

# Immersive Stereoscopic Panoramas

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## ABSTRACT

Immersive stereoscopic imaging requires sharp wide field images, special software, and high resolution displays. Examples of some successful image capture, splicing, viewing, hosting, and posting techniques used in digital stereoscopic panoramic photography are given.

Image capture uses camera movements that approximate natural eye positions reasonably well by using manual or motorized gimbal mounted systems designed for the purpose. Processing requires seamlessly stitching dozens or hundreds of images into left and right panoramas. Creating stereoscopic images over 50 mega pixels benefits from programmable motorized camera mounts. The 2 gig limit of TIFFs is often exceeded and requires the use of GigaPan.org hosting technologies. Gigapixel stereoscopic images are viewed as a single whole while many small files are quickly uploaded to improve the sharpness of the areas viewed and may be seen at [3d-360.com](http://3d-360.com) [1]

Immersive stereo contents, active scrolling and deep zoom capabilities take stereoscopic photography from snapshots into the realm of immersive virtual presence when combined with modern web and display technologies. Scientific, artistic, and commercial applications can make effective use of existing stereoscopic displays systems by using these extended capabilities.

**Keywords:** immersive stereoscopic stitched panorama extreme resolution deep zoom

## 1. INTRODUCTION

Immersion is the perception of complete absorption into the stereoscopic contents presented with little or no attention directed at details or limits of the viewing system. Achieving this subjective effect using still images depends heavily on the quality of the contents as well as the methods of capture and display. "A perfect stereoscopic picture should be one that, when seen in an instrument, it would appear that we are looking at nature itself, without the interposition of any medium, and produce the same appearance as, for instance, if we were looking at a view through an open window." Henry C Delery, 1912 .[2] Gigapixel stereoscopic panoramas are here now with the ability to use all of the pixels of any display.

Early computer games were immersive enough until superseded by better games. If the content is satisfying, one's attention may be held by that alone. Gaming systems use movement and speed to captivate the viewer, minimizing the need for resolution. Slow moving or still images are subjected to a higher level of examination and thus benefit from improved resolution and an increased field of view. Stereoscopic panoramas become more immersive by allowing the viewer to control where they look, how deeply they zoom, as well as having content worthy of exploration. Large stereoscopic images are only browsed by a viewer if the contents are deeply absorbing.

Photographers often seek improved resolution and field of view as a matter of continuous improvement. Manually pointed paired and mounted digital cameras were used for stereoscopic panoramas since the late 1990s. Improved results encouraged further development, use of software, and dedicated camera mounts. The advent of GigaPan [3] Stitcher allowed us to successfully stitch, open, and view 100 megapixel and larger images. The use of motorized panoramic heads improved the ease, quality, and consistency of producing large stereoscopic panoramas. Such large panoramas vastly exceed the capabilities of any display available, and thus meet the requirements for immersion. Improvements in viewing and methods of display are currently the quality limiting factors.

## 2. CAPTURING STEREOSCOPIC PANORAMAS

### 2.1 Capturing Panoramas

A stereo camera, or a pair of cameras, may be mounted on a manual or motorized panoramic head. When hundreds of movements and photos need to be taken, motorized systems have clear advantages. When speed and weight are important manual methods and smaller panoramas may be adequate. The separation between taking lenses is typically 65mm to keep the scale similar to human vision with 100mm being acceptable for most landscapes. Closer spacing is used for closer and smaller subjects.

Camera positions approximate natural eye positions reasonably well using manual or motorized gimbal mounted camera systems designed for the purpose. Flat panoramas use a single camera rotating about its iris, which is not possible with two irises and two cameras for 360 degrees of rotation because the vantage points change. If the zoom lenses are extended and smaller rotations are used positioning errors are minimized.

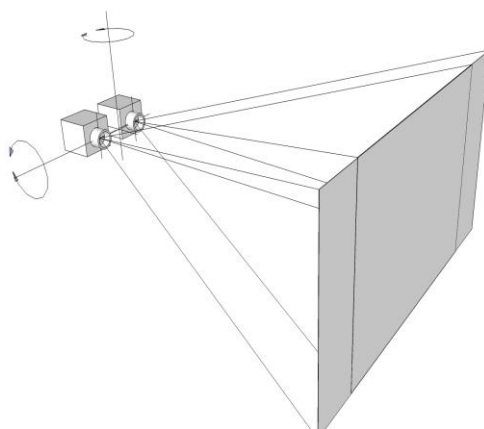


Figure 1. Stereoscopic panoramas are produced by pivoting at a point between the iris of twined cameras to capture rows and columns.

Custom camera supports are typically designed around modified available systems. Fitting two cameras on a single motorized head requires custom brackets and wiring. Single stereo cameras are available and the Fuji W3 has been used effectively with a modified GigaPan head. A pair of synchronized cameras can provide better results with more weight, complexity, and batteries. Scratch designed manual systems are very practical and cost effective for DIY photographers.

Stereo Data Maker (SDM) [4] is a program that allows certain Canon cameras to be tightly synchronized by reprogramming the cameras [5]. A voltage pulse is used to set focus and exposure (if not manually set) and the release of that pulse trips the shutters. This voltage pulse can come from a GigaPan head and thereby replace the GigaPan button pulsing solenoid.

Stationary subjects are relatively easy to shoot. Wind, clouds, shadows, people, water, wide dynamic range, and changing light present significant issues in field work. People appearing in one frame and not the adjacent frame will be cut into pieces. Objects appearing in one eye and not the other are disturbing distractions in stereoscopic images. The right and left images should be taken of the same region at the same time. Synchronized and aligned cameras are almost required for consistent results.

Larger panoramas require many more photos that are usually taken as rows or columns. While a single row is easily shot by hand, double and triple rows benefit from monopod or tripod mounted cameras. Row shooting is also more able to deal with changing clouds and top to bottom exposure differences. Shooting columns is difficult without a motorized mount. The only advantage of shooting columns is that a good panorama of a set height becomes wider as one waits for the batteries to die.

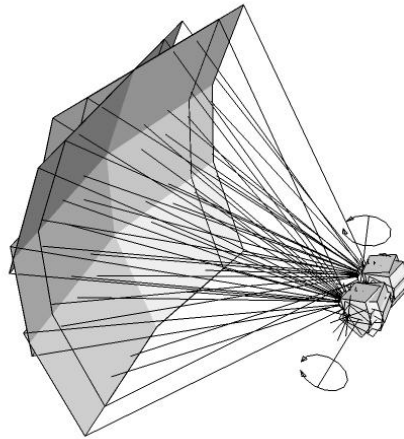


Figure 2. Two columns and three rows of stereo pairs would be shot to cover this arc segment with six images. Stereoscopic panoramas of hundreds of stitched images can produce pairs of billion pixel (gigapixel) images

Longer focal length lenses can produce much larger stitched images and also need more stable mounting. Image stabilization is always good and stiff weighted tripods certainly help. Astronomical telescopes mounts like the Merlin have been used with DIY software to produce panoramas. The angular stability and repeatability of panoramic heads becomes a concern when using telephoto lenses. Programmable motor controllers, gear reduction, balanced loads, large battery packs, and astronomical mounting are necessary for stability for 500 mm equivalent focal length lenses and longer.

## 2.2 Single camera Stereoscopic Panoramas

A number of cameras have a built in capability to shoot “sweep” panoramas and to even create stereo panoramas. With the camera pointed outward and held at arm’s length, the camera changes position while taking overlapping photos. The left and right sides of each image are used to create the right and left side panoramas. Three 180 degree sweeps may be combined into 360 degree panoramas, and rows may be stacked to provide taller images. Using a mechanical arm on a tripod would facilitate the production of stereoscopic sweep panoramas as well as allow for control of the effective stereo base.

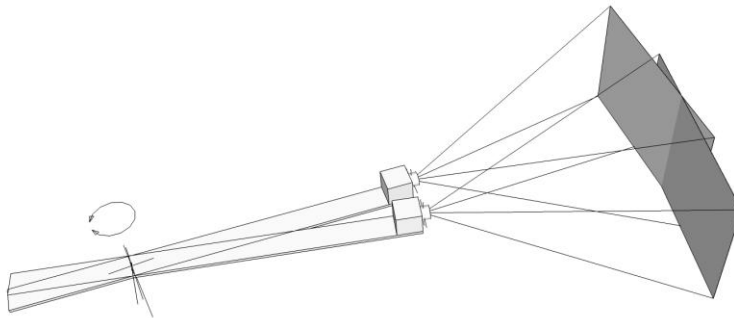


Figure 3. A single camera is mounted on an arm that pivots around a point behind the camera. Each rotation and capture creates a stereo pair with the last and next image. Arm length, field of view, and rotation angle are variable.

Many cameras are capable of shooting every two or three seconds to make a continuous sequence of hundreds images. This interval is shortened when manual exposure and focus are locked and a high speed memory card used. One seeks to rotate the camera immediately after the last shot and have it still by the time the next image is taken. Using a fast shutter speed minimizes motion blur, but is not as good as holding the camera still at the moment when each photo is taken. Stereo Data Maker (SDM) may be used to control synchronized stereo shooting using two or more reprogrammed Canon cameras. Stereoscopic sweep panoramas can be made using a single camera in continuous mode or by simple overlapping and button pushing.

Hyper stereo panoramas use left and right image pairs taken at a separation that is greater than our normal 65mm. Distant mountains, clouds, bridges, cities, and geology can benefit from exaggerated depth. It is often possible to shoot a left panorama, quickly move, and then shoot the right panorama before the scene has changed too much. This is called shooting a “cha-cha” because one shoots, steps sideways, and then shoots the same subject again. Hyper stereo shots are limited to less than 180 degrees wide where the effective base becomes zero if only two vantage points are used.

It is possible to create a very long stereoscopic panorama by shooting a series of sequential images. If a series of images are taken of storefronts from a car or terrain from an airplane, the interval between images and speed set the stereo base. It is possible to make a good stereo panorama or movie from such a sequence. Microscopic, terrain, or human scale subjects use the same scale independent methods.

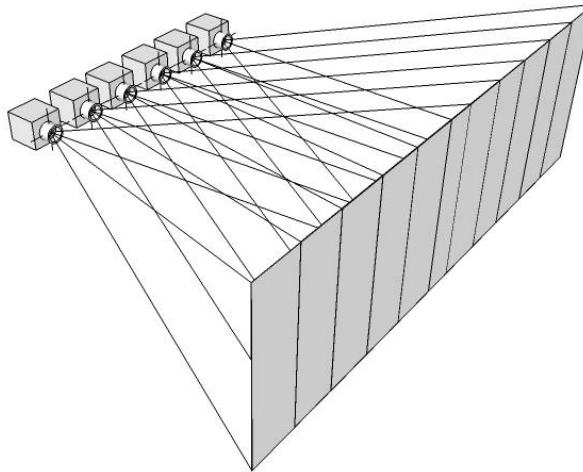


Figure 4. A single camera is moved to capture a sequence of images to produce a stereoscopic panorama of indefinite length from aerial photos or micro-photos. Gangs of cameras may be synchronized for a variety of purposes.

Shooting stereo panoramas requires capturing a view for each eye. The views can be captured simultaneously or sequentially with one, two, or more cameras. A robotic or manual panoramic camera mount can greatly aid in the capture of high resolution scenes. Good handheld manual techniques allow a photographer to shoot scenes well even when lightly equipped.

Obtaining a high vantage point is a great way to improve a panorama. Tall tripods and masts are used as well as balloons, kites, and drones. Movement is a problem for panoramas unless software is used to create 3D models using those movements. Many of these hybrid technologies are converging to produce results that are technically beyond the two points of view used for stereoscopic panoramas.

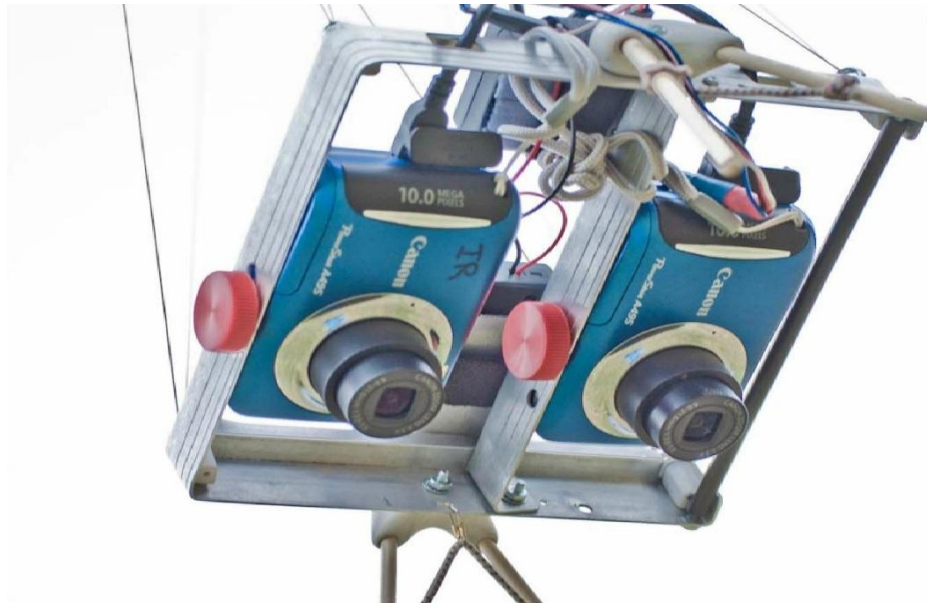


Figure 5. Paired kite mounted cameras are used for taking visible and IR photos and not for stereo. Since cameras are flown at above 200 feet the separation for good stereo should be more than a few inches. System by Chris Fastie. [6]



Figure 6. A single camera is kite suspended from a motorized mount by Chris Fastie. [7]

### 2.3 Example Field Methods;

Among the many methods used to produce stereoscopic panoramas these are often used in the field.

This is a quick manual method using a single camera, for lower resolution handheld grab shots in the field. Using a DSLR, a photographer may simply shoot a scene holding the camera vertically and eyeballing overlap with a grid viewfinder, attempting to move the camera through an arc to keep the lens's entrance pupil stationary while rotating the camera, shooting images with a 30% overlap. A single or multiple rows of images may be shot. When complete, the photographer takes a single horizontal step and shoots the scene again. The benefits of this method are that no equipment or setup is required and the photographer can capture static scenes with ease. The negatives include possible image stitching errors due to camera drift, causing parallax errors. Also, any movement (including branches and leaves) in the

scene between the two shots will become instantly visible to a viewer of the scene using a 3D viewing method (the errors will literally 'pop' into conspicuous visibility and will be very hard to ignore).



Figure 7. Manual Stereo Panoramic Mount with pair of Nikon DSLR cameras. The mount keeps the cameras rotating vertically through the lenses entrance pupil, and keeps the horizontal rotation of the lenses as close to the entrance pupil as possible. This mount allows the photographer to capture a full 360x180 degree image.

A second manual method uses a manual panoramic mount and shooting with two DSLR cameras mounted base to base to keep the lenses as close to the central pivot point as possible. This method has significant benefits over the single camera method as it allows both the left and right eye shots to be captured at the same time (the shutters are synced through the cable release sockets of the Nikon D300s used. When the shutter of one camera is tripped, the other camera fires at the same time.) The manual panoramic mount allows action sports to be followed such as a skier going over a jump or a snowboarder in a halfpipe. After following the action in a scene, one then captures the rest of the scene by manually moving the panoramic mount through the steps required to cover the entire scene with 30% overlap between each shot both vertically and horizontally. Excellent results can be obtained, even when there is significant action in the scene. Depending on the patience of the photographer and the focal length of the lens, even very high resolution panoramas can be captured with a manual panoramic camera mount. The mount keeps the cameras moving close to the entrance pupil of the cameras lenses although they will not be perfect as they have to have a few inches of displacement in order to obtain the stereo separation necessary for the illusion of stereopsis. If a very close up scene is shot, stitching the images may fail or produce stitching errors. With scenes further from the camera, no problems should be expected.



Figure 8. GigaPan Robotic Panoramic Mount with a pair of Panasonic FZ50 digicams mounted on a horizontal board. The camera separation allows for the hyperstereo capture of distant scenes, but the distance between the lenses would preclude image stitching success with subjects that are close to the cameras due to parallax error.

A motorized method using a GigaPan Epic Pro robotic camera mount and mount both Nikon D300s DSLRs or a pair of Panasonic FZ50 cameras to the tray with a horizontal bar to accommodate both camera. A custom synchronization circuit is used to fire both cameras simultaneously. This method is best for capturing very high resolution scenes with a

long focal length. Stereo panoramas of up to 18 gigapixels have been captured with this method. The method is not conducive to capturing action scenes as the robotic mount goes where it wants, not necessarily where the action is. Special care must be taken when using long focal lengths that they are indeed pointing to the same place or the benefits of simultaneous capture will be lost (although the left and right scenes will still be captured, they just will not necessary be capturing the same close up events) and this alignment will change with varying distances of subjects from the cameras. The weight of two DSLRs with lenses, the GigaPan mount, and tripod can become daunting and set up can be frustrating and cumbersome when dealing with high winds, cold weather, and mechanical challenges. The results are fantastic, but the effort required is not minimal.



Figure 9. Aspen CO firehouse crossed side by side stereoscopic panorama sized to fit the page. [8]

### 3. STITCHING AND SERVING

#### 3.1 Stitching and Serving

Digital image stitching is the combination of many images into a larger stitched “panorama” using software. Image stitching software builds a mosaic from overlapping images. Stitching finds corresponding SIFT points in adjacent overlapped images warps, rotates, aligns, overlaps, blends and fuses them into one. Normally, panoramas are made by rotating the camera around its own iris, so as not to change the points of view between photos. Stereo cameras have two irises and a point of rotation between the irises provides the best stitching results. Stereo images need to have a 30 to 50 percent overlap of each frame to the previous frame. Objects that are too close will not splice properly. Splice errors create non-depth differences between the right and left image that appear as disturbing flaws with erroneous depth.

There are many good programs used to stitch images. GigaPan Stitcher and Stitcher EXF require input images sequentially numbered and ordered in columns or rows. EXF has color, gamma, saturation and tint controls. Hugin [9] was the shareware source for AutoPano Pro and AutoPano Giga now available through Kolor [10]. AutoPano accepts images of any orientation and of mixed focal lengths. AutoPano also does minor keystone corrections to compensate for the slight perspective offsets. AutoPano also has many controls like setting horizons and vertical lines that can be used to correct and pair globally warped images, set vertical lines, or edit image links. PhotoShop and PaintShop Pro have some stitching capabilities but limits on size of 60K wide for JPGs and 2 gig for TIFFs and PNGs.

Sharing enormous images on the internet requires that the gigapixel image be parsed into tiles and sub-tiles. All tiles are 256 x 256 pixel jpg images that are served up on demand. GigaPan Uploader and Stitcher are capable of creating such files of sub-sub-tiles.. Their server recognizes and reads files that the user is likely to view next, providing a relatively smooth download with a broadband connection. Dedicated servers are currently the only practical way to seamlessly serve billion pixel images. [3d-360.com](http://3d-360.com) actively hosts the viewing software for the dynamic and immersive viewing of stereoscopic stitched images.

#### 3.2 computers and software

Computers, software, and displays are challenged by billion pixel images. Stereoscopic images are usually twice as large as flat images and carry an additional processing overhead. Corresponding objects in the right and left images need to be aligned in relation to each other and the edges of the display. 32-bit software does not open or process images larger than half a billion pixels due to a 4 gigabit memory limit. Stereo Photo Maker is a popular 32 bit full featured program limited to about 10K by 2K pixels. A dedicated 64-bit stereoscopic authoring or viewing program capable of larger images does not seem to exist at this time.

Silverlight or Ajax image hosting use JavaScript and Flash to serve up the correct images for nearly seamless pan and zoom transitions. Fortunately, large image servers have been in use for years assembling image tiles for maps and are now in use for panoramic images on the GigaPan site.

GigaPan panoramas, like Google Earth, allow pan and zoom using Silverlight map viewing methods. Each panorama is divided into tiles and sub-tiles that are loaded to only display the region of interest selected. The GigaPan website hosts and shares tens of thousands of 50 megapixel and larger panoramas that are taken, shared, and viewed all over the world. Engaging GigaPan panoramas that are displayed on large HDTVs are very absorbing, especially when viewed in stereo.

Many highly skilled photographers seek to recreate a sense of presence using stereoscopic photography, increased resolution, wider fields of view, and high quality content. Some of these people created stereoscopic GigaPans and posted them as anaglyph images. Separate left and right were also posted and cross viewed as side by side stereo. A sample html page with a pair of GigaPans was made to display right and left images, but with no shared controls.

Scrolling across the image pair is now done with keystrokes or JavaScript. Stereoscopic viewing requires the coordinated control and simultaneous display of two separate panoramas. Jason Bucheim wrote scripts that moved both images to equivalent locations when only one was moved. He has also has develop a method of designating corresponding points manually that compensates for cropping differences in position and optimization of the viewing window. Jason created a website to view stereoscopic panoramas at [3d-360.com](http://3d-360.com) that uses his new software.

## 4. VIEWING STEREOSCOPIC PANORAMAS

### 4.1 Display

Different stereoscopic displays have different accommodation and alignment considerations. Many displays have no adjustments and images must be preformatted for best results. Generic alignment may not work for all systems, and viewing software with manual or automatic window adjustments is usually required for best results. These refinements are ongoing but are not yet market driven.

Heads up displays using 1080p with inertial sensors are likely to become available in the near future. When the user turns their head the image would scroll to present the appropriate view. This method of viewing is probably the most like viewing the real world. Ongoing improvements in micro-display display technologies makes heads up displays the most likely to improve in affordable resolutions. Accommodation of focus can be nominally correct with optics.

Wrap around displays using multiple projectors or display walls with wide angle viewing only need images with resolution that matches the display. Zoom could be beneficial there, but probably unnecessary. Position tracking, head tracking, and providing new viewpoints are often desired in such immersive systems. Stereoscopic panoramas are a great image source for 3D models, but more images are usually needed to cover hidden views.

Fortunately, modern 3DHDTVs do a great job with immersive stereoscopic images and are now a popular display system when connected to a computer and the internet. Stereoscopic image input is already standardized for these systems using over/under half height, side by side half width, and other default viewing formats. Due to the stationary nature of 3DHDTVs, one scrolls the image across the display using a controller, mouse, or keystrokes. Double clicking to zoom into an image is not intuitive, but is easily learned. Game controller and joystick controls become reflexive and intuitive to experienced viewers.

1080p images are 1920 pixels wide with approximately 2 million pixels over a 40 degree field of view. This is 1.25 arc seconds/pixel and 20/20 vision resolves 0.5 arc seconds [11]. The advent of 4K x 2K displays will allow us to match our visual resolution over a wider field of view while using an in place technology to serve the images. No reformatting of stereoscopic panoramas will be required for these larger displays. Experience shows that interesting and interactive flat graphics are easily enjoyed by most viewers. When active or passive stereoscopic displays are used the experience is taken to the next level.

Printing is the only way to view all of the pixels of these images at once. The sharpest print usually has about 300 horizontal pixels per inch producing a 100" x 25" print from a 30K by 10K image of 300 megapixels. The each side of the image would contain the same number of pixels as one hundred and fifty 1080p displays. Viewing the stereoscopic image is done with a dual mirrors or a single mirror in the ways of Sir David Brewster and Dr. John Hart. Panning is difficult.

## 4.2 Three dimensional panorama viewing software.

High resolution panoramas require special software to aid in the comfortable viewing. Unlike the static scenes of a View Master or stereogram, modern viewing of a high resolution panoramic image on a computer is an interactive process where the viewer zooms in to various areas of interest in the image and pans around. Using GigaPan type viewers, a viewer can take snapshots of various areas, tour around a scene, and examine areas with high magnification, downloading only the parts of the overall high resolution image necessary to construct the scene of interest.

With the advent of creating high resolution stereoscopic panoramic scenes, separate left and right panoramic images are presented to the viewer to be fused by the viewer's brain into the perception of a scene with depth. Presenting slightly different views taken from different vantage points, the 3D effect is achieved through the process of stereopsis. In order to provide a comfortable viewing experience, viewing software must coordinate the panning and zooming between the separate left and right eye panoramas. When the viewer zooms in sufficiently, the right and left eye views will become out of synch unless a correction factor is input to keep the same part of a scene in view for each eye. The correction factor can include shifting horizontally and vertically each image so that the same part of a scene is centered in each eyes' view, as well as other corrections including rotation, magnification, and tone balance. The correction factor normalizes and minimizes any differences between the two separate left and right panoramic images for the local region of interest.

Due to the stitching nature of modern, high resolution panoramic imagery, various warping, alignment, and rotational errors can be present in a panoramic image that looks individually perfect to a viewer when viewed by itself as the blending algorithms hide any defects very well, but when viewed side by side with a left and right eye view, the viewer's brain can instantly detect inconsistencies which literally 'pop' for the viewer. Using the various correction abilities, these inconsistencies can be minimized to be at a level acceptable to a viewer. Keeping the same region of interest in view for both left and right eyes is of paramount importance. If one part of a scene goes off screen for one eye, the entire stereopsis effect is lost and eye strain develops.

In the past with 3D photography, a disparity alignment point is set for the entire image pair, so that one region of interest will have zero disparity, and the rest of the images elements will have various amounts of disparity based on the distance of the elements in the image to the camera. With a single alignment point set, if one were to increase the magnification of the image to show only a small part of the scene at a distance away from where the region of interest disparity was set, parts of the left or right eye view may go off screen, showing two misaligned or separate magnified regions to the viewer. If the regions are misaligned, eyestrain will be present for the viewer, and if one region goes off screen, the entire stereopsis effect will be destroyed.

Keeping the region of interest in view (on screen) upon zooming in is an absolute requirement of successful enjoyment of exploring high resolution immersive imagery. To achieve this goal, a depth map of disparity between the two views is developed so that a proper alignment correction can be applied between the left and right eye views to keep both views on the same part of a scene. The disparity map needs to be fluid throughout the entire panorama region.

The website [3d-360.com](http://3d-360.com) uses proprietary technology developed by Jason Buchheim to synchronize the left and right eye views and deliver to the viewer the same region of interest within a scene regardless of the level of zoom applied. Even when zooming into the fine details of an 18 Gigapixel image, there is no eyestrain and the disparity is zero at any given region of interest. To achieve this, a disparity correction map is programmatically computed between the left and right eye panoramic images using a SIFT algorithm. Additional zooming and rotational corrections are computed throughout the images at different zooming amounts. With the corrections applied to position, magnification, and rotation, the viewer is able to the right and left eye views of a region of interest always on-screen and with zero disparity. The region of interest is determined interactively with the viewer and corrections are applied in real-time. The viewer is presented with views suitable for cross-eye, free-viewing, 3DHDTV, and anaglyph glasses.

The 3dpan.org panoramic viewing software allows the region of interest in the scene to be determined through various interactive methods, including mouse position, using head mounted gyroscopes and accelerometers, or through touch screen interaction. Future development of eye tracking hardware to determine the viewers gaze position would further enhance the experience. The regions of interest is cross referenced against the alignment, zoom, and rotation correction tables and the corrections are applied, allowing the viewer an on-screen stereopsis 3D-stereo viewing experience. The amount of enjoyment of looking at panoramic images is greatly enhanced, and the experience is much more immersive and potentially enjoyable. Without the corrections being applied, upon zooming in, each eye would be viewing a

different part of the scene, and no stereopsis effect would be possible. The viewing correction technology allows this deep immersive experience to be possible. See a video of the processes here [\[12\]](#).

### 4.3 The Future

Real life provides us with new perspectives when we turn our heads or change position. People using a glasses free display expect the subject to change when they move. This requires more than two captured and displayed viewpoints. Mounting more than two cameras on a panoramic head can directly provide information used for lenticular panoramas, or 3D modeling.

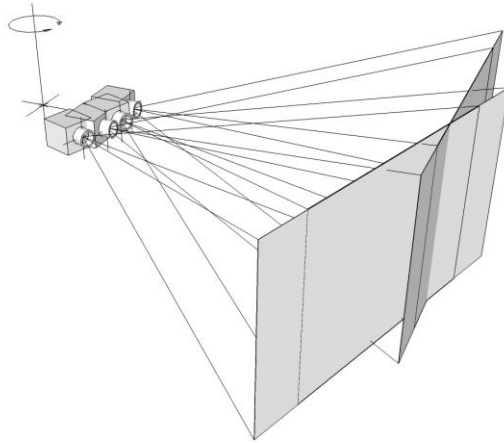


Figure 10. Turning our heads from side to side changes the positions of our eyes due to pivoting around our necks and not a point between our eyes. This enhances depth perception in the real world, but requires more views to emulate.

Panoramic models are volumetric spherical or half shell models allowing the viewer to see from many different vantage points near the center of the sphere. Such models allow viewpoints to change over a range, providing a more natural stereoscopic viewing experience at the price of much more complexity in capture and processing. Multiple stereo panoramas and individual stereo pairs were used to make spherical panoramic model [\[13\]](#).

Stereoscopically viewed models that surround the viewer are a convergence between photography and stereoscopic gaming environments. This is part of a transition of photography from flat to volumetric. It is not just about images or stereo images anymore. It now becomes about viewing photographically captured objects stereoscopically.

## 5. CONCLUSION

Immersive stereoscopic panoramas consist of a right and left image with sufficient resolution to surround the viewer and absorb them in the viewing experience. This includes zooming into details, much as one would use binoculars or a stereo-microscope in the field. The digital experience allows seamless scaling transitions when panning across or zooming into subjects. It is possible to include, mountains, a forest, a stream, ants, and flowers in one stereoscopic panorama that has yet to be taken. Science and art have new methods to explore.

The effective use of media continues to change the modern world. Science and nature programming is entertaining and educating the world with “infotainment”. New artistic mediums appear along with new devices and apps. Stunning stereoscopic images are now accessible via mobile apps and through web connected 3DHDTVs. Virtual tourism, stereoscopic photography, student efforts, and personal arts are leading the way in finding new uses for the medium. Digital imaging is literally changing the way we visualize, and immersive stereoscopic panoramas are a “big” part of the ongoing evolution of stereoscopic media.

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