Leica ScanStation
White Paper

HDS™

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Gregory Walsh Ph.D.
Leica Geosystems AG
Heerbrugg, Switzerland

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HDR for Leica ScanStation P-Series

Gregory Walsh, Ph.D.

1. Summary

For Leica Geosystems P-series scanners, a High Dynamic Range (HDR) imaging mode is supported both on the scanners and in the input processing for Leica Cyclone. High Dynamic Range imaging on the instrument involves the collection of additional images, and in the software, requires the additional step of "tone mapping" for the meaningful display of the image. The tone mapping algorithms uses not only the extra image information, but also the factory calibration of the scanner together with the scan data collected on the scene to properly and automatically combine all of the images collected at the work site. The HDR imaging mode hence not only introduces improved data collection on the instrument but also a new way to look at image assemblies inside of Leica Cyclone.

2. High Dynamic Range Imaging

The notion of High Dynamic Range (see **[1]** for a summary) imaging means many things to many people, as it is an idea that has been around since the early days of photography more than a century ago. Pioneering photographers struggled with the limited dynamic range or contrast ratios of their cameras and film and so developed techniques for combining two or more images of low dynamic range into a single image with improved dynamic range (Figure 2). These techniques, time consuming as they were, provided a way to approach more closely the gold standard set by the human eye.

Figure 1: Tone Map image assembly from the Leica Scanstation P40, shown as an equirectangular projection.

Although the method for capturing the image has evolved, the basic concept has remained the same throughout the decades – even today; HDR photography almost without exception involves the capture of multiple low dynamic range images and combining them. Even specialised HDR camera sensors have image pixels within image pixels, capturing two different images for later combination (Figure 3). There are many techniques for collecting High Dynamic Range information, for example, some digital sensors have sufficiently high signal to noise ratios that a single image can approach the eye. The process of capturing a series of low dynamic range images and combining them is what the P-series scanner does.

No matter how the High Dynamic Range image measurements are collected, display technology such as computer screens also do not typically match the range of dark and light found in nature that can be perceived by the eye. For this reason, a meaningful integration of HDR for scanning includes not only improved capture but also ways to map the wide range of light intensities to a displayable range. The process of converting a High Dynamic Range image into one which can be viewed on lower dynamic range equipment is called Tone Mapping. As today's computer monitors are usually limited to 24 bits per pixel colours (8 bits per colour channel) or less, Leica Cyclone includes a default "Tone Mapping" algorithm.

HDR imaging with scanners has been utilised by customers in one form or another since at least 2009 [4]. Technically the full dome image sets from Leica ScanStation scanners have, since 2004 with the release of the HDS3000, been High Dynamic Range, as they are composed of many images with variable exposures and considerable overlap. Various methods for displaying this wide dynamic range information (Tone Mapping, in various forms) in Leica Cyclone have been introduced over the years, such as the Blend Multi-Images function released in 2012, which smooths the transitions between images. The P-series scanners, however, are the first to offer an explicit HDR mode integrated with the image assembly and tone mapping process in Cyclone, with the goal to greatly reduce HDR halos.

Figure 2: Gustave Le Gray HDR Image from 1850's **[2]**.

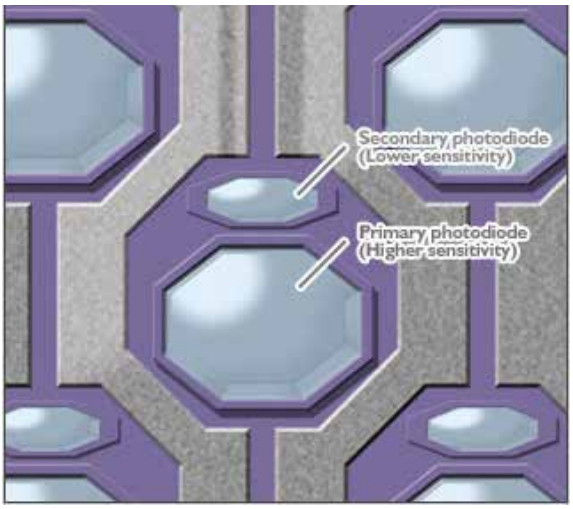

Figure 3: Example HDR Imager: Fuji SuperCCD high dynamic range image sensor [3].

3. HDR Imaging on the Leica ScanStation P-Series Scanner

The P-series scanner comes equipped with a factory calibrated internal camera which is employed for the HDR imaging mode. The factory calibration identifies both how the camera is mounted in the scanner and the properties of the lens to approximately within the Bayer pattern uncertainty. Internally the camera in the scanner, like many colour cameras, is composed of an array of repeating blocks of individual detectors of different colours. The scanner has 2x2 pixel blocks of detectors of different colours called a Bayer pattern; these blocks define a target uncertainty for the camera calibration. At this level of fine level of performance every scanner, camera, and lens appears unique and hence meeting this quality standard requires each scanner manufactured by Leica Geosystems to be individually calibrated. Once calibration is completed these parameters are stored internally by the instrument and are used by the instrument and by Leica Cyclone to correctly locate the imaging pixels with respect to any scan measurements collected.

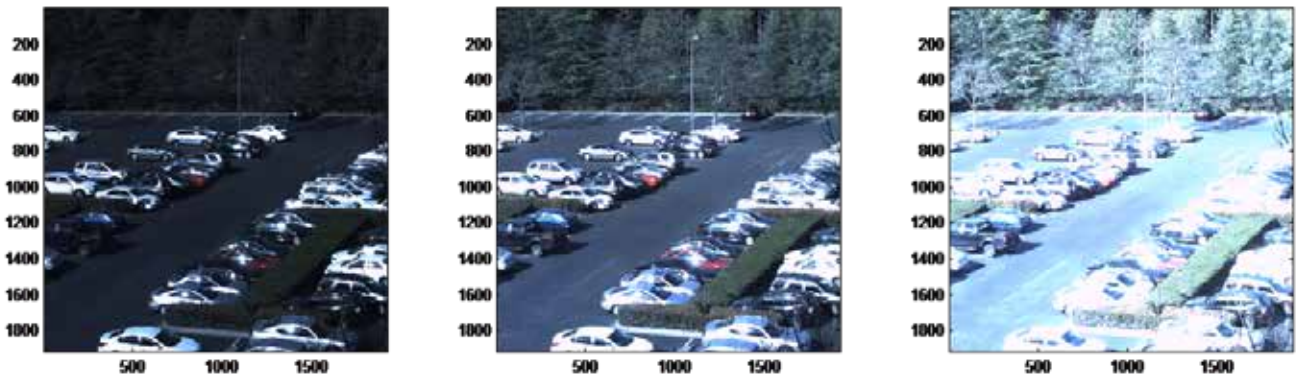

Figure 4: Collection of multiple images for a Leica ScanStation survey-grade scanner.

HDR photography involves taking multiple images at different exposures and combining them into a single image with greater dynamic range – that is, capturing detail both in the shadows and in the bright. The more images taken, the greater the span captured, but also the time required for capture grows. The P-series HDR mode represents a measured compromise between acquisition time and resulting image dynamic range, tested over a number of iconic scanning scenarios.

As seen in Figure 4, collecting an HDR image on the scanner is similar to collecting an HDR image on a standard digital camera with a few important exceptions – first, HDR imagery on the scanner will involve not only the assembly of images pointing the same way, the common notion of HDR, but also the assembly of many such combined images where each of the combinations are pointing in different directions, or "stitching". Image stitching used in panoramic photography

as it is usually performed is out of question for a survey grade product like the Leica P-series scanner, because the pixel locations should not be moved to make the images look right – the stitching must have a measurement basis and be right.

Because the P-series scanners are first and foremost surveying instruments, the internal camera is designed to support long distance target acquisition. The surveying orientation drives the factory calibration – a user needs to be able to accurately pick out a target from the video stream at distances on the order of 100 metres. The consequence, however, is that the field-of-view of each camera image is relatively small, coupled with a high imager resolution. This means a full dome image set consists of a large number (260) images. In HDR mode, the number of images is simply multiplied. This challenge is managed by combining the different exposure images on the scanner during the acquisition process.

Whether taking regular full dome image sets or HDR image sets, the resulting number of images saved by the scanner remains the same. When HDR imaging mode is engaged on P-series scanners, the scanner takes multiple images as needed at each imaging position and these images are combined and saved on the scanner in a JPEG XR, or JPEG extended range, format. This format, provided by Microsoft and available in recent versions of Windows, preserves the high dynamic range information with a comparable file size to standard JPEG image files. Many HDR image formats were considered for the P-series scanners but JXR appeared the best blend between file size and fidelity. Hence a full dome image set in HDR results in 260 JXR images; a full dome image set in normal mode results in 260 JPEG images.

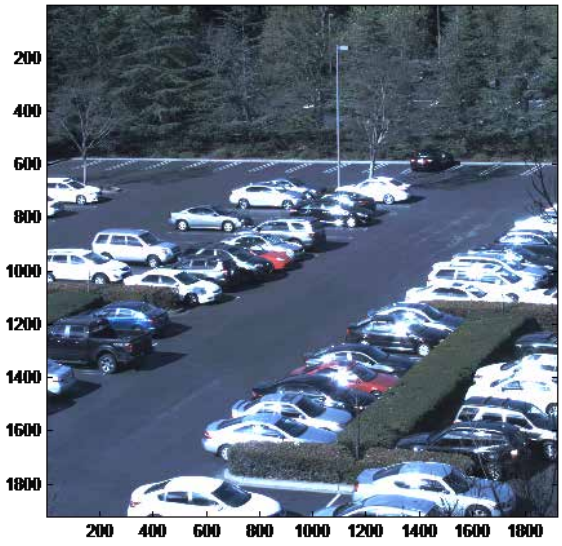

Figure 5: A combined HDR image in Microsoft® HD-photo format, labelled with the JXR extension. The image is linearly tone mapped in order to be displayed in the figure.

4. HDR Imaging in Leica Cyclone

From the point of view of the import, the normal image data sets and HDR data sets appear very similar. When JXR images are found in the place of JPEG images, however, Leica Cyclone converts all images into an HDR image assembly and then applies a tone mapping algorithm to produce the multi-image. This additional processing includes the image blending and mixing and requires scan data and some additional minutes on the import. The result is a cube map set of images aligned to the scan data. Steps in the process are shown in Figure 6.

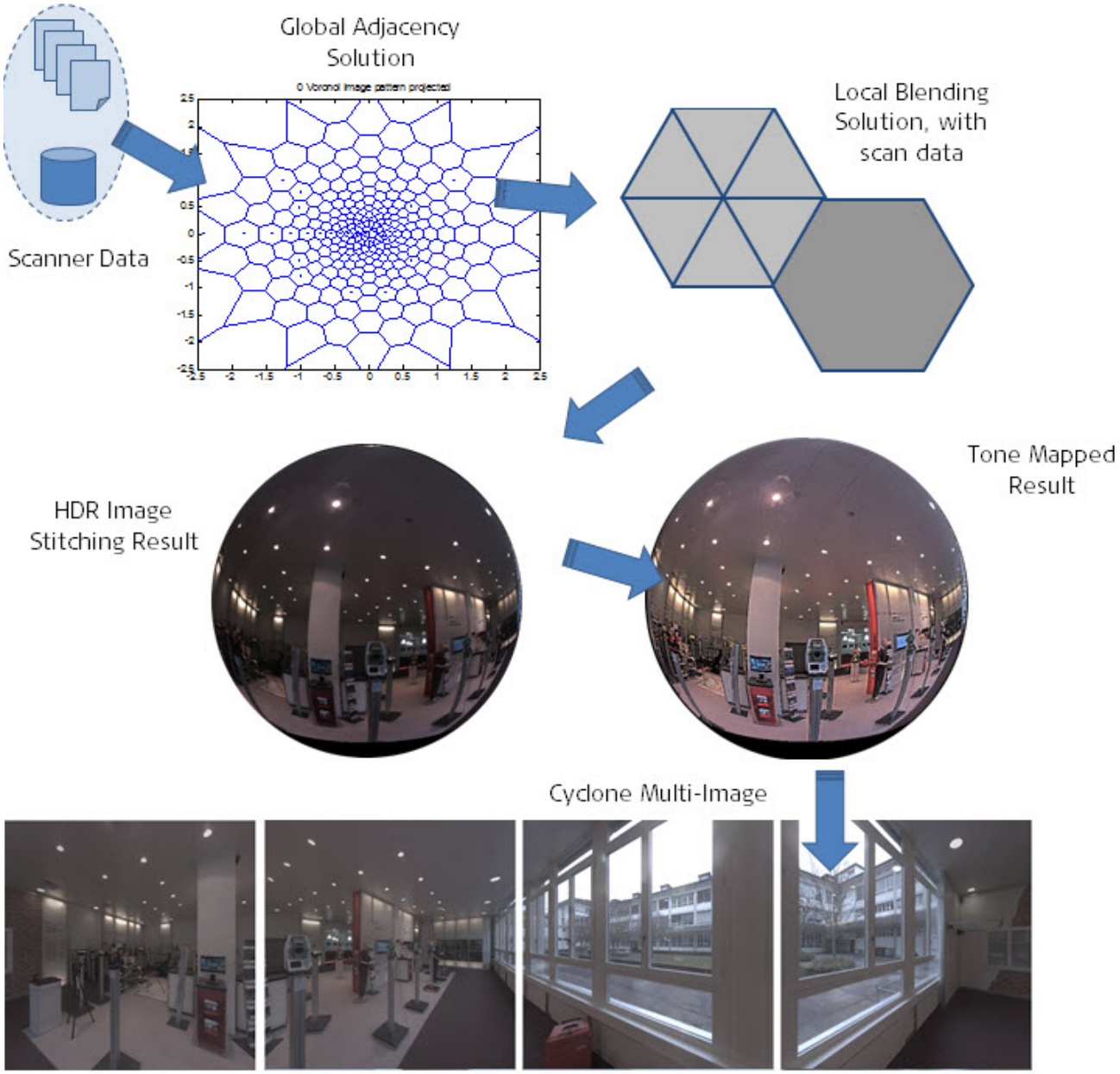

Figure 6: Imaging import in Leica Cyclone, with the Leica Geosystems Showroom as an example data set in default resolution. High resolution (96 megapixels) tone maps are also available.

Without scan data, Leica Cyclone will convert the JXR images into JPG images and process the data set as a normal low dynamic range image set, resulting in a normal multi-image with up to 260 sub-images. This LDR bypass can be selected in Cyclone even when scan data was acquired through the Cyclone import preferences. The preferences also include the ability to increase the HDR cube-map multi-image resolution, with an impact on import time.

When images are imported into Leica Cyclone, first Cyclone solves for the relative placement of the images building an image network by projecting image direction normal to the plane using the Riemann sphere, taking advantage that the camera cannot be pointed down. A Voronoi cell diagram is built and back projected to the sphere, forming blending triangles and edges, which are used subsequently in the stitching and blending process together with the scan data.

Critically, the factory calibration and scan data are used by Leica Cyclone to assemble the panoramic image assembly instead of feature detection and matching as is perhaps normally done because with the internal camera we know in advance the camera positions and lens distortions to a known uncertainty, unlike with traditional panoramic image assembly. We also have the advantage of scan data to properly select image source pixels for mixing. In this way, alignment of the HDR panorama and the scan data is maintained to factory level accuracy.

The image stitching, blending, and tone mapping processes integrated into Leica Cyclone 9 are required to make full use of the HDR imagery acquired by the scanner because applying tone mapping on each of the individual images produces an ugly result – very often large bright and dark areas of the world span multiple images and can only be identified properly on a clean image assembly. For this reason Leica Cyclone first assembles an HDR panorama preserving the dynamic range information acquired at each image position, and retains the HDR panorama internally. The HDR panorama can then be appropriately tone mapped to a panorama that can be displayed.

5. Summary

The Leica ScanStation P-series scanners together with Leica Cyclone 9 support an HDR image capture and processing mode. This new mode involves the scanner taking multiple images at each image position and requires matching scan data to be collected. It is recommended to collect only ("target all") full dome image and scan sets in HDR, with the scan and image data taken at medium resolution. Cyclone fully supports the imaging mode by image stitching in HDR the source images using the scan data and tone mapping the result so it can be displayed on normal computer monitors, as well as used to colour point clouds.

Figure 7: Tone map of the Atrium at the San Ramon, California office of Leica Geosystems.

Some key points to remember about HDR Imaging with the Leica ScanStation P-series scanners:

(1) HDR imagining mode takes additional time because additional data (images) are being collected by the scanner and merged on-board to save space and time.
(2) HDR images are stored in extended JPEG format, or JXR, on the scanner.
(3) It is recommended to only take full dome images and scans with HDR data sets.
(4) Medium resolution images and scans produce good quality results.
(5) A high resolution import mode is available, resulting in a 96 Mega-pixel full dome.
(6) Because scan data is used in the image stitching process in Leica Cyclone, defects in the scan data will result in image defects.
(7) Leica Cyclone's image stitching process does not involve feature detection and matching like most panoramic image assembly packages because the camera exterior and interior orientations are known apriori and in addition scan data is available, resulting in imagery with controlled uncertainty.

[1] Richard Szeliski, 2010. Computer Vision: Algorithms and Applications (Texts in Computer Science). 2011 Edition. Springer.
[2] Wikipedia contributors. "High-dynamic-range imaging." Wikipedia, The Free Encyclopaedia. Wikipedia, The Free Encyclopaedia, 4 Jul. 2015. Web. 13 Jul. 2015.
[3] Fuji Super CCD, Web 13 Jul. 2015 http://mydigitalcamera.us/fuji-super-ccd/
[4] Justin Barton, "HDR Photography: Digital Preservation Technologies", CyArk, Web 1 Jan. 2010, http://www.cyark.org/education/hdr-photography

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Leica Geosystems AG
Heerbrugg, Switzerland

www.leica-geosystems.com

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