# Time Lapse High Dynamic Range (HDR) Photography

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**Abstract**

In this paper, we present an approach to a pipeline for time lapse photography using conventional digital images converted to HDR (High Dynamic Range) images (rather than conventional digital or film exposures). Using this method, it is possible to capture a greater level of detail and a different look than one would get from a conventional time lapse image sequence. With HDR images properly tone-mapped for display on standard devices, information in shadows and hot spots is not lost, and certain details are enhanced.

(For pdf file with color images see **http://www-viz.tamu.edu/faculty/ergun/bridges/p3.pdf)**

## 1. Introduction

This paper presents an approach for creation of HDR (High Dynamic Range) time lapse image sequences. A few frames of an example of HDR time lapse photography are shown in Figure 1.

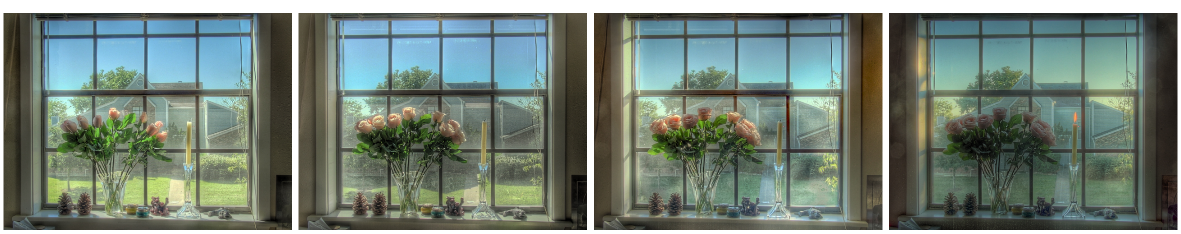
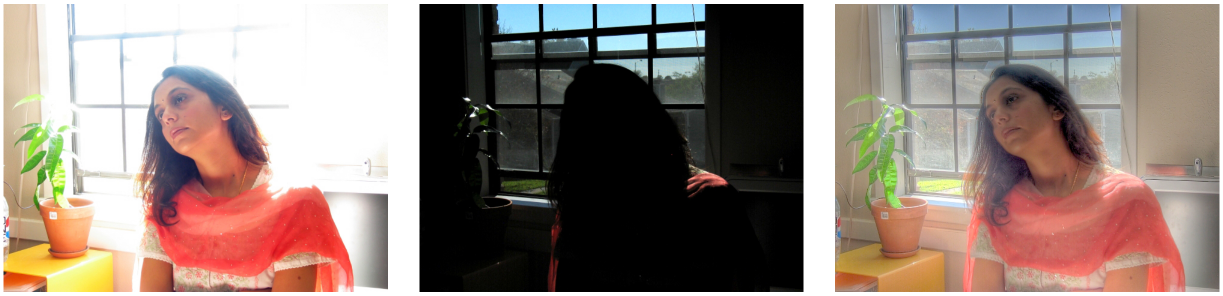


**Figure 1**: Four frames from the ”Flowers” time lapse sequence. The shadows move and the flowers open over the course of the sequence. Such exposures would not be possible with conventional time lapse photography.

Conventional digital photographs are Low Dynamic Range (LDR) images in which a single exposure can capture only a small part of the range of light intensities visible to the human eye. Anyone who has ever taken an indoor picture of someone in front of a window on a sunny day has witnessed this effect. The camera can only expose for the people and the indoor part of the scene, which means that the outdoor scene will be blown out, or the camera exposes for the outdoor part of the scene. (See Figure 2.(A) and (B)). With High Dynamic Range (HDR) images, it is possible to record the range of dark to light that is detectable by the human eye just for one image. Figure 2.(C) shows that using HDR it is possible to simultaneously record detail in both shadowed and highlight areas.



(A) Overexposed Image (B) Underexposed Image (C) HDR Image

**Figure 2**: With conventional photography, the user must choose between exposing for indoor or outdoor objects as seen in (A) and (B). On the other hand, Tone-mapped version of HDR image constructed from five LDR images in (C) shows full range of brightness with details.

### 1.1. HDR Images

Main difference between LDR and HDR is that in LDR a limited range of integers is used to represent color values, in HDR floating point values are used. HDR images can be created synthetically, by rendering a scene from some imaging software. Radiance is one such package, and is one of the first ones to make use of the High Dynamic Range format. The native format for Radiance is still one of the most prevalent formats today.

Another way to create HDR images is to capture HDR data directly using very expensive hardware. Such a camera is generally used to capture HDR environment maps. A company named Spheron makes ”SpheroCam HDR,” which is capable of capturing 26 f-stops of dynamic range in a single exposure. Unfortunately, this camera comes with a $65,000 price tag, which makes it less than practical for anyone not using this camera on a regular basis in the employ of a studio.

The most common method is to set up a camera on a tripod and take multiple exposures of the same scene, varying the shutter speed for each exposure. The sequence of photographs can then be assembled into a single HDR image by using the data from each of the individual images, combined with the knowledge of the relative exposures of each image. The intensity of each pixel can be calculated by looking at the same pixel in each different exposure[3]. Such a method was presented by Paul Debevec at Siggraph in 1997. Debevec also created software called HDR Shop specifically for assembling HDR images. Greg Ward, creator of the Radiance software package, released software called Photosphere that also assembles HDR images from multiple exposures. He also released a command line utility called hdrgen, which we found to be the most useful for time lapse HDR purposes, since command line interface allows for scripting automation.

## 2. Displaying HDR Images with Tone Reduction

The problem is that an HDR image could very well have a dynamic range of $10^6 : 1$, but conventional computer monitors have a dynamic range of 100:1 [16]. So not only is the data in a format beyond the capability of the display devices, the amount of luminance the device can put out is not even close to the dynamic range of the HDR image. A various tone-mapping methods have recently been developed to give the viewers the illusion that they are looking at an image with a high dynamic range, while in fact, it is a low dynamic range image.

In 1993, Jack Tumblin investigated a method for displaying computer generated images that accounted for the difference in human vision and conventional display screens[15]. In 1997, Greg Ward introduced a method for tone-mapping HDR images to LDR images that involved altering the histogram of the image to suppress brighter areas without losing detail in the image[20]. This method produces smooth clean images, and works fairly well, but when looking at an area that is directly sunlit next to an area completely in shade, the image looks as if all the pixels have been divided into bright and dark. This makes the image too ”contrasty,” as there seems to be no midrange, which is where we are accustomed to viewing the details of an image. Jack Tumblin introduced ”Low Curvature Image Simplifier (LCIS)” in 1999 [16]. LCIS uses a model for heat dissipation (anisotropic diffusion) to determine how to reduce the contrast between large gradients while keeping details. The method works well for bringing everything into a clear visually appealing intensity range, but introduces some noise and halo effect to the image.

In Siggraph 2002, there were three new methods for tone-mapping of HDR images, and the results offered in the papers are very impressive. Durand and Dorsey introduced ”Fast Bilateral Filtering”. This method uses an edge preserving filter and separates an image into a detail layer (high frequency) and a base layer (low frequency), and then reduces the contrast of the base layer to fit into LDR space, while leaving the detail layer unchanged in order to preserve detail[4]. Erik Reinhard, et al introduced ”Photographic Tone Reproduction”. This method tries to duplicate The Zone System which was developed by Ansel Adams, and is a method used by conventional photographers in order to get a properly exposed photograph even in unusually bright (or ”high key”) scenes and in dark (or ”low key”) scenes. The method works by pushing the average intensity, or key of the image into the middle zone. It also looks at areas bounded by high contrast, and uses ”dodging” and ”burning,” two terms borrowed from conventional photography, to preserve detail in bright and dark areas. To do the digital version of dodging and burning, it treats these areas as separate images, choosing a local key for such areas[12].

In this work, we have implemented, Fattal and Lischinski’s ”Gradient Domain High Dynamic Range Compression,” method which looks at the gradient of image intensities and compresses only large gradients, while leaving the small gradients alone. This preserves detail, while bringing the image’s dynamic range down to the point where it can be shown on conventional displays[5]. This method provides the most impressive results, however, it is extremely hard to reproduce. As far as, we know ours is the only other implementation of Gradient Domain High Dynamic Range Compression.

All these methods have been developed from the fact that the human visual system can detect very subtle differences in light intensities over a small localized area, but is not good at judging absolute brightness [17]. In other words, human visual system can detect subtle differences in brightness when the areas are directly next to each other, but it cannot tell how bright a scene is in general. Before digital images, computers, or even photography, artists have been exploiting this fact. It is possible to paint a picture that contains fire or some other light source, where the painting is properly ”exposed” (to borrow a photography term) to capture detail in the light source, and to also capture detail in shadow on the other side of the picture. The artist pulls off the illusion by varying the brightness of the image locally to express detail, and can use the same values elsewhere in the image to express detail in a darker area, as long as the two areas aren’t directly adjacent to each other.

## 3. Time Lapse HDR Photography

In this paper, we applied tone-mapped HDR to Time-Lapse photography. Time lapse photography offers a view of a scene across time, while conventional photography only provides one slice of time. With time lapse photography, objects that are in transition are apparent to the viewer, so a greater understanding of what is happening in a scene is possible. In this way, it is shares a characteristic with HDR photography in that more information is captured than in a conventional photograph.

Another similarity shared by HDR and time lapse photography is the mood that can be brought by each. HDR images have a surreal quality about them, almost as if they were painted or computer generated, since they look like photographs, yet they display the world in a way that it is not normally seen in photographs. The same is true of time-lapse photography. The viewer sees the world in motion, but at a rate that is not normal. Things that normally happen too slowly to be observed are quite apparent in time lapse sequences, and events that normally happen at a comfortable pace for the viewer are suddenly so fast that they are blurred, and pass in an instant.

Combining the surreal qualities of HDR and time lapse photography enhances the surreal qualities of each without adding any perceptual difficulties for the viewer. The viewer has already seen, and is therefore already familiar with time lapse photography. Likewise, the viewer has already seen paintings and illustrations that represent a higher dynamic range of light than one would see in a photograph.

## 4. Implementation

As an HDR format we use OpenEXR, the open-source HDR format created by Industrial Light and Magic [6]. OpenEXR provides a library for read and write operations, and also offers the option of reducing the amount of storage required by using the ”half” data type. Half is a floating point data type, but it cleverly rearranges the way data is stored so that it only uses 2 bytes for a number, as opposed to 4 bytes for a float. It does this by sacrificing the precision of numbers with higher values. More information is available at http://www.OpenEXR.net. OpenEXR also has a viewer that allows the user to view a clipped LDR version of the image. The user can select what exposure to view, and thus confirm that an OpenEXR file contains the data that it should. For converting a set of images to HDR format, we use Greg Ward’s hdrgen, which is available for both Linux and Macintosh. Since it is a command line application, it is possible to set up a script to do batches of conversions when the time came. For Tone Mapping, we have implemented Fattal’s method.

Our user interface work on both Macintosh and Linux platforms, it is based on gtk, a gnome-based interface. We can load sequences of images, set keyframes, and apply them to the sequence.

Time Lapse HDR requires to take huge number of images: Each HDR image requires up to 13 LDR images and one second of animation requires 30 frames; so a Time Lapse sequence that will take only 3 seconds to view requires approximately 1200 photographs without moving the camera. It is not only hard to take this many pictures changing shutter speed in each step, it is also impossible not to bump or move the camera slightly when adjusting the shutter speed. Thus, the only practical solution is to hook up the camera to a computer via USB (or FireWire) cable and control the camera remotely. Since the memory card in cameras is insufficient to capture enough exposures to do a time lapse of any significant length in HDR, it is also necessary to download images as they are captured. Even when hooked up to a computer, adjusting the shutter speed via mouse and keyboard is too repetitive a task to do be practical. The possibility of moving the camera can be gone, but the possibility of clicking the wrong speed, naming the file improperly, or overwriting other files is too great. The capture process simply must be automated.

For automatic capture, we use a software by Sean O'Malley, called AHDRIA (Automatic High Dynamic Range Image Acquisition), which controls Canon cameras and takes a sequence of LDR images specifically designed for HDR image creation [10]. AHDRIA controls the aperture, shutter speed, interval between exposures, and captures all the frames as fast as the USB interface will allow. For Time Lapse photography, Robert James Knopf wrote an utility to simulate a click on the AHDRIA button at specified time intervals. As a camera, we use Canon G3. There are limitations to this process. It takes between 35 seconds and 4 minutes to capture a single HDR frame's worth of data with the camera. The variation in the capture time depends upon how many exposures are taken, which affects the quality of the final image.

## 5. Results

Since it takes so long to capture data for one HDR frame, the subject matter is limited. Moving objects need to move slowly enough that no significant change takes place during the capture otherwise artifacts will be introduced. Therefore, people and animals usually do not work well. It is extremely difficult for even a willing subject to sit still enough that no artifacts are introduced.

Figure 3 shows a romantic dinner scene, lit by candles, christmas lights, and lights on artwork. While it was too dark for someone sitting in the actual scene to comfortably read, the darkness of the scene is ambiguous, even mysterious in the final image sequence. Detail is visible everywhere, even in corners and under the table. Yet, the image maintains the characteristics of a dark place. For example, small lights and candles casts a glow on objects around them, which wouldn't be noticeable in a brightly lit room. Colors seem subdued as they are in lower light situations. The candles are slowly burning down and works surprisingly well when the air is still around the candles.

Figure 4 shows another time lapse HDR that is shot in front of a window. In conventional time lapse photography, the subject or the background would not be exposed properly. The flowers open up over the course of the image sequence, which takes place over the course of an afternoon. The sun also moves from overhead to the horizon, and while the sun itself is not in the sequence, the shadows of buildings and trees around tell the story of the passage of time. Detail is visible both in the outside world, and in the objects on the window sill, which normally would not be properly exposed with the outdoor part of the scene.

Figure 5 show a more chaotic scene from a local restaurant, The Blue Baker, which has large windows suitable for a time lapse HDR experiment. An image sequence is captured in front of one of these large windows. Everything including tables in the interior of the building, a light bulb on the interior, tables on the patio, the parking lot, and buildings in the distance are visible. The artifacts resulting from the speed of the process are usually not desirable. However in this restaurant case, it works to see the patrons as blurs.

**Figure 3**: Single image in a time lapse series captured by the Canon G3, assembled with hdrgen, and tone-mapped in gct.

## 6. Conclusion and Future Work

The results yield a look that is somewhere between photography, painting, and computer generated images. This is because it is an image with the detail of a photograph, but is describing scenes that the viewer has never been able to see in a photograph. The person viewing knows that there is something unusual about the image, but can't immediately decide what it is. The results to look somewhat idealized, like a Norman Rockwell painting.

Though there is room for improvement, this approach for creation of time lapse HDR image sequences works quite well. Once the tools are assembled, the pipeline makes the process efficient, and minimal user input is required to create the image sequences. This frees the user to concentrate more on subject matter, rather than the tools for creating the images.

There are many ways to improve this process, including hardware, software, and exploring more subject matter. For hardware improvements, we imagine a camera capable of capturing enough data for high dynamic range images in a few seconds. It could be a commercially built camera, or one constructed from several conventional cameras firing at the same time. Perhaps the parallax between cameras could be overcome by mirrors.

A simpler solution, of course, would be to find a camera with higher download speeds. Since the majority of the time capturing is spent downloading, not exposing the camera's CCD, perhaps a FireWire camera could download almost as fast as the image is captured, meaning a much higher frame rate would be possible.

**Figure 4**: Six frames from the ”Flowers” time lapse sequence. The flowers open and the shadows move as time passes.

**Figure 5**: Six frames from the ”Blue Baker” time lapse sequence. Note that the patrons are blurred if they are moving when different exposures for the HDR frames are taken.

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