TECHNICAL PAPER

Archiving Color Images to Single Strip Black-and-White 35mm Film—The Visionary Archive Process

By Sean McKee and Victor Panov

For decades, color motion pictures have been archived for long-term preservation storage by separating the three primary color components that when combined make a full-color image, yellow, cyan, and magenta, known as YCM separations, and recorded each color channel onto a black-and-white strip of film, also known as a "3-strip." Black-and-white film stock is known to have a longer shelf life with less degradation than color film stock. This archival process is the same whether the movie was shot on film, or with modern digital cinema cameras. In the case of stereoscopic 3D movies that contain left-eye and right-eye content, a total of six strips (three for each eye) would have to be made for archival purposes. Ultimately, a future generation would be able to take these strips, recombine them (called registration), and view a full-color movie.

This process is costly and has inherent, age-related deficiencies. It is possible that each strip of film will decay or warp at a different rate over time. If even one strip is warped, the registration of the three color channels will not line up, causing color fringing in the images, which requires additional processing to correct.

The Visionary Archive* process eliminates the need for a strip of film for each color channel. By using proprietary software, a full-color 4K motion picture frame is digitally encoded into a specially designed multichannel color space. This creates a recording of the black-and-white version of the image to a single strip of black-and-white film stock. This black-and-white image contains all the color information for all three color channels, encoded within, for instance, an RGB intra-pattern mosaic. This process requires one-third the number of resources as the traditional method, at both the recording stage and the re-scanning and recombining color registration stage. In fact, no color registration is required. Traditional 3-strip methods introduce three layers of film grain to the recombined image; whereas this process introduces one.

When an archivist wants to view a full-color, archived film, he or she simply scans the one strip of black-and-white film via traditional film scanning methods. The footage is then processed using an algorithm based on correlation information between the pixels. De-mosaicing is one such possible algorithm, and a freely available method. A variety of approaches are available to use when creating a de-mosaicing algorithm, with differing quality results. A de-mosaicing service using a proprietary version of an algorithm will be offered, but the end user is not tied to any one de-mosaicing solution.

The initial solution to archive the image takes the following steps:

1. The image is divided into groups of N x M pixels (where N >0, M >0).
2. For each pixel in the group only one color value is kept, and the others discarded according to some rule. One example of such a rule is a mosaic pattern filter, in which each group is 2 x 2 and one pixel keeps a red value, one a blue value, and two others a green value.
3. The resulting image is recorded on the media. Because the image contains only a single value for each pixel, it can be recorded on a broad range of media types, such as black-and-white film. Each value for the pixel can be recorded in "analog" and/or "digital" form.

To reconstruct the image (**Figs. 1-3**):

4. The single-channel image is retrieved from the media. In the case of the black-and-white film, a common film scanner can be used.
5. Using an algorithm based on correlation information between the pixels, all missing values for each pixel are restored. One such algorithm is demosaic and is commonly available.
6. The image is converted back to the original color space.

Although unarchiving via this method proved to be successful, variable difficulty in unarchiving was introduced in some footage, based on the contrast of the film recording and scanning (using lower contrast makes it more difficult to recognize the mosaic pattern in the green color channel) and the amount of grain.

The initial pattern used was a four-pixel square with a GBRG arrangement. To guarantee successful unarchiving, a new method was devised to arrange each of these unique color pixels/color channels in its own quadrant of the film frame, as shown in **Fig. 4**.

*Visionary Archive is a trademark. Patent pending.

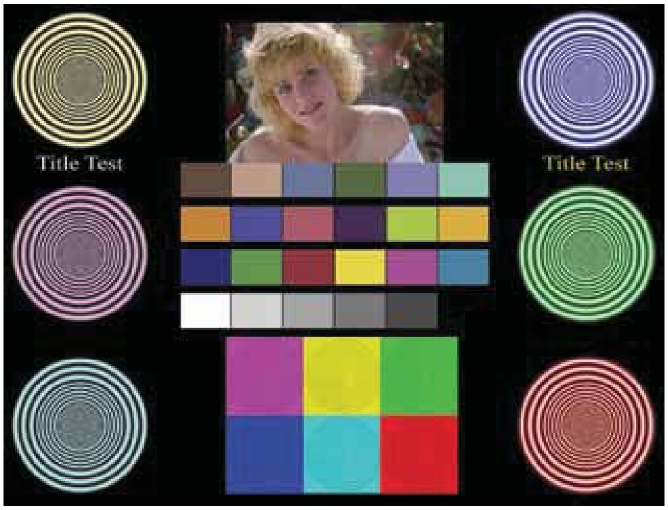

Figure 1. Source image.

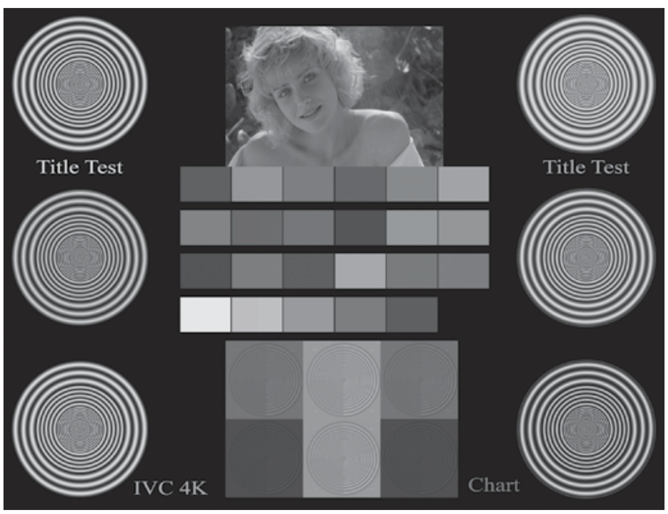

Figure 2. Color space conversion and RGB intramosaic pattern applied.

Figure 3. Close-up of mosaic pattern.

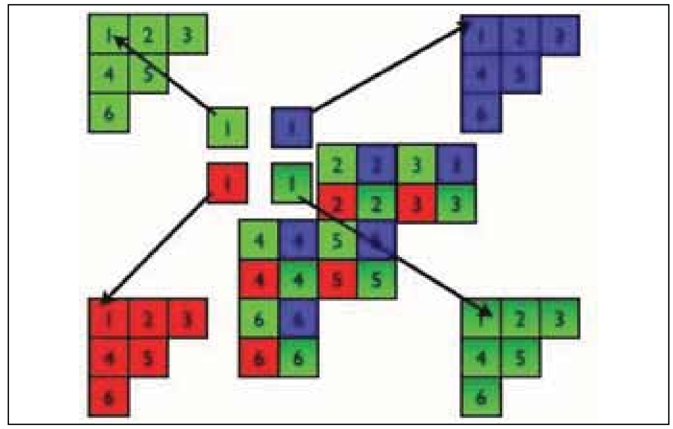

Figure 4. Separating color channels from mosaic pattern into quadrants.

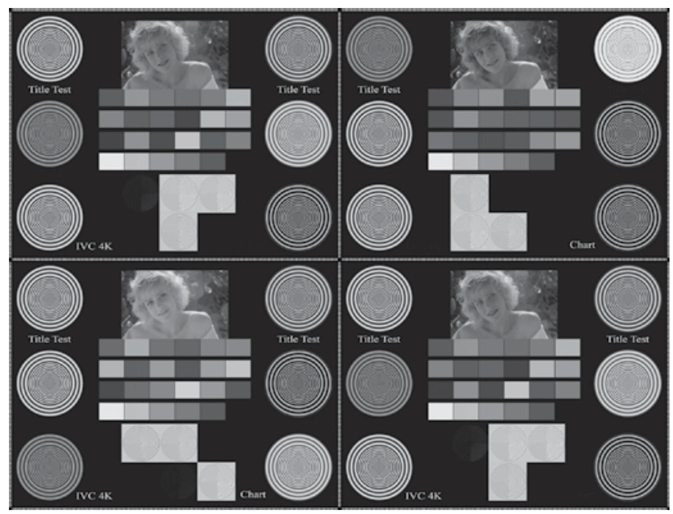

Figure 5. Final image with alignment patterns, to be recorded to film.

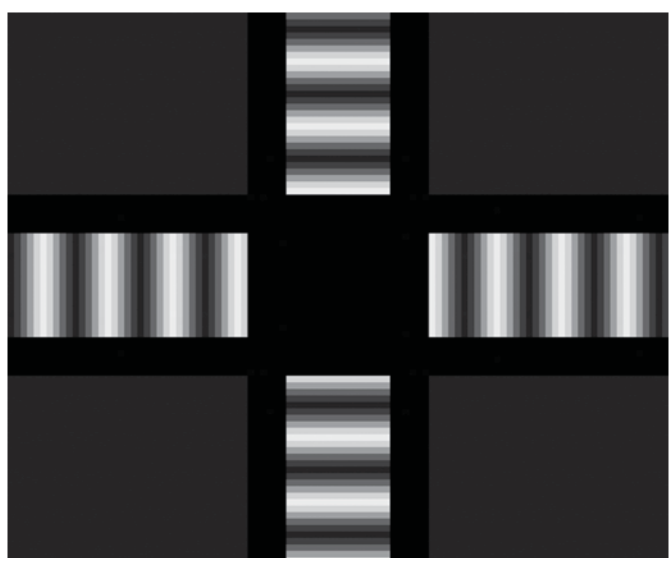

Figure 6. Close-up of repeating calibration /alignment patterns.

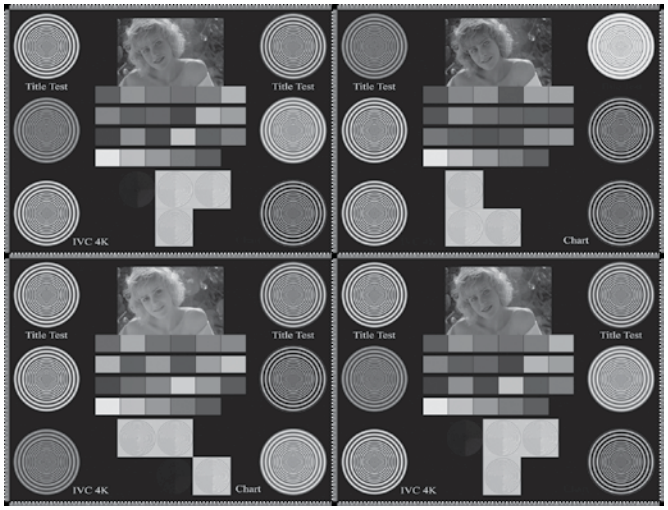

Figure 7. Final calibration patterns.

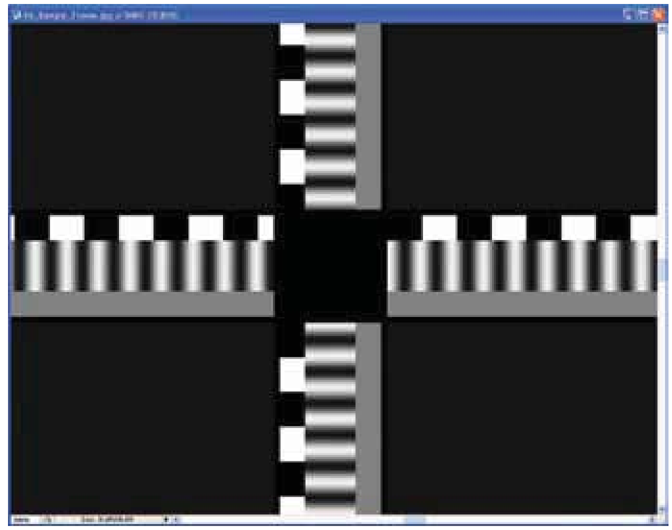

Figure 8. Close-up of final calibration patterns.

Figure 9. Original source (left), YCM separations recombined (middle), Visionary archive (right).

A means of calibration and alignment was also devised to ensure pixel accurate recreation of the image, with no registration errors. A computer-generated, sine wave pattern based on prime numbers was created, which encompasses and represents each pixel in the recording and is placed as a cross hair between the color channels, and as an outline border around the entire frame (**Figs. 5 & 6**). By applying this method, an added benefit is that, for instance, in 100 years when the film is unarchived, it is assumed that the film has warped over time. If it is possible to get the warped film through a scanner, the software will be able to recognize the alignment patterns, and effectively de-warp an image to return it to the exact composition of when it was first recorded.

Although this method worked well, it was observed that some film recorders or scanners would sometimes exhibit luminance differences across the frame. So a gray bar and black-and-white patterns were added to ensure consistent luminance, blacks, midtones, and whites (**Figs. 7 & 8**). With traditional YCM separations, future generations have no record of where black, white, and contrast levels should be. By adding these additional calibration patterns, future generations will now be able to get a much more accurate color representation of what a movie was intended to look like, without the need for further color correction (**Fig. 9**).

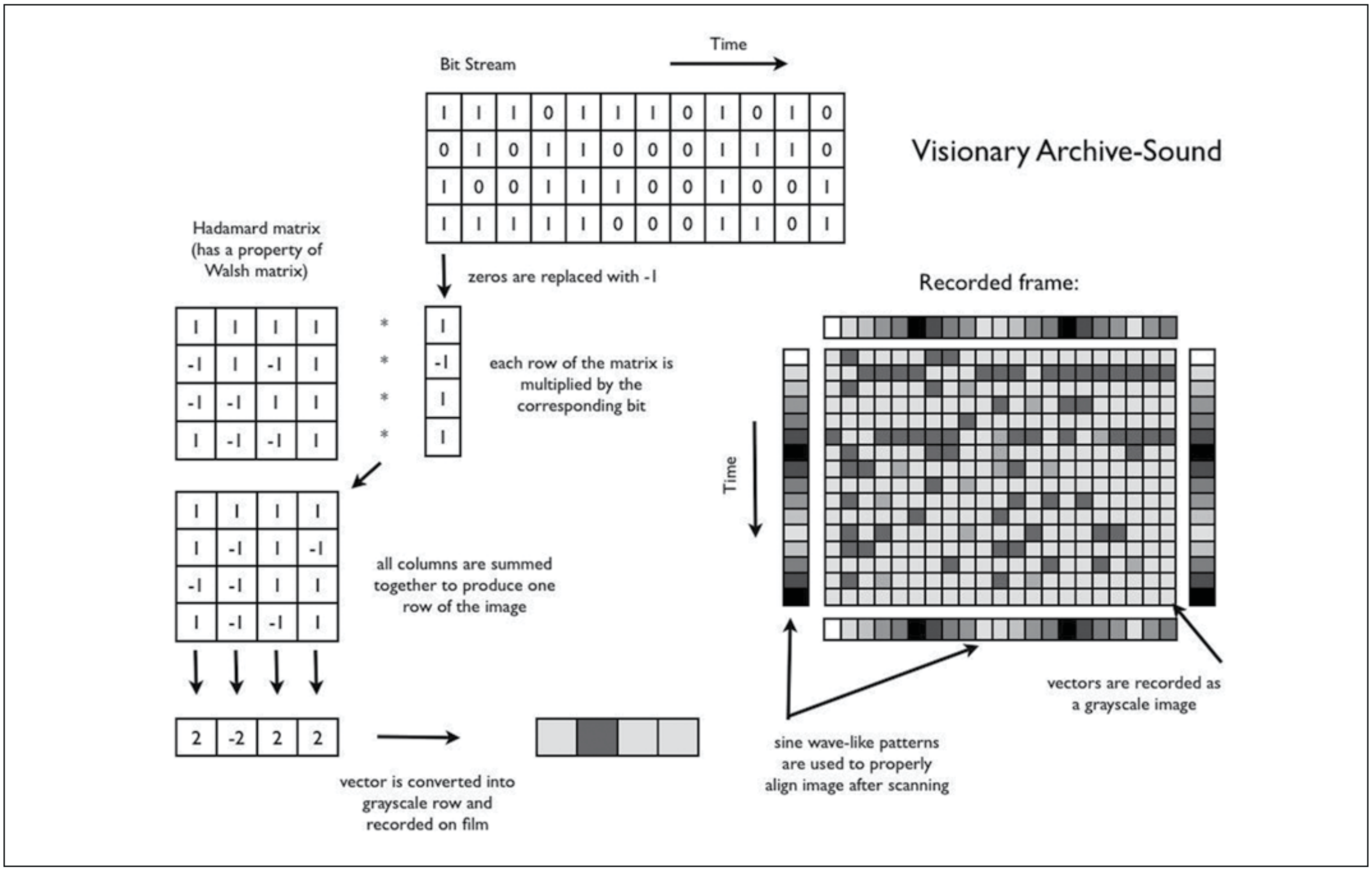

Figure 10. Visionary archive audio.

For lower-resolution images, such as high-definition or 2K, an RGB archive is achieved by recording to 4K, without the need for mosaic patterns, since the HD/2K canvas fits into a quadrant of the 4K frame. The image will still reap the benefits of all the calibration patterns as described, and because this method leaves one of the quadrants open, additional information, such as audio content, metadata, and such, can be placed here.

As for film stock/recorder/scanner requirements, the system was designed to work with any combination. Of course, the higher the quality of the devices and the finer the grain of the stock, the higher quality the results will be.

AUDIO

A method for encoding digital audio in an analog "wrapper" for use in both the available quadrant as mentioned earlier, or on the entire area of the film frame has been developed. Depending on how much of the film frame is used, and if lossless compression is applied, anywhere between 8-64 channels of 24-bit, 96 KHz can be recorded onto film (**Figs. 10 & 11**).

1. Sound is first digitized into the stream of groups of samples using common analog-to-digital conversion. Each group of samples (in the case of stereo sound there are two samples per group and in the case of surround sound there are at least six

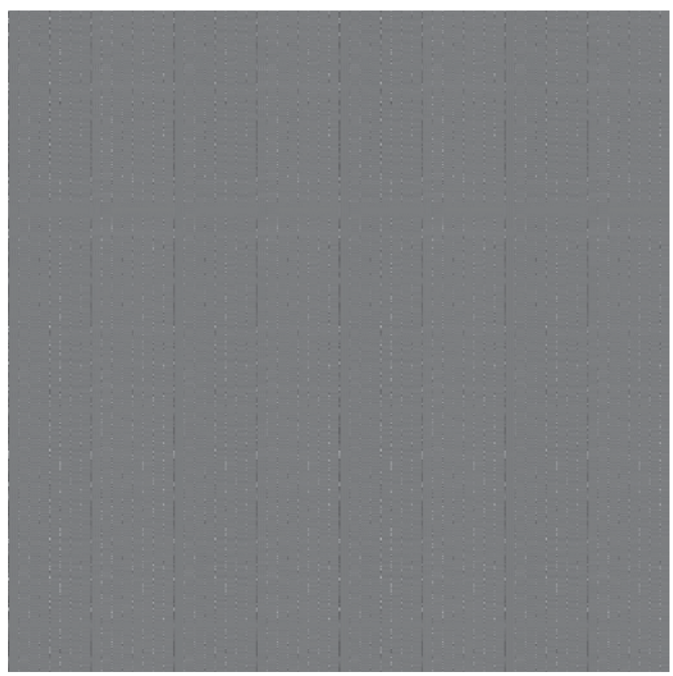

Figure 11. Visionary archive audio close-up (8 channels in 2K quadrant).

samples per group, but number of samples per group is limited only by the resolution and dynamic range of the black-and-white film and, in general, can be as much as 100 samples per group) is represented by a binary encoded integer number, which can have from 16 to 24 bits, depending on the desired resolution.

2. The Walsh matrix, which is a square matrix, is generated with a width equal to the horizontal resolution of the film and, in general, equals 2048 (the width of one quadrant of a 4K resolution image). The Walsh matrix has a unique feature, which is a dot product of two vectors generated from any two unequal rows of this matrix, equal to zero; in other words all the rows of this matrix are orthogonal. One possible matrix that has this property is the Hadamard matrix, which is used in cellphone communication.
3. Each row of the Walsh matrix is assigned to a bit in the group. For example, the first bit of the first sample in the group is assigned to the first row of the Walsh matrix. If this bit is equal to 0, an entire row of the matrix is multiplied by -1; otherwise it is kept as it is.
4. All rows corresponding to the bits of the group are summed together producing an "analog vector," with the size equal to the width of the chosen Walsh matrix. This analog vector represents one row of the image.
5. The process is repeated to all groups of samples for each time stamp and the generated image is recorded on black-and-white film. In the case of 2K resolution recording 1,556 groups is recorded in a single frame. The process is repeated for all groups of samples.
6. On the sides of the frames, a special pattern of sine like wave is recorded in order to aide in determining the position of rows and columns during decoding.

In order to decode sound (or/and recorded data) from each frame:

7. Scan film.
8. The same Walsh matrix should be generated (as in (2)).
9. In order to restore n-th bit of the group, the scanned row of the frame should be multiplied to the n-th row of the Walsh matrix. If the result is less than zero, the related bit is set to 0; otherwise it is set to 1.
10. The entire process is repeated to all bits and groups.
11. Sine-like patterns (from step 6) are used to properly align the image.

CONCLUSION

The Visionary Archive process is the first new method of archiving movies, television, and images on film in more than 50 years. Reduced cost benefits are achieved by using two-thirds less film stock, two-thirds less billable recording time, and two-thirds less billable scanning time. Benefits from archival image quality are achieved by adding only one layer of grain, compared to three layers of grain, eliminating color layer registration issues and image warping/stabilization issues.

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Sean McKee is the director of restoration and new technology for Point.360 Digital Film Labs, in Burbank, CA. In the past year, McKee and team have developed a number of proprietary technologies for both the classic movie/archival market, as well as for current productions. The most recent being Visionary Archive, a patent-pending process that allows a full color motion picture to be archived onto a signal reel of 35mm black-and-white film stock, eliminating traditional YCM archival issues. Other developments include Advanced Restoration Tools (ART) grain and noise reduction, best-in-class RAW camera image processing, automated color matching, a perceptually uniform color space, and other bleeding-edge algorithms/ software which McKee says are based on "alien" technology. For 12 years prior, McKee was CEO of Screen Time Images, a Chicago based company specializing in film restoration, rights acquisition, and distribution. McKee was the world's first user of the popular Revival film restoration system, and worked closely with da Vinci to develop the software. He has been featured in numerous interviews on national TV, radio, and industry magazines.

Victor Panov is a key member of the Point.360 Digital Film Labs development team headed by Sean McKee. He is a theoretical physicist, and high-level programmer. Before working at Point.360, Panov was part of team at the Motion Picture Marine that received a Sci-Tech Academy Award for camera stabilization hardware. He was a consultant to NASA JPL, creating communications hardware and software for picosatellites. Before that, Panov worked with Rockwell to design hardware and software devices for reliable wireless transmission. Before migrating to the U.S., Panov worked at the Kurchatov Institute of Atomic Energy of the Russian Academy of Science and the Institute of Molecular Genetics of the Russian Academy of Science, creating software for finite element model visualization and processing, hardware oriented programming for video adapters for finite element model, as well as data stereo visualization and 3D stereo graphics software and GUI design.