SPHERICAL VIDEO: YOU HAVE THE POWER

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Abstract: The Museum of Science, Boston's Charles Hayden Planetarium team has become skilled at creating remarkably high-quality spherical video at or above 4K domemaster resolution. And we are doing it at a remarkably low cost – about $5k for the video equipment. This paper will explain how you can create and use spherical video, as well as the equipment and software you'll need. Right now we're using spherical video only to create scenes for a new recorded planetarium show. But we think it has a place in live, presenter-led programs, too.

Introduction

In 2010, the Museum of Science renovated its Charles Hayden Planetarium, gutting and refurbishing the facility and installing a new Zeiss star project and Sky-Skan's Digital Sky system. At the same time, our team learned a range of new animation and production skills, in February 2011 opening our inaugural production, *Undiscovered Worlds: The Search Beyond our Sun*. In late 2012, *Moons: Worlds of Mystery* followed. Neither show used live-action; every visual is a 3D animation. Innovative work from several planetariums as well as the rapid pace of video technology advancements made us wonder what we might do if we could readily and affordably shoot 4k fulldome video live.

This paper outlines some of the highlights leading to the availability of affordable, live-action spherical video, provides an overview of how we are doing it at the Museum of Science, and opens a conversation on how spherical video may prove useful in the future. Detailed technical information, fuller descriptions, and tips are available in Jason Fletcher's blog (find it by searching online for: thefulldomeblog 360 video).

The Promise of Fulldome Video

In 2013, the work of others suggested both that 4k video would be compelling for audiences. The World Views Network's presenter-led programs placed the audience within a sphere textured with appropriately stitched photographs, for example of a valley in the Himalaya Mountains. The image was a still frame, so the only movement came from panning and tilting. The effect was noteworthy and memorable but it also made me long for video in place of that immersive, yet stationary, image.

In producing the *Awesome Light* series of shows, Sky-Skan used an array of DSLR cameras mounted in a rig and synchronized through software, to create time-lapse fulldome video sequences. The DSLRs produce spectacular quality images; but their frame-rate is a limitation. With a maximum frame rate at or below 8 frames per second, the resulting video, viewed at 30 or 60 fps, can be cartoon-like if people are within view. Further, this technique was expensive and very challenging operationally. It did however, yield gorgeous time-lapse video.

In producing *Earthquake*, California Academy of Sciences used two different live-action techniques. The opening scene skillfully stitched multiple HD videos of waves on beach into a 3D model of the surrounding environment. Later, the producers used a Red One, 4k video camera, with a fisheye lens to bring the audience right into a scene. The beach scene required skillful modeling and great care in compositing, but utilized modest-cost cameras to capture the live action. The second scene required a specialized and very expensive camera, a trained operator, and thus great expense, but required no stitching.

All these examples represent compelling audience experiences illustrative of the promise of fulldome video. But none were straightforward technically or modest in cost. But the rapid pace of advance in digital video technology suggested that fulldome video capture via a single, moderately priced device was close.

Spherical Video for the Masses

By late 2013, three critical pieces of technology had become available at moderate prices. The GoPro3 camera offered HD video in a very small package. 360Heros manufactured (via 3-D printing) a very compact, tripod-mountable rig for securely holding ten GoPros oriented so their combined perspectives cover a complete 360 degrees. And software from Kolor offered the ability to stitch and blend the ten GoPros' video streams into a single set of spherical master frames.

The key pieces of hardware and software for our setup included:

- Ten GoPro3+ Black Edition cameras
- A H3Pro10HD Rig from 360Heros to hold and orient the GoPros
- Autopano Video Pro and Autopano Giga software for stitching and blending
- A PC with sufficient storage, processing power and an excellent video card (since Autopano Video Pro can leverage the card's processing capability to speed rendering). A USB 3 port and a compatible card reader are essential.

In addition, we purchased extra memory cards and batteries, a set of ten chargers, a case to carry and protect the rig and camera, a tripod mount for the 360Hero camera rig and a few other items.

The combined price of the 10 GoPros, the 360Hero rig and the software along with extra batteries and memory was about $5000.

One doesn't need a full sphere of video to create domemasters. But capturing more than the dome's typical 180 degrees is useful for two reasons. First, having the full 360 sphere gives one complete flexibility to shift the zenith in post-production. Second, it turns out that giving the audience a view of immediate foreground is essential to creating a normal-feeling view in any terrestrial situation. A unidirectional tilted dome provides this naturally, but in any horizontal concentric dome, it's critical to compress more than 180 degrees of view – say 220 degrees – onto the dome so there is foreground all around the audience. This, in turn requires filming more than just a hemisphere. Spherical video, then offers the fulldome producer maximum flexibility to handle any scene.

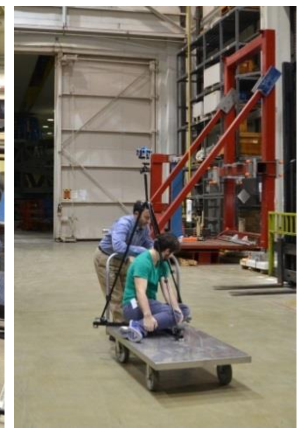
Shooting and Work Flow

This section provides an overview of the work flow. A detailed technical account is available at the "360° Video Fundamentals" post at thefulldomeblog.com, maintained by Jason Fletcher.

Prior to setting up for a shot, it's critical that the cameras' video settings are all correct and that they all are synched properly to a wireless controller. When properly set up, all ten cameras can be turned on and off and filming can be started and stopped via a single wireless controller.

Physical setup consists of mounting the rig on the tripod and inserting the cameras. It requires care, but is straightforward. Of course, each camera needs a charged battery and properly formatted, empty memory. Small details, like lens caps that fit on the cameras when mounted in the rig, make a difference.

For shots with camera motion, we've experimented with several modes of transport. Mounting the tripod on a dolly that rides on a track provides the smoothest shot, although it requires care to keep the person moving the dolly and the tracks out of the shot – or rather the portion of the shot that you intend to use. Mounting the tripod on an electric wheelchair above the rider can work remarkably well, and we've even had some success with simply placing the tripod on a cart and carefully wheeling it by hand – while scrunched down well below the camera rig. With any shooting option, it's vital to keep the camera motion as smooth as possible. Imagine the camera rig as a spaceship with your audience inside so every bump or jolt is magnified for them at least tenfold when put onto the dome.



In all cases, it's critical to know what part of the spherical video stream you'll be using in your final shot, and to ensure that dolly tracks, lighting, any equipment, bags and other paraphernalia, and filmmakers remain in the unused portion.

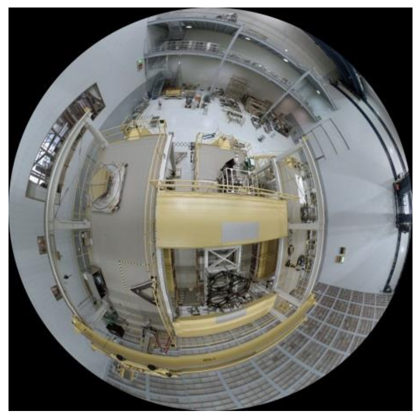
In planning shots, it's best to keep the rig at least 10 feet away from anything to avoid parallax error and consequent stitching problems. Shots involving people can be tricky on the dome; it's easy to have them too far away or too close. Given how tough it is to figure out what will look good on the dome, it's best to study others' work and to experiment. We feel that we're only just beginning to travel up the learning curve.

Once you have planned and set up a shot, the next step is to execute. It's critical to make sure that all cameras are working properly and then to synchronize them via several quick twists of the entire rig. Later on, the stitching software interprets these motions and uses them to synchronize the multiple video streams since there is no guarantee that all 10 cameras started at exactly the same moment. Once the cameras are rolling, execute the shot – smooth camera motion, action in the shot – and then make sure the cameras are still working properly. The GoPros are not 100% reliable; it's best to recognize that every now and then a camera will quit on you and you'll need to retake the shot.

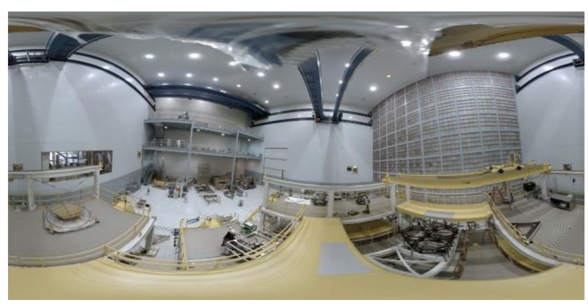
Our batteries were good for a little less than 1.5 hours of filming on a full charge and our memory cards were had capacity for about 1.5 hours-worth of data (32GB). Once we exhausted them, we'd remove the cameras, swap batteries and memory cards, and then reinstall the cameras in the rig to be ready to shoot again. We'd then upload the data from the cards onto our computer and begin the stitching process. Each 1.5 hours of shooting represents about 320GB of data. Uploading via the camera's USB 2 port is far too slow; you'll need a card reader connected via USB 3. Even then, it takes about 1.5 hours to upload the data from the 10 cards.

Given all the files, it's critical to have a system for content management. 360Heros has file management software that can help. There are numerous details reviewed in our blog. The key thing is to group the10 video streams for each shot together into their own file folder, to name them reasonably, and to ensure that none of the files are corrupt.

Autopano Video Pro has several convenient capabilities. First, it uses the overlaps between the cameras' fields of view to establish how to do the stitching; you don't need to specify a template to inform it of the cameras' orientations. Second, it can do substantial amounts of color and brightness matching to blend all 10 video streams into a pleasing set of master frames. Third, it can render directly into fulldome master frames or produce equirectangular frames that can be imported into other tools such as After Effects. Finally, it can render 1k frames quite quickly and thus provide a good sense of how a shot looks.



Fulldome domemaster frame



Equirectangular frame of the complete sphere

Rendering at full resolution takes more time, of course, and we use the equirectangular format, importing those frames into other tools such as After Effects and the Navegar Fulldome Plugin. Although the GoPros have excellent color and exposure latitude, and Autopano Video Pro blends exposure and color nicely between the cameras, After Effects permits us to control overall color temperature and adjust saturation to create images that look great on the dome.

Conclusion

The fulldome community now has a moderately priced set of tools at its disposal for shooting spherical high-resolution video and producing remarkably high-quality live-action fulldome footage. The cost of the required hardware and software is in the vicinity of $5000, which makes places it within reach of many of us. While it takes technical knowledge and skill to implement the work flow, with a little support from the community (and resources such as the 360 Video Basics primer on our blog) most planetarians with any production experience can produce satisfying results.

The challenge before us is learning how to use this tool. Some of the questions for us as a community to explore include: What makes for a really good fulldome live-action shot? What techniques best leverage the unique characteristics of a tilted unidirectional dome as well as a horizontal one with concentric seating? What techniques work well for including people in shots? How might we use spherical video in presenter-led, interactive programming? Can we imagine new kinds of audience experiences, new *kinds* of shows, that might be compelling?

While there are certainly technical challenges and technical improvements to come, the most important progress in this new medium/technique will be creative. As a community of producers, we have been given the power. Now, how shall we use it?