UNCURVE™ USER'S MANUAL

Version 1.1

Pop3DArt

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Versions history

Number	Date	Modifications
1	August 19, 2020	Release
1.1	August 24, 2020	Modified the pitch measurement procedure. Added description of install process

The content of this manual is the result of the author's research and thoughts. Every effort has been made to validate its correctness and accuracy. However, reliance on the manual content is the sole responsibility of the user.

Contents

1 Setup

1.1 Installation

Download the "Uncurve_setup.exe" file and execute it. A dialog will open asking you to choose the installation folder. The default is c:\users\<username>\MyApps\UnCurve'. If you approve the default folder, it will be created. You may choose any other folder, but any existing content in the chosen folder may be overwritten during setup.

Once the installation folder is chosen, UnCurve™ download will start. A progress bar will indicate the download progress (Figure 1). The download time depends on your internet speed, with a typical value of about 15 minutes.

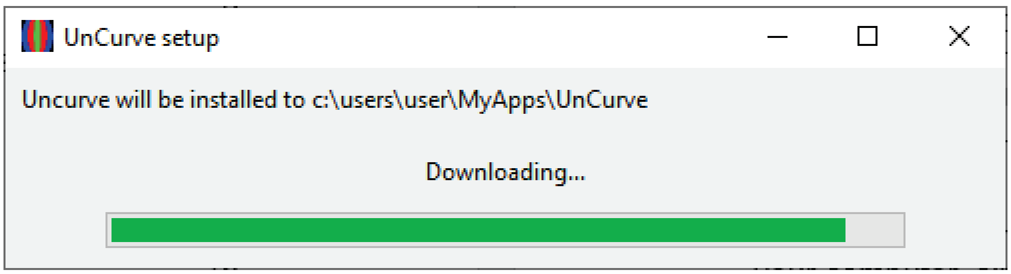

Figure 1: UnCurve™download progress bar

In the next step the setup program will extract the downloaded file, and then will install certain components in your PC registry.

The setup process can be terminated anytime by closing the setup window.

UnCurve™ must be launched from the installation folder. For your convenience, the setup program will make for you a shortcut to UnCurve.exe on your desktop, depending on your approval.

The setup program does not register UnCurve™ in the Windows Apps registry, and therefore you will not be able to see it in the Windows Apps list.

UnCurve™ does not come with an uninstall tool. To remove UnCurve™ from your computer, simply delete the installation folder (or only its contents).

1.2 Registration

When you run UnCurve™ for the first time, the product registration window will appear (Figure 2). If you have the product key, choose the first option, and enter your key. If you want to register UnCurve™ as a trial (second option), you will be able to proceed without a product key.

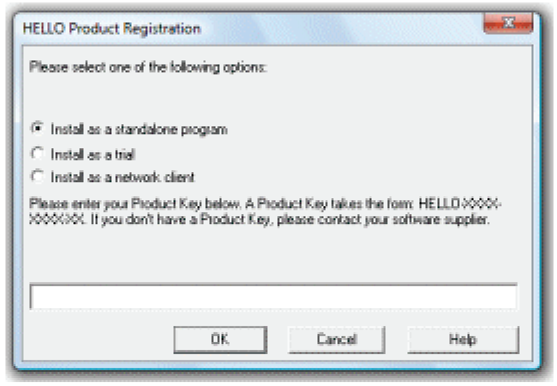

Figure 2: Product registration window

Next, you will be asked to fill in certain details about your installation, and then UnCurve™ will become ready to use.

A connection to the internet is needed to register UnCurve™. Pop3DArt does not support offline (manual) registration.

2 Overview

The quality of a lenticular picture depends on the degree of matching between the printed and the lenticular grids. If both grids are ideal, the degree of matching depends only on the skill of the practitioner. However, both grids are physical entities, and therefore cannot be ideal. The distortions of these grids set a limit to the degree of matching which can be achieved, and, therefore, they limit the quality of the picture.

In the present state of the art, the distortions of the lenticular sheet are dominant. These distortions are created during the sheet manufacturing process. UnCurve™ software solves the grids matching problem by warping the interlaced image so that it will fit the distorted lenticular grid. It is necessary to measure the distortions to apply the warping. The measurement is done using a special pattern, which is called “Fringe Pattern.” Hence, the UnCurve™ workflow consists of two main stages:

1. Distortions measurement,
2. Interlaced image warping.

The algorithms of UnCurve™ in both the measurement and the warping functions are rather complex. All their complexity is completely hidden from the user, who is exposed only to a simple and intuitive interface.

The biggest effort in the workflow is the photography of the fringe pattern (Section 5.4), which requires certain tools and setup to achieve good results.

3 Printing workflow with UnCurve™

The conventional workflow of lenticular print is shown schematically in Figure 3. The process starts with the preparation of the lenticular sequence and the pitch measurement. The results serve as inputs to the interlacing program, which creates an image ready for print.

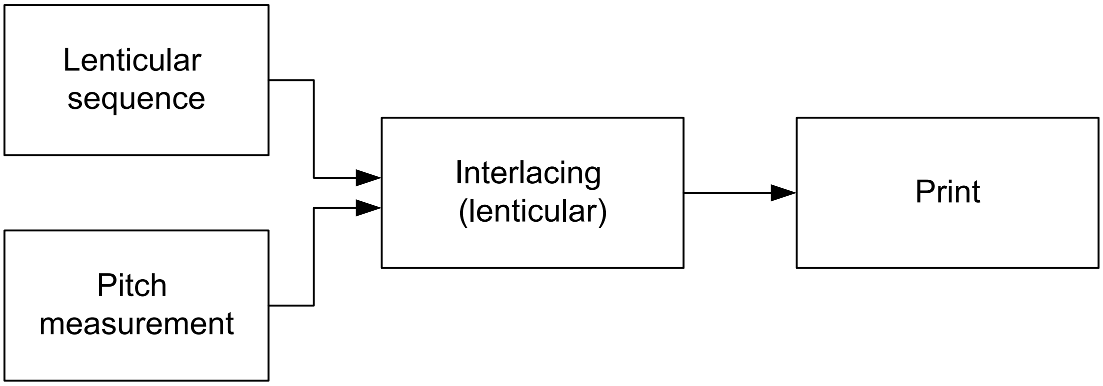

Figure 3: Conventional lenticular print workflow

The workflow with UnCurve™ is shown in Figure 4. In this workflow, the output of the interlacing program is first inputted to UnCurve™ for compensation of the sheet curvature. The output of UnCurve™ is a warped interlaced image which is ready for print. The extra steps in the UnCurve™ workflow (compared to a conventional print) are highlighted by yellow color.

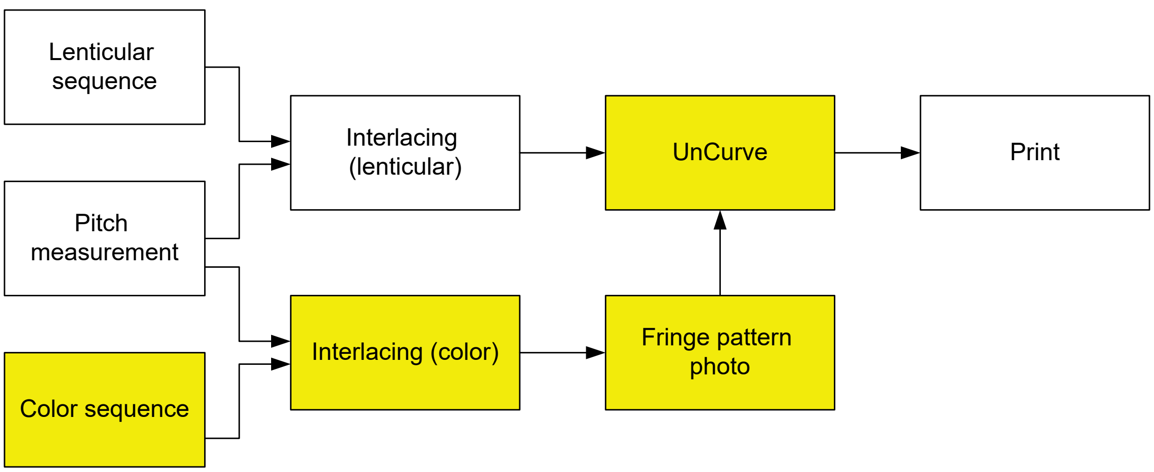

Figure 4: Workflow with Uncurve™

To accomplish the curvature compensation, UnCurve™ needs data on the lens curvature. This data is read from the fringe pattern photo. The fringe pattern is created by interlacing a special sequence, called “Color Sequence”, with the same pitch as the lenticular interlace.

To run UnCurve™, you must have both the lenticular interlace and the fringe pattern photo ready.

4 Choosing the pitch for a curved sheet

Accurate pitch setting is critical for the quality of a lenticular picture. However, one of the manifestations of sheet distortions is pitch variations over the sheet area. In such circumstances, the customary pitch measurement procedures become ambiguous.

Ideally, one should choose the pitch value which is valid for the largest area of the lens sheet. Such pitch may be called “optimal”. However, the measurement of the optimal pitch requires special procedure and analysis. Another option is to measure the pitch at the sheet center. Compared to the optimal choice it is much more straightforward. This pitch will be called “central”.

The measurement of the central pitch for a distorted lens sheet is shown in Figure 5. This sheet will be used to illustrate UnCurve™ functions and performance throughout this manual. The sizes of this sheet are 60cmx80cm. Due to the large curvature of this sheet, even the central pitch value is ambiguous, and may be chosen as 24.37/inch with a certain arbitrariness.

Figure 5: Central pitch measurement of distorted lens sheet

The choice of the pitch value determines the magnitude of the distortion. Warping is always accompanied by interpolation errors, which increase with increasing warping magnitude. Therefore, optimal pitch may yield better results than central pitch. Correct choice of the pitch value will allow the user to minimize the warping magnitude (by choosing correctly the zero-level, as explained in 6), and, therefore, will improve the results. This is the only mechanism related to the pitch choice which affects the UnCurve™ results. Other than this, Uncurve™ shows little sensitivity to reasonably small variations in the chosen pitch value.

As can be seen in Figure 5, the value of the central pitch is approximately valid in the whole left half of the sheet. Therefore, in this example, the values of the optimal and the central pitch coincide.

5 The fringe pattern

5.1 The color sequence

The fringe pattern is derived from a special sequence of images, called “Color Sequence”. The pixel sizes of the color sequence images must be the same as those of the lenticular sequence images. However, in contrast to the lenticular sequence images, the color sequence images are made of solid colors.

The colors of the color sequence images need not be unique. However, there are two rules regarding the choice of the color sequence colors. To formulate these rules, it is necessary to consider the cyclic color sequence. This sequence is created from the color sequence by replicating it. For instance, an RGB color sequence creates the RGBRGBRGB… cyclic color sequence, etc.

The first rule is that any two adjacent images on the cyclic sequence must be different and easily discerned. Therefore, a sequence like WRGBW is invalid because its cyclic sequence WRGBWWRGBW… contains adjacent white images.

The second rule is that for any image in the cyclic sequence, the colors of its left and right neighbors must be different. Thus, for example, a WK (white-black) color sequence is invalid, because in the corresponding cyclic sequence WKWKWK… each image has identical neighbors to its left and its right.

Table 1 lists the three most useful color sequences. The user can easily construct sequences of different lengths and colors on their own. Three images is the minimal length for a color sequence. The considerations for choosing the color sequence length are explained below.

Table 1: Valid color sequences

Length	Colors
3	RGB
5	RGBKW
6	RGBRGB

5.2 The color interlace

The color sequence is interlaced with the same parameters as the lenticular sequence, namely, with the same pitch and the same picture size. The print of the color interlace should have the same size as the print of the lenticular interlace.

The interlaced image corresponding to the color sequence consists of an array of identical cells. Each cell is composed of an array of colored columns, one column per each image of the sequence. Thus, the number of columns in a cell is equal to the color sequence length. The columns colors of the color interlace may be regarded as the cyclic sequence of the color sequence.

An excerpt of typical color interlace in shown in Figure 6. This interlace was created from a sequence of five solid-color images: R, G, B, K, and W. A sequential group of five columns starting with red forms a cell.

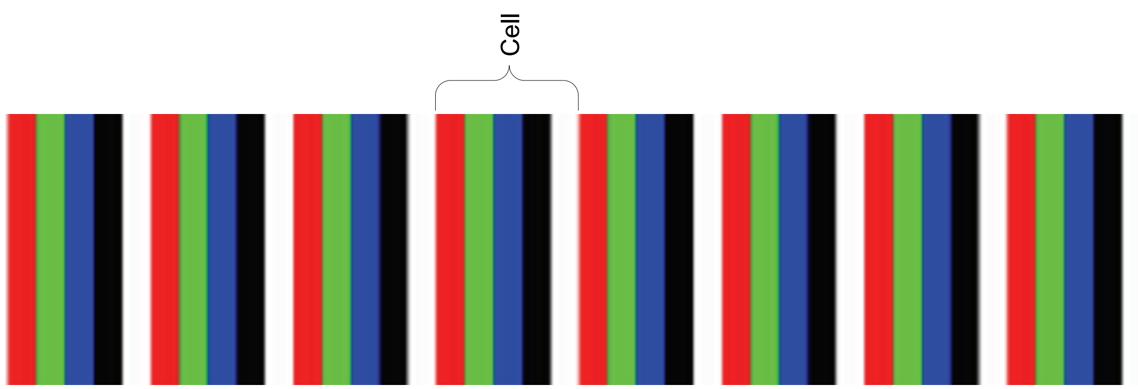

Figure 6: Excerpt from a color interlace

In Figure 6, the leftmost column of the cell corresponds to the first sequence image (red in this example). In some interlacing programs, the colors order may be reversed. The order of the colors is important, so you must inspect the interlaced image to verify the order of the colors in your interlaced image.

5.3 The fringe pattern

Next, the color interlace is printed with the same printing densities that are intended for use with the lenticular interlace. The printed color interlace size should be identical to the printed lenticular interlace size. The fringe pattern appears when the printed color interlace is covered by the lenticular sheet.

If both the printed and the lenticules grids were perfect and were perfectly matched to each other, then the fringe pattern would have displayed a uniform color over its entire area. The color of such ideal fringe pattern is always one of the sequence images colors and will change according to the viewing angle.

The lens sheet in the present example displays a pattern made of twisted bands of colors, as shown in Figure 8. A color sequence with colors R, G, B, K, and W was used to make the color interlace. All five colors are seen in the fringe pattern, indicating that this lens sheet is useless without curvature compensation.

The fringe pattern should display at least three colors for distortion correction. Longer color sequences yield more information on the sheet distortion field, and therefore allow more accurate compensation. However, a fringe pattern with too many colors may be obscure in some places and will require careful photography. A good color sequence to start with is the five-color sequence RGBKW. If the corresponding fringe pattern displays only one or two colors, then, for most purposes, the sheet can be used as is without distortion compensation. If it displays only three colors, one may consider trying a longer color sequence. If the fringe pattern displays five colors or more (as in the present example), the RGBKW sequence will be adequate for most cases.

5.4 The fringe pattern photography

It is best to put the printed interlace and the sheet stack on a light box, so it is illuminated from behind. If the sheet deviates from a planar shape, it may be necessary to put on top of it a thick glass plate, to achieve good contact between the sheet and the printed color interlace. In some cases, it may be advantageous to use an elastic foam sheet as support instead the light box, to further improve the contact between the color interlace and the lens sheet.

The curvature compensation will be most effective at the viewing distance which is equal to the photography distance. The compensation will become worse with increasing deviation of the viewing distance from the photography distance. Therefore, the fringe pattern should be photographed from the viewing distance of the real picture.

The photography setup with a light box is shown in Figure 7.

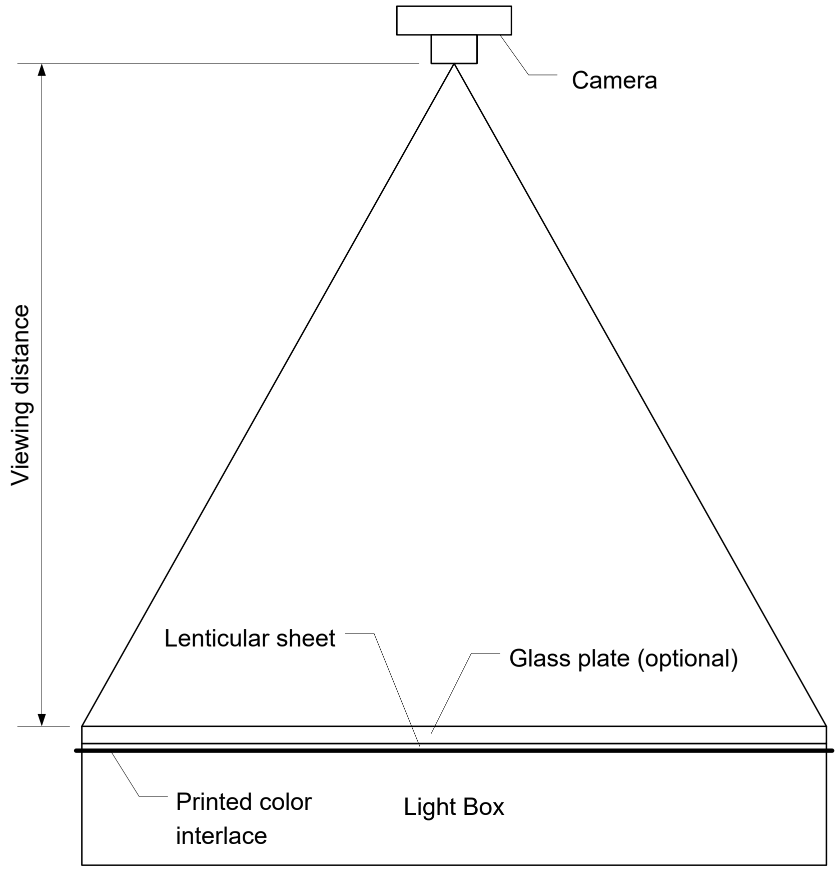

Figure 7: Photography of the fringe pattern

The fringe pattern should be photographed with a camera with low distortions. Use a professional camera if you have one. If not, a smart phone photo will usually be good enough.

The raw photograph of the fringe pattern will contain, in general, projective distortions, like keystone and rotation, as shown in Figure 8. The fringe pattern image that is used for the distortion measurement must have the same geometry as the printed lenticular picture. It means that it must be perfectly rectangular and that both must have the same aspect ratio. The rectified fringe pattern is shown in Figure 10. UnCurve™ has a built-in utility to derive the rectified fringe pattern image from the raw photograph. Note that the rectified fringe pattern contains the alignment aid margin.

The fringe pattern photography is the most time-consuming task of the UnCurve™ workflow. A good quality fringe pattern image is essential for getting good results.

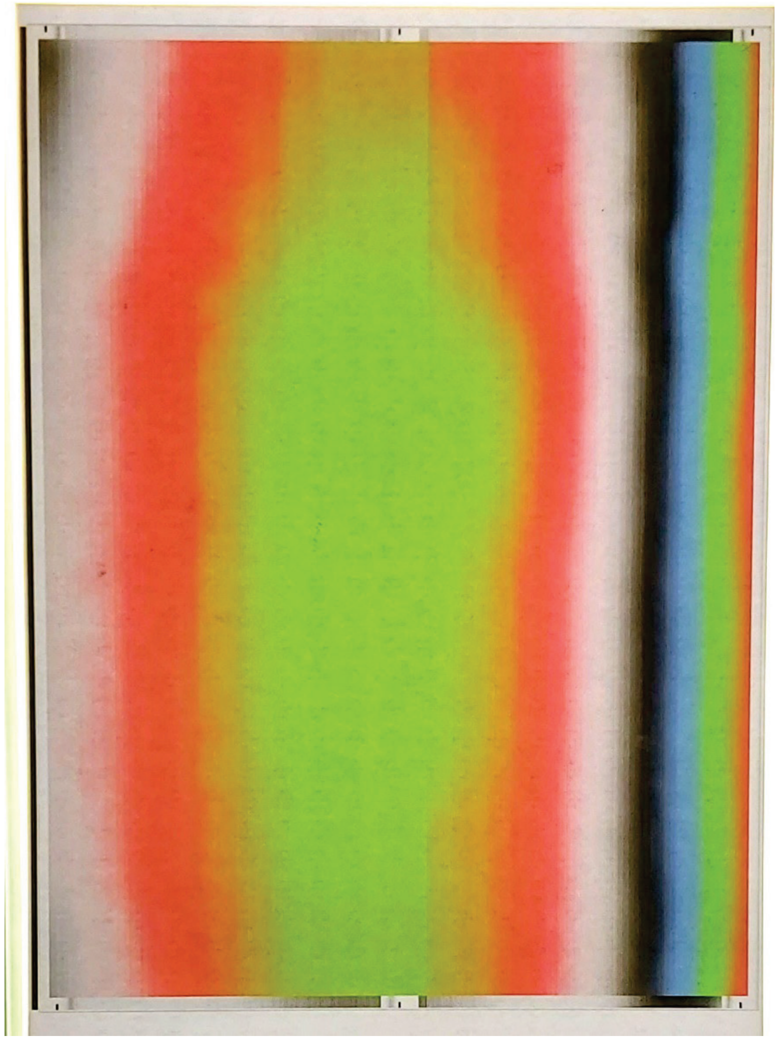

Figure 8: Raw fringe pattern photograph

5.5 Workflow with two pitch values

Ideally, the fringe pattern photography distance should be matched to the intended picture viewing distance, and both the fringe pattern and the picture interlaced images should have identical pitch settings, as explained in Section 5.4. There are, however, two instances which may require a different pitch for the color and the lenticular interlaces.

The first instance is the case in which the color and the lenticular interlaced images are to be printed with different printers. This may occur, for example, if the fringe pattern is prepared by the lens manufacturer as a service to the customers. Another instance is the case in which the viewing distance is too large for the fringe pattern photography.

Using UnCurve™ in these instances requires two different pitch values: one for the color interlace, and the other for the lenticular interlace. As noted, curved sheets do not have a well-defined pitch value, and the pitch value should be chosen using the same guidelines as described in Section 4 in both cases (either central or optimal). The workflow with two different pitch values is shown in Figure 9.

In this workflow, the fringe pattern photography distance (Figure 7) should be set to be equal to the inspection distance of the color interlace pitch measurement, instead of the real picture viewing distance.

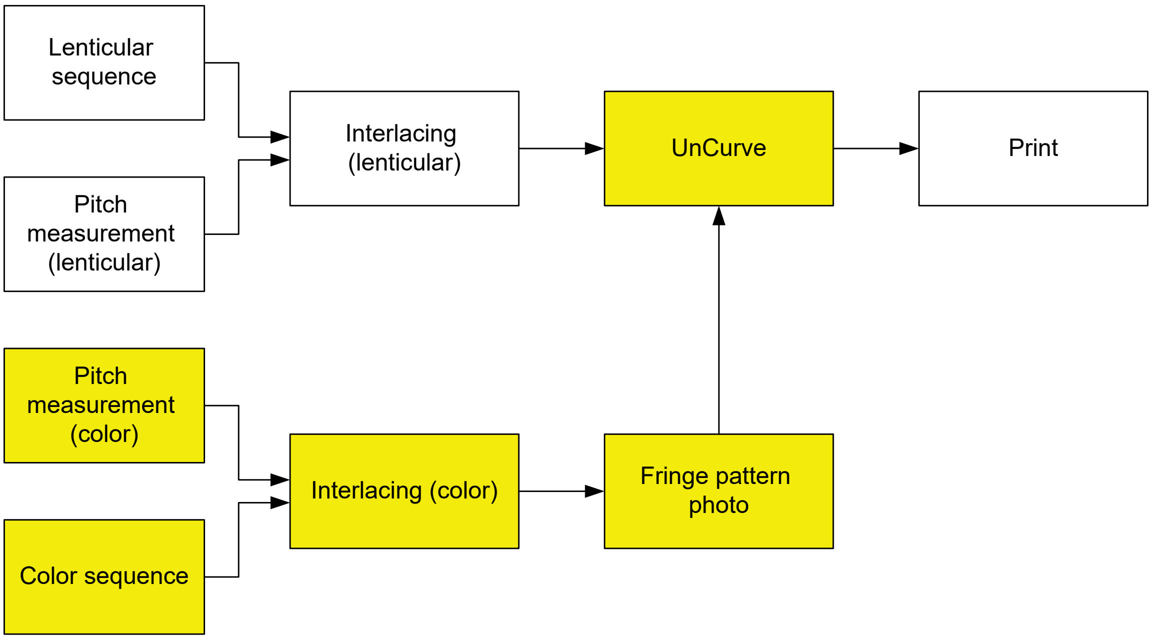

Figure 9: The workflow with two different pitch values

If both the color and the lenticular interlaces are printed on the same printer, one can use an analytical formula for deriving pitch values for different viewing distances:

$$\frac{\gamma_1}{\gamma_2} = \frac{V_2}{V_1}\frac{nV_1 + t}{nV_2 + t} \approx 1 + \frac{t}{n}\left(\frac{1}{V_1} - \frac{1}{V_2}\right)$$

The approximation is valid in the limit nV_1, $nV_2 >> t$, which is normally satisfied in practice.

The various symbols, their descriptions and units are given in Table 2. The unit “1/inch” was chosen for the pitch values, because it is the customary choice in the art. The parameters V_1, V_2, and t can have a different length unit, like millimeter, but the same unit must be used for all three.

Table 2: The variables of the pitch equation

Symbol	Description	Units
γ_1	Pitch at distance V_1	1/inch
γ_2	Pitch at distance V_2	1/inch
V_1	Viewing distance 1	length
V_2	Viewing distance 2	length
t	Sheet thickness	length
n	Sheet index of refraction	-

The pitch formula can be used in practice only as a guideline. It requires the knowledge of the sheet index of refraction *n* with a precision of four digits. This is usually unknown. Refraction index variations on the relevant scale occur in plastic materials during production and cannot be controlled to the relevant degree. In fact, refraction index variations may be one of the mechanisms causing the lenticular grid distortions.

The success of using UnCurve™ with two different pitch values depends on choosing each pitch value in the same manner in both cases. Unfortunately, there is no way to guarantee this in practice, and the success depends to a large extent on the experience and the expertise of the practitioners involved. The use of UnCurve™ with different pitch values was not tested experimentally.

6 Assignment of distortion levels to the fringe pattern contours

The boundaries between the color bands are called “contours”. These contours are used to measure the sheet distortions. The distortion level along a given contour is constant. However, different contours correspond to different distortions levels.

Let us explain the levels assignment process by considering the fringe pattern shown in Figure 10 which is the rectified version of the fringe pattern raw photo shown in Figure 8. The zero-level contour can be chosen at will.

The warping magnitude depends on the choice of the zero-level contour. As described in Section 4, it is important to reduce the warping magnitude. Therefore, the zero level should be chosen so that the maximal picture area will get a nearly zero distortion magnitude. In the present example, this is achieved by assigning the zero level to the green-red interface.

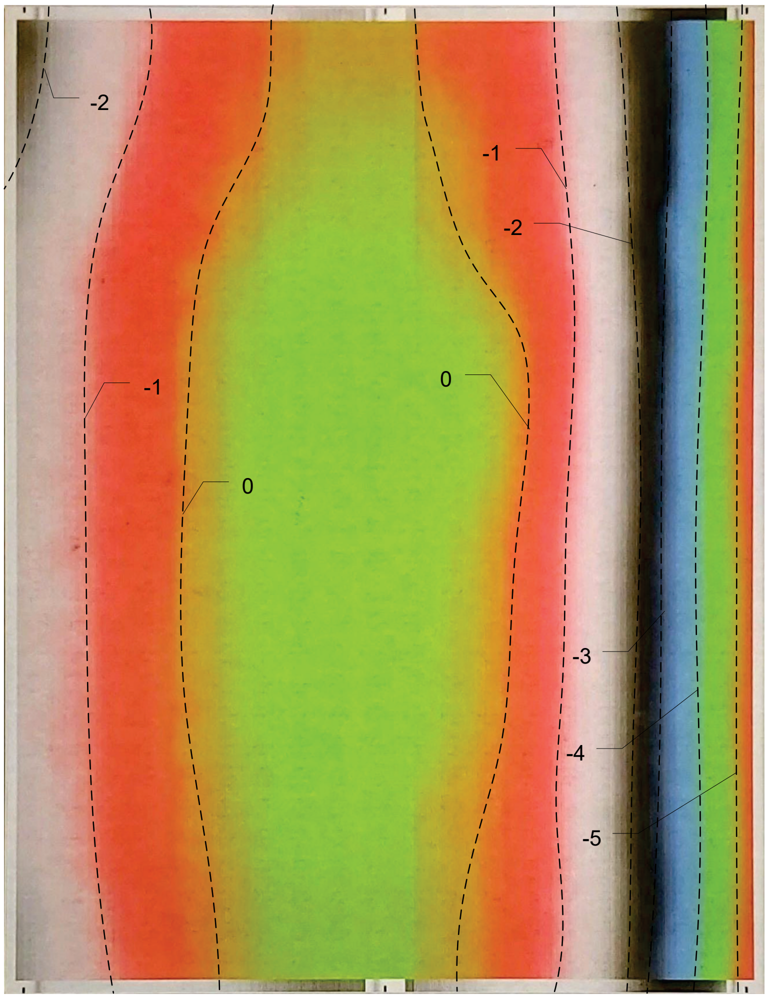

Figure 10: Fringe pattern of a curved lens sheet with contour levels annotation. The contours are shown as broken lines

Once the zero-level contour is chosen, the values of the other contours can be determined. Adjacent contours levels differ by ±1. The level assignment method depends on the order of the colors in the color interlace.

First, let us consider the contours which are adjacent to the zero-level contour. In Figure 10, the adjacent contours to the zero-level contour are red-white interfaces on both sides. In order to determine whether the level of the red-white interface is 1 or -1, one must consider the color interlace shown in Figure 6.

Adjacent color interfaces in the fringe pattern are also adjacent to each other in the color interlace. Inspection of Figure 6 reveals that the red-white interface is located to the left of the red-green interface. For Uncurve™ the value of the interface adjacent to the left is lower by one unit, and that of the interface adjacent to the right as higher by one unit. Therefore, the value of the red-green interface is -1, as shown in Figure 10.

The fact that the red-white interface is located on both sides of the red-green interface is a special case. It might have happened, for instance, that the interface adjacent to red-green on the right side would have been green-blue, in which case it would have distortion level 1. The structure of the fringe pattern contours is determined by the distortion field of the lens sheet.

The order of colors in the interlace shown in Figure 6 is such that the first image color (red) appears at the left edge of the cell. The level assignment of the color interfaces for this case in shown in Figure 11 (with the red-green interface as 0).

The level assignment for the case in which the first color appears at the right edge of the cell is shown in Figure 12. In this case the levels signs of the color interfaces are reversed. This would have led to reversing the signs of the contour levels in Figure 10, and to reversing the sign of the distortion field. Applying UnCurve™ with reversed distortion field would have amplified the distortions instead of compensating them. This is the reason why it is necessary to determine the order of the colors in the color interlace.

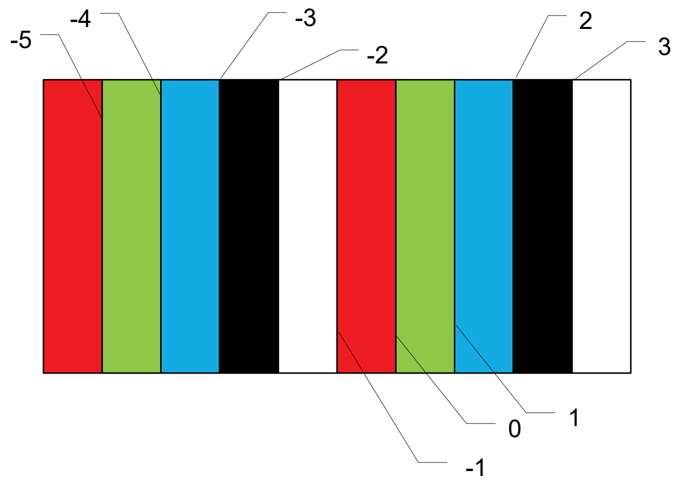

Figure 11: Color interfaces and level assignments in the color interlace: first sequence color at the left edge of the cell

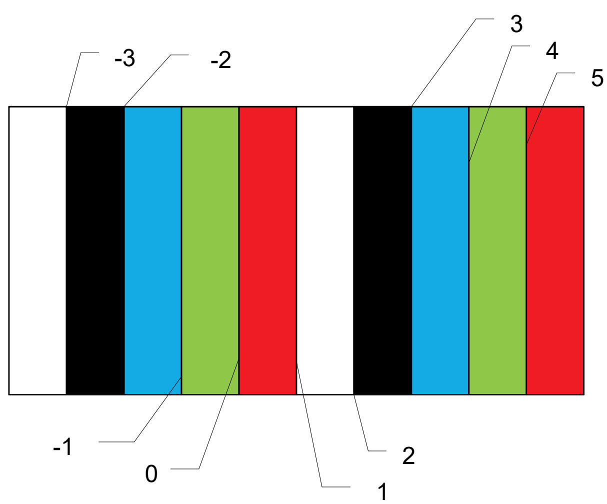

Figure 12: Color interfaces and level assignments in the color interlace: first sequence color at the right edge of the cell

Let us return now to the fringe pattern in Figure 10. The interface which is adjacent to the red-green interface, on both sides, is the red-white interface. This interface has level -1. The next interface is white-black, which has value of -2. In this manner, levels are assigned to all contours of Figure 10. In this example, all levels are non-positive. This is, of course, a special case; in general, there may be both positive and negative levels.

7 Running UnCurve™

7.1 Initial setup

When you launch UnCurve™, you are asked whether to open a job file. If you have a job file from previous runs, you can load it here. If you hit "Cancel", the default job will appear:

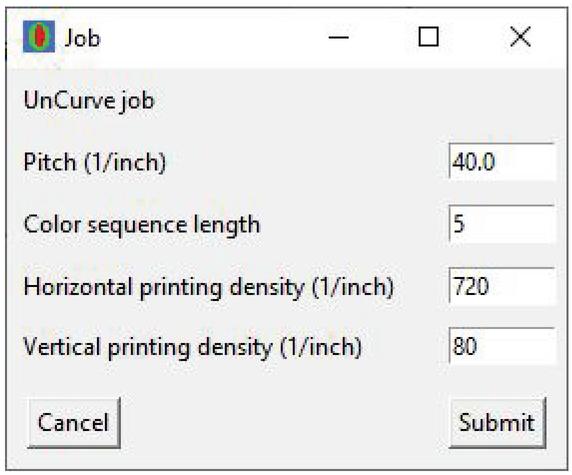

Figure 13: The default job

All entries are editable. If any entry is changed, you will be prompted to save the new job. UnCurve™ job files are text files.

The UnCurve™ job has only four parameters. The first one, "Pitch", is the pitch value that was used for the color interlace. Its units are 1/inch. The second parameter is the length of the color sequence, and the two remaining parameters are the printing densities that will be used to print the interlace. Once you are satisfied with the job parameters values, press "Submit". Pressing "Cancel" will terminate UnCurve™.

Next, you are prompted to open the lenticular interlace that needs to be warped. It must be in either .tif or .png format.

Next, you are asked whether you want to use a saved distortion measurement:

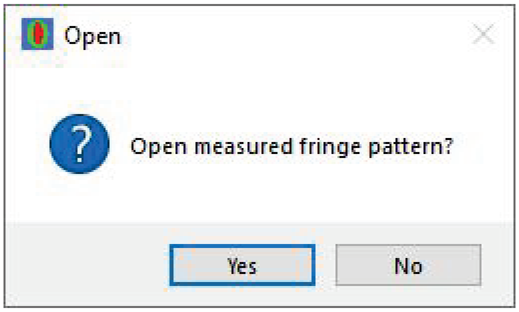

Figure 14: Open measured fringe pattern dialog

Using a previously measured fringe pattern may be useful when you discover that there is a group of sheets with similar fringe patterns (distortions). In such case, there is no need to measure each sheet separately, and the same measurement can be applied to the whole group.

7.2 The fringe pattern

If you press “No” in the dialog if Figure 14, you will be asked whether to open a rectified fringe pattern. You may have such pattern from a previous run or may have created it from the raw photograph with software other than UnCurve™. The corresponding dialog is shown in Figure 15.

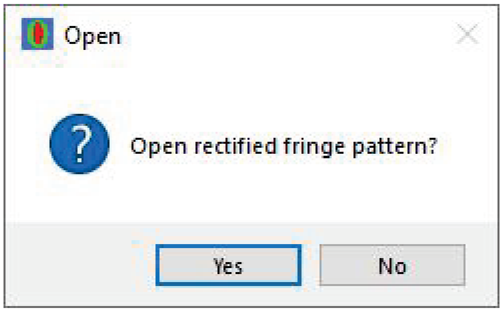

Figure 15: The open rectified fringe pattern dialog

Both the rectified and the raw fringe pattern images must be in .jpg, .tif, or .png formats.

If you press “No” in the dialog of Figure 15, you will be prompted to open the raw fringe pattern photograph, and the fringe pattern rectification utility will be launched. It will display the raw fringe pattern, and will ask you to click on its top left corner, as shown in Figure 16. When you click on the top left corner of the image, a magnified view of the top left region will be displayed, as shown in Figure 17, and you need to click again on the top left corner point. This will allow you to choose the top left corner point precisely. The process will repeat for the rest three corners.

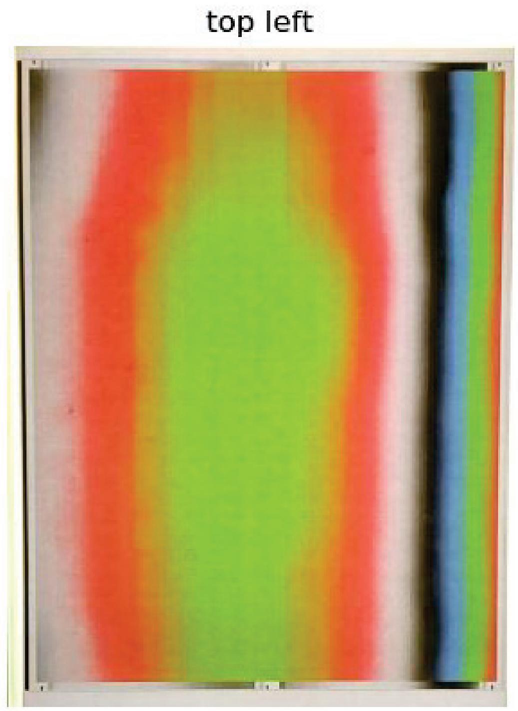

Figure 16: Fringe pattern rectification utility

Figure 17: Top left corner region magnified

It is recommended to include the alignment margin in the fringe pattern.

7.3 Contour measurement

Next, UnCurve™ launches the contour measurement utility, and the rectified fringe pattern is displayed, along with a contour measurement input dialog shown in Figure 18. Enter the number of points that you think you will need to outline the contour and its level and click “OK”. In this example the user decided to use 23 points to outline the central contour (the red-green interface) which has level value of 0.

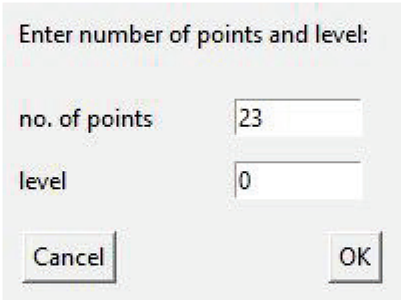

Figure 18: Contour measurement input dialog

Contour measurement is accomplished by clicking on the contours of the fringe pattern with the mouse. Each click leaves a small black cross on the fringe pattern. The measurement of the central contour is shown in Figure 19.

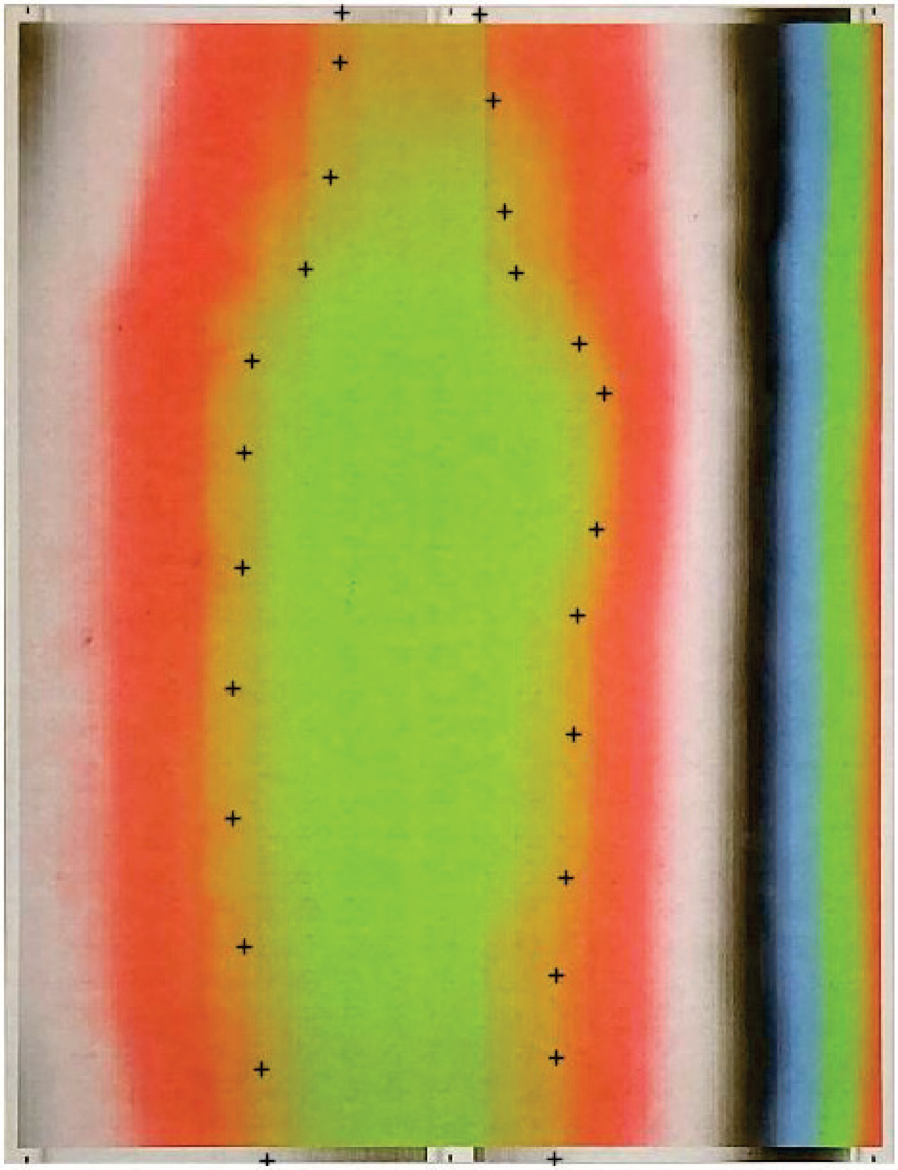

Figure 19: The measurement of the red-green interface

Once the number of points is exhausted, UnCurve™ asks whether you want to measure another contour, or you want to stop (Figure 20). Click “yes” to measure another contour. Continue this process until all contours are measured. The result is shown in Figure 21.

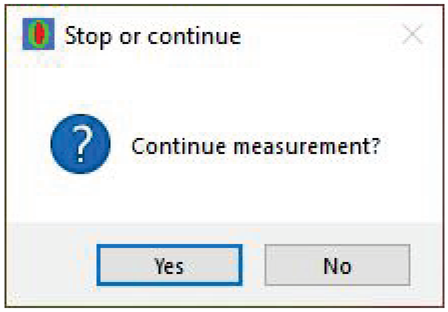

Figure 20: Stop or continue measurement dialog

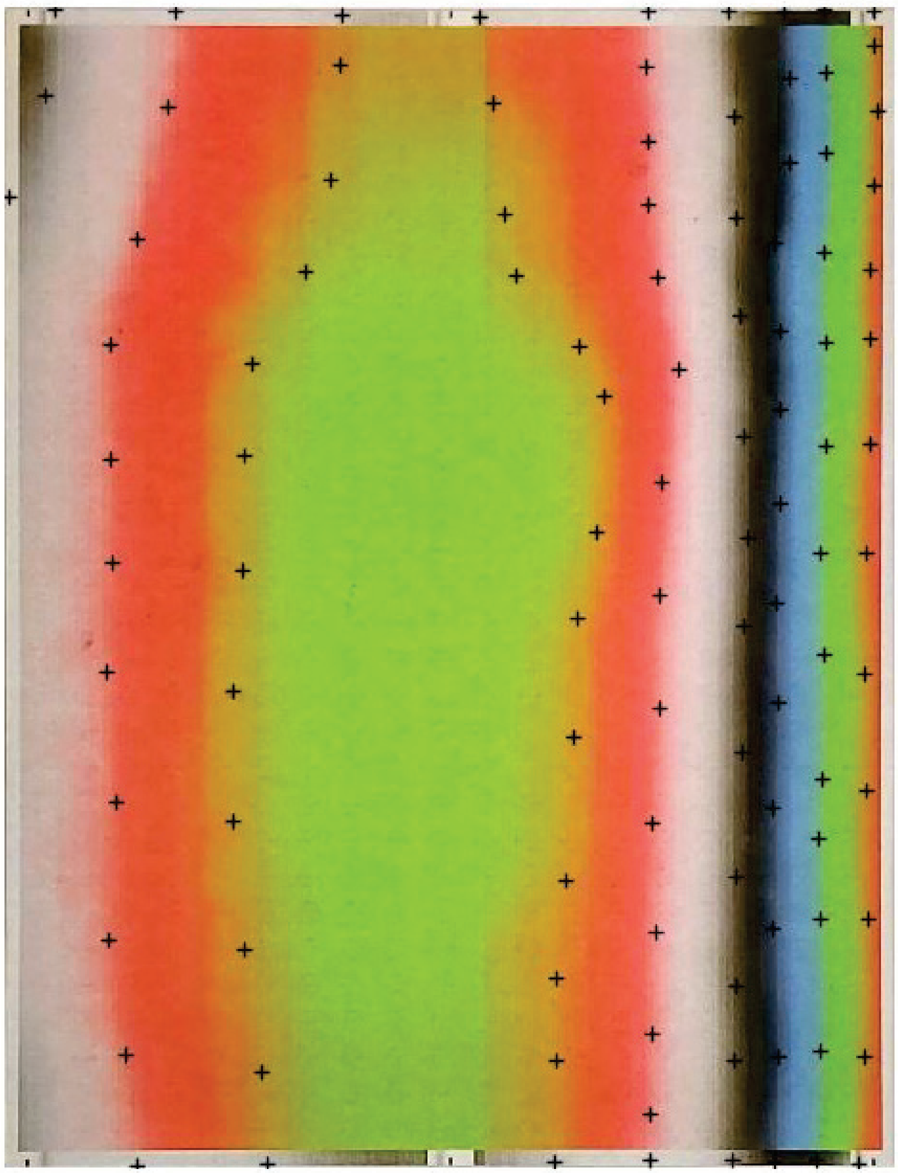

Figure 21: The fringe pattern image with all contours measured

When the measurement is completed, press “No” in the dialog of Figure 20. Now UnCurve™ computes the contours and displays them as shown in Figure 22. These contours are remarkably similar to the manually drawn contours in Figure 10.

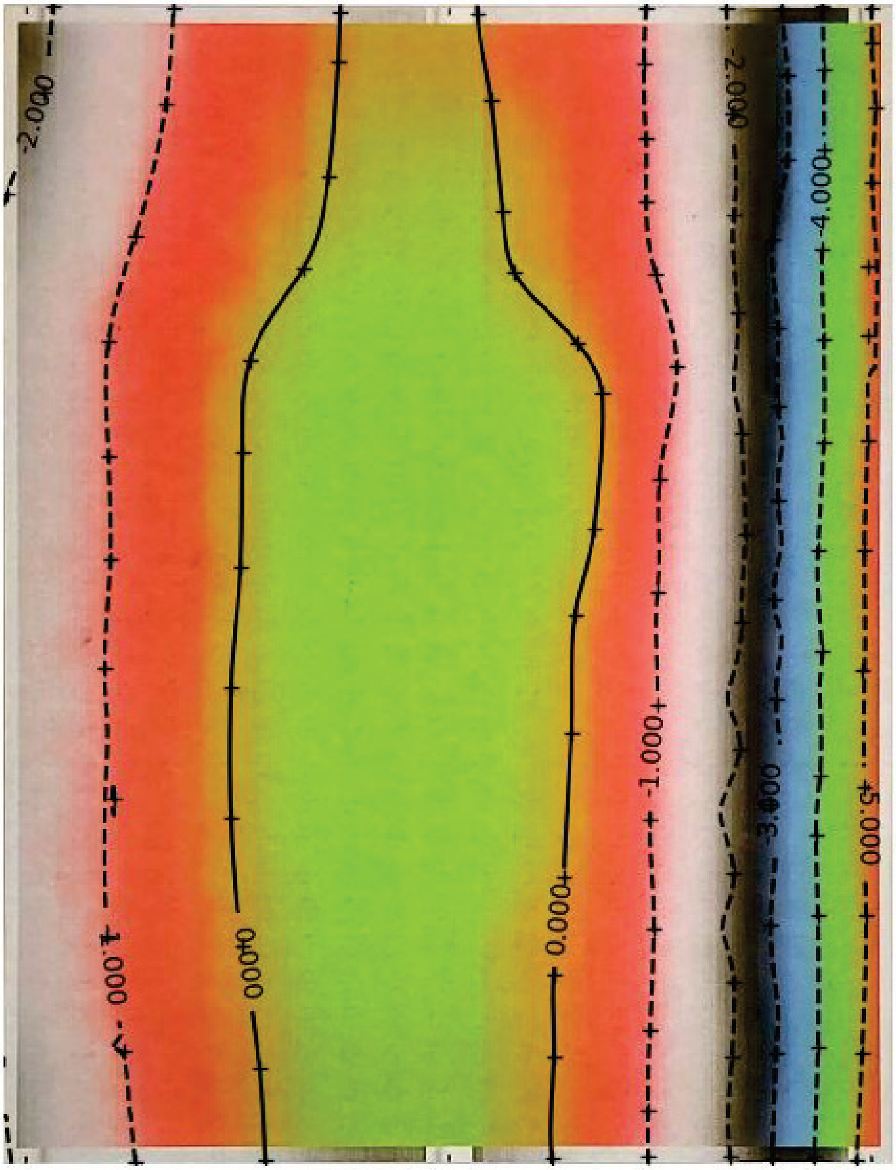

Figure 22: Measurement result

Along with the display of the results, UnCurve™ will ask whether to repeat the measurement:

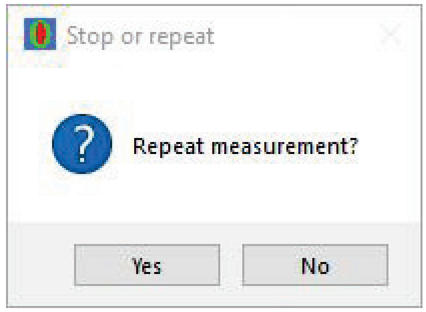

Figure 23: Repeat measurement dialog

Inspect the contours and decide whether their geometry is satisfactory. If it is, click on “No”. Otherwise, click on “Yes”, to start the measurement all over again.

7.4 Remarks for contour measurement

The measurements can be stored only after the measurement is completed. UnCurve™ does not have an intermediate saving facility, nor a measurement editor. If you click in the wrong position, you must start the whole measurement process all over again. UnCurve™ can be terminated any time during the measurement by pressing “Cancel” in the contour measurement input (Figure 18).

If the number of points is exhausted before the contour outline is completed, you can add measurement points for the same contour by specifying the same level.

UnCurve™ interpolation engine requires the measurement of at least two different levels.

Inspection of the contours shown in Figure 22 reveals that they pass through the measurement crosses with a remarkable precision. However, between the crosses there may be deviations between the computed and the real contours. An example of such deviation can be seen in the white-black contour in the right part of Figure 22. Such deviations normally do not cause any significant effect, and the measurement may be approved. The only way to remove such deviations is to reduce the distance between the crosses, namely, to use more points to define the contour. But this means that the measurement must be repeated. Furthermore, it cannot be guaranteed that deviations will not occur in a denser measurement.

Note that there are crosses in the alignment margins, where there is no contour data. This is a recommended practice, because UnCurve™ computes the contours over the whole area of the fringe pattern. Omitting crosses in the alignment margin will force UnCurve™ to extrapolate the measurement data, which may introduce larger errors. These errors, even if they occur, will be confined to the alignment margins, so will not cause any significant harm. However, it is useful to also compensate the alignment margins to assist with the alignment process of the lenticular interlace.

The level value is written as a label on each contour. Negative value contours are drawn as a broken line, whereas non-negative values are drawn as a solid line. In the present example, the only non-negative contour is the level 0 contour.

An example of a fringe pattern image is included in the UnCurve installation package.

7.5 Uncurving

As soon as the measurement is completed and approved, the uncurving process starts automatically. When the compensated interlace is ready, you will be prompted to save it. It is saved in .tiff format, with the printing densities that were specified in the job.

8 Correction area and alignment

The corrected interlace must be located in the same area of the lens sheet as the color interlace. It is a common practice to match the size of both color and corrected interlaced images with the size of the lenticular sheet, and to correct all its area. In such case, the need to match the areas is avoided. However, you must be careful to place the lenticular sheet on the corrected interlace in the same orientation as it was on the color interlace (not rotated by 180º).

If the sheet is larger than the printed interlace, it is a good practice to mark on the sheet the corners of the measured rectangle. The corrected interlace print should be positioned in this area.

9 Testing UnCurve™

The function of UnCurve™ can be tested by applying it to the color interlace itself. Such test is shown schematically in Figure 24.

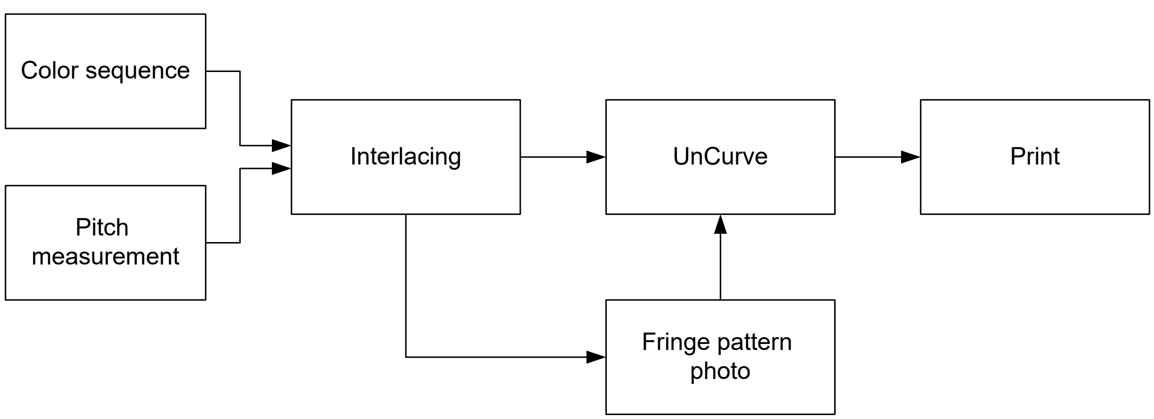

Figure 24: UnCurve™ testing workflow

In this test the interlace of the color sequence is inputted to UnCurve™ for distortion compensation. It is also printed to create the fringe pattern, which is also inputted to UnCurve™. The compensated interlace is printed and covered by the lens. This setup should behave as if the lens is free of distortions, namely, should display a uniform color.

The compensated fringe pattern in the present example is shown in Figure 25. In this view the dominant color is green, but there are traces of blue and red. The compensation is not perfect, but there is a remarkable improvement compared to the unprocessed fringe pattern shown in Figure 10.

Figure 25: Uncurve™ test

10 Support and links

In case that something goes wrong, send us an email to info@pop3dart.com and we will make our best to respond asap and fix the problem. Please include in your email the files 'uncurve_setup.log' (for problems with the setup program) or 'uncurve.log' (for problems with UnCurve).

UnCurve™ product page: https://www.pop3dart.com/uncurve-software

Blog post: https://www.pop3dart.com/post/fixing-lens-distortions