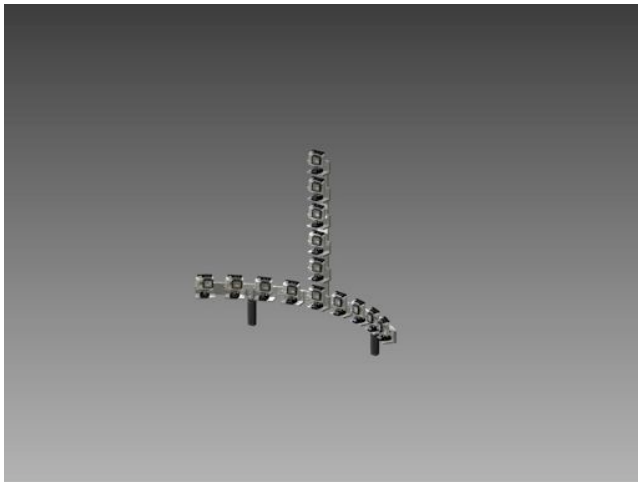
*E. Original Rig Build AutoCAD Documents*





F. College of Imaging Science Budget Overview

		Total Budget		Remaining Budget							
		\$5,000.00		\$39.46							
Purchased Items											
Order Date	Order Number	Vendor	Item(s)	Item #	Price Per Unit	Shipping Cost	Quantity	Total			
11/20/2013	207961 - 1	Jack's Surfboards	GoPro Hero 3 Black Edition	CRDIX-301	\$339.00	\$0.00	2	\$678.00			
11/27/2013	609740942 - 2	Cabela's	GoPro Hero 3 Black Edition	HK-460814	\$333.49	\$6.65	4	\$1,280.61			
11/27/2013	58365068 - 3	Cabela's	GoPro Hero 3 Black Edition	HK-460814	\$333.49	\$6.65	4	\$1,280.61			
11/27/2013	609741146 - 4	Cabela's	GoPro Hero 3 Black Edition	HK-460814	\$333.49	\$6.65	4	\$1,280.61			
			Multipurpose 6061								
2/4/14	7479049	McMaster-Carr	Aluminum 90 Degree Angle, 1/8" Thick, 2" x 2" Legs, 8" Length	8982K25	\$36.27	\$0.00	1	\$36.27			
2/4/14	7479049	McMaster-Carr	Multipurpose 6061, 1/4" Thick x 2" Width x 6" Length	8975K26	\$22.67	\$0.00	2	\$45.34			
2/4/14	106-9823520-0327814	Amazon SanDisk	Ultra microSDHC 8GB Class 10 UHS-1	8008F18P4M	\$8.25	\$0.00	14	\$115.50			
2/4/14	9847599	Monoprice	12-Port USB 2.0 HUB w/ AC Adapter	6435	\$26.61	\$7.73	1	\$34.34			
2/24/14		McMaster-Carr	Easy-to-Machine Polystyrene Rod 1/2" Diameter, 8" Length	8720K34	\$3.18	\$0.00	8	\$25.44			
2/24/14	105-2542373-6783451	Amazon PitagiveU	500K Brand New Chrome & Rubber Motorcycle Handgrip Bar End Hand Grips for Honda CBR Yamaha YZF FZ1 FZS R1 R6 Suzuki GSXR GSX F600 750 Kawasaki ER-6N E		\$8.90	\$23.99	1	\$32.89			
4/1/14	110-9678399-5584267	Wasabi Power	Wasabi Power Battery (2-Pack) and Dual Charger for GoPro Hero3, Hero3+ and GoPro AHDBT-201, AHDBT-301, AHDBT-302, AHDBP-302, ACARC-001, AWALC-001 (with Car and US Plug)	8002VIR2M	\$32.99	\$0.00	7	\$230.93			



# Data Management/ GoPro Studio Workflow

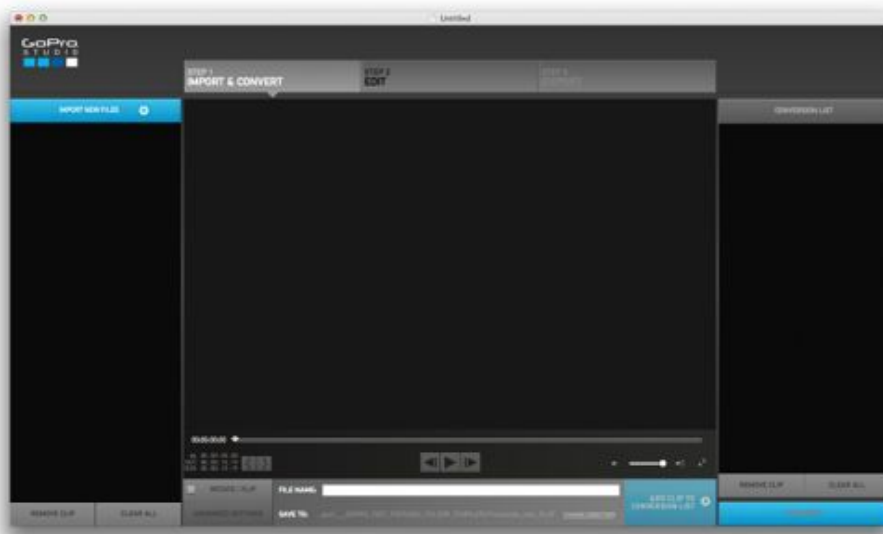


Figure 1: GoPro Studio Overview

- 1) GoPro studio must be installed first. This program not only allows for easy fisheye removal, but also installs the Cineform.
  - 2) “NO\_NAME” GoPro Memory Card.
    - a. Copy over ONLY MP4 files to “FOLDER\_TEMP”
    - b. 1080p .MP4 Original → Flashdrive → ”FOLDER\_TEMPLATE” → “Original Footage” → “0M...”
- NOTE: Do not rename original clips.
- 3) Place each camera .MP4 in specific clip folder in “Original Footage” (Figure 2).

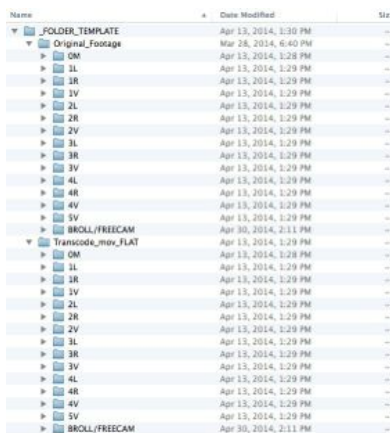


Figure 2: Finder; “FOLDER\_TEMPLATE” Overview



- 4) Open GoPro Studio software.
- 5) Import new files with the “IMPORT NEW FILES” button
- 6) Select “Original Footage” with all clips in sub folders.
- 7) On mid-bottom, select “Save to:”
- 8) Select “Transcode\_mov\_FLAT” to save all clips to.
- 9) Select all imported clips on the right with [cmd + A] on Mac.
- 10) Once all clips are selected, make sure the image size is;
  - a. Source (1920x1080)
  - b. Frame rate source (59.94p)
  - c. Quality: High
  - d. Select – Remove fisheye
  - e. Select – Remember settings for future clips
  - f. Click OK
  - g. With all clips still selected, Select - Add clips to conversion list
  - h. Once on the right side panel select all clips again and select “Convert”
- 11) Once converted select “Proceed to Step 2.”
- 12) One by one, select each clip, click “1970s”
- 13) In the presets tab in the bottom right corner, select “none.”

NOTE: You must select each clip individually, select “1970s” then “none” on presets.  
(This does not work for select all) If you do not pre-form this step, your output clips will have a significant increase in saturation and overall color shift.
- 14) Your exported clips are now located in the “Transcode\_mov\_FLAT” folder, outside of the individual camera folders. Each clip will now have the camera ID prefix appended to the original clip name.
  - a. ex. GoPro1234 → 0M\_GoPro1234
- 15) Clips can now be dragged into their specific camera folders for organization without being changed by the GoPro Studio software.

NOTE: The average conversion rate ratio when converting the original GoPro .MP4 clips to the Flat .mov format is 10:1. In this case that means for every 1 gigabyte of information you are converting, that will be equal to about 10 gigabytes of information when Flattening the image through the GoPro Cineform conversion in the GoPro Studio software.

NOTE EXAMPLE: One of my test shots early on, I took about 90 seconds of video at 1080p, 60fps, Narrow FOV, AUTO WB. For all 14 cameras it totaled to be about 1.1GB in the .MP4 format encoded on the Class 10 8GB MicroSD card. When converting and flattening the image I reached roughly 120GB. PLEASE PLAN ACCORDINGLY

# Adobe Premiere Pro Workflow

- 1) Open “GoPro\_ARRAY\_RIG\_TEMPLATE”. Located on the “GOPRO\_RIT” flashdrive in the Adobe Premiere folder. (Figure 1)



Figure 1: Finder; “GOPRO\_RIT” flashdrive Overview

- 2) Save as... as your own project name.
- 3) Import camera media into specified folder under “Transcode\_mov\_FLAT”.
- 4) Drag all clips onto timeline from each camera folder onto their designated video track. (Onto the already created video sequence)
- 5) Cut each clip to length of cam 0M and sync all 14 cameras vertically via slate.
  - a. Place marker on each clip at slate – to be used for later.
- 6) Select camera at first desired position.
- 7) Under effect controls, select/enable “Time Re-mapping”.
- 8) Place key frame at the frame you wish to begin the effect.
  - a. Arrow over one frame and set another key frame.
- 9) Place a key frame before the action where you wish to begin slow-motion on the starting camera (but still on the same selected clip).
- 10) Place a key frame on the same clip after the effect where you wish the speed to return back to normal.
- 11) Between the 1 and 2keys, drag the level to ~33% (30%-50%).
- 12) Between keys 2 and 3, drag the level down all the way to 1%. This will effectively stop all the action between those two key frames (technically slowed to 1%, but visual looks paused)
- 13) Between keys 3 and 4, drag the level down between 50% and 75% to create a smooth ramp-up.
- 14) Leave the last key frames untouched so the action goes back to the normal speed. (Shown in Figure 2)

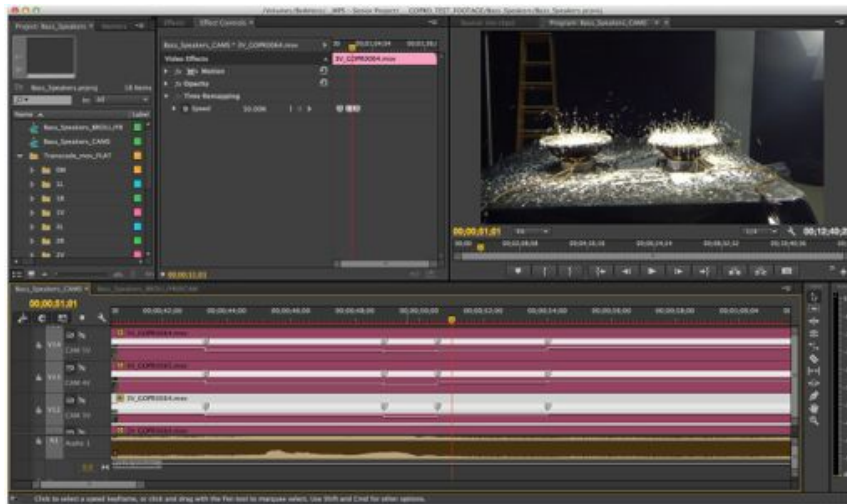


Figure 2: Adobe Premiere Pro CC – Time Remap Overview

# Adobe After Effects Workflow

- 1) With your last Adobe Premiere Pro project file open (Figure 1), open up Adobe After Effects.

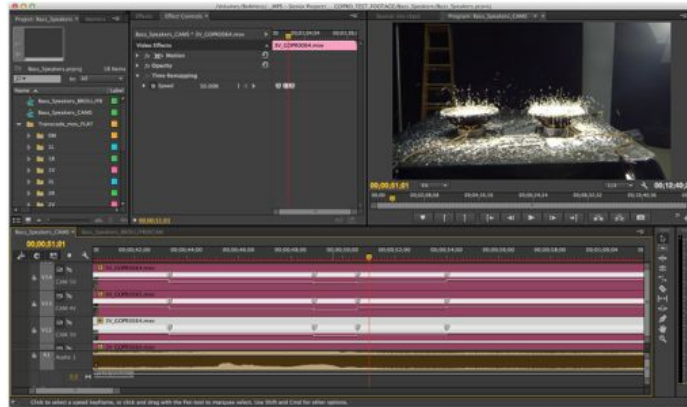


Figure 1: Adobe Premiere Pro CC Test Workflow Overview

- 2) Select the single shot you want to continue adding the bullet time effect to and copy all of the camera layers within that shot with [cmd + c].
- 3) In Adobe After Effects open up a new composition [cmd + n]
  - a. Make sure you have your composition frame rate set to the native 59.94fps Drop Frame of the GoPro media being used.
- 4) Paste the Adobe Premiere Pro content [cmd + v] into the layers timeline at bottom section of After Effects. This step should copy all of the media from the selection in Premiere Pro and any applied markers and key frames.
  - a. Line up all of the markers, key frames, and content just like how they were in Premiere Pro.
  - b. Ordering the cameras should be done at this step by dragging the layers at the bottom to the position desired. The top camera should be the camera you wish to see first. For example, if you wanted to start at CAM 4L and interpolate around the horizontal arc, order your clip in the order 4L, 3L, 2L, 1L, 0M, 1R, 2R, 3R, 4R from top to bottom.
- 5) Scrub to the location of the first frame where the first 1% Time Remapping key frame is located.
- 6) Select all of the clips [cmd + a] and duplicate these clips within the timeline [cmd + d]
- 7) Without clicking anywhere else and these duplicated layers selected, cut the media on these layers down to a single frame by holding the Option key and hitting the left bracket then right bracket keys. {Option + [} then {Option + ]}

- 8) With these duplicated clips (and them all selected) a new composition has to be made with the duplicate clips within it. To do this, a Pre-Composition can be created by going to Layer → Pre-Compose [Shift + cmd + c] and clicking OK.
  - a. These duplicated clips are now within the single composition (default name, Pre-Comp 1)
- 9) Go into the Pre-Composition setting [cmd + k] and change the duration of the composition to match the number of cameras you will be interpolating around, plus an additional frame.
  - a. Horizontal curve; 0;00;00;10
  - b. Vertical curve; 0;00;00;06
- 10) Offset each of the individual frames by one to the right, shown in Figure 2.

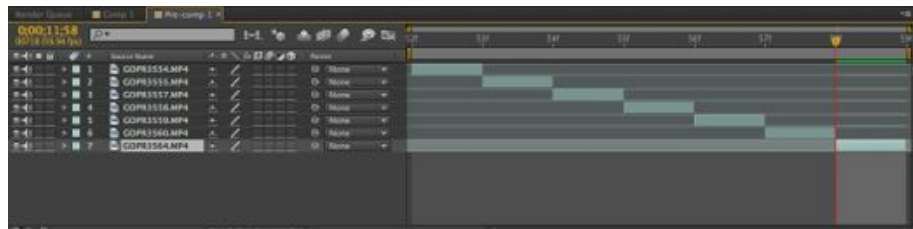


Figure 2: Pre-Composition frame/camera offset example

- 11) Select all the clips and hit the T key to open up Opacity adjustments.
- 12) Starting with the first frame, extend it out one more frame and adjust the opacity to about 40%.
- 13) Place your scrub position at the point between both frames so that you can see both images overlapping on the monitor.
- 14) Adjust the second image by clicking and dragging, to overlap the main subject you are pulling the effect on (or any stable markers in the scene) so that they line up correctly.
  - a. Continue doing this for the rest of the camera layers until they are all aligned.
- 15) With the opacity back to 100% for all of the clips, selected all of the clips again and hit the R key to adjust the rotating of each frame. Choose a position in the frame where you believe that it is as horizontal to the scene as possible and use that as your reference.
- 16) To compensate for some of your clips being out of the monitor frame from both the position and rotation adjustments, scaling must be applied. Select all of the clips again and hit the S key to bring up scaling options.
- 17) Scale each clip up to the same amount, but just enough so that all of the frames are in the monitor frame.
 

NOTE: When shooting, stand further back than you would normally shoot to allow for less image scaling. As a base, I normally shot about double the distance I normally would have with a single camera.

NOTE: If you adjust the rotation or scale of either the first or the last camera, you must adjust both the scale and rotation of the first and last camera in your main composition to match each other.

- 18) Back in the main composition, to clean things up, you can delete the all the camera layers from the timeline except for the Pre-Composition, the first camera, and the last camera.
- 19) Trim the first camera layer to end when the Pre-Composition layer starts and trim the last camera layer to start when the Pre-Composition layer ends.
- 20) Select all of the clips and enable Time-Remapping [Option + cmd + t]. You should now be able to see the key frames you made in the Premiere Pro project.
- 21) Select the Pre-Composition layer and enable Pixel Motion Frame Blending.
  - a. Right click the Pre-Composition layer
  - b. Frame Blending dropdown menu
  - c. Select Pixel Motion
- 22) NOTE THIS MINI LIST CAN ONLY BE DONE IF YOU HAVE THE TWIXTOR AE PLUG-IN
  - a. Apply Twixtor to the Pre-Composition layer and tweet these attributes
  - b. Color Source: Reference your Pre-Composition layer
  - c. Input Frame Rate: 59.940
  - d. Motion Vectors: Best
  - e. Image Prep: Contrast/Edge Enhance
  - f. Speed Perfect: 50%-75%
  - g. Frame Interp: Motion Weighted Blend
  - h. Smart Blend: Selected
- 23) Select the last key frame associated with the Pre-Composition layer Time-Remapping and drag it to the duration you wish the effect to be.
- 24) Select the key frames from the last camera from the end of the Pre-Composition layer on. Drag them over to start when the Pre-Composition layer ends so the last camera layer can pic back up. Your ending composition should look similar to Figure 3 below.



Figure 3: Adobe After Effects CC Overview