Drawing Abrasive Hologram Animations with Auto-Generated Scratch Patterns

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***Abstract*—Abrasive holograms allow people to experiment with impressive quasi-holography and create hologram artwork through simple means of creating reflective scratches on sheets of plastic. Most of the reported accounts of abrasive holography address the creation of three-dimensional illustrations. This work explores abrasive holograms for creating arbitrary holographic animations through scratch patterns. The opportunities and limitations of scratch patterns are investigated. A model for classifying abrasive holographs is introduced. The classification framework is used to derive two new scratch pattern generation methods allowing the creation of arbitrary animations.**

Keywords-abrasive hologram; scratch pattern; animation; graphics; artistic expression

I. INTRODUCTION

The concept of abrasive holograms was popularized by William Beaty in the 90s [1]. Abrasive holography allows holographic effects to be achieved with simple means. In its basic form, arcs or circles are scratched onto the surface of reflective transparent plastic plates such as plexi-glass using calipers. The back of the glass is covered with black non-reflective material. When viewed under a bright light source, a certain point on the scratched arc will reflect the light as a bright highlight. The highlight position is determined by the position of the viewer and the light source. With a fixed light source, the reflected spot will move along the arc as the observer moves the head. Such scratches also appear stereoscopic due to the different viewing angles of the eyes.

Depth is controlled by modifying the radii of the arcs; the larger the radius, the further away the point will appear. The orientation of the arc controls whether the point is below or above the drawing surface (see Fig. 1).

If full circles are drawn instead of arcs, two points appear per circle – one below and one above the drawing surface. Simple 3D shapes such as cubes can thus be easily constructed [2, 3]. Erosion holograms have been performed with other materials including metal engraving [4].

Several automatic approaches to scratch pattern generation exist [5, 6]. Regg et al. document a complete pipeline that converts a three-dimensional model into a set of scratch patterns which can be previewed and sent to a milling machine [6]. Their computer-oriented approach generates correct representations from different viewing angles as opposed to the approximate three-dimensional object representation the caliper approaches. The approach has similarities to that reported by others [7, 8, 9].

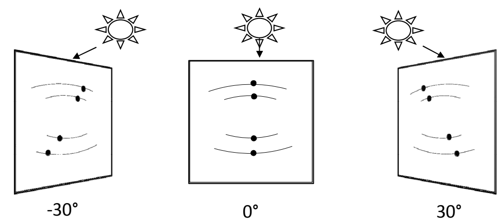

Figure 1. Abrasive hologram principle

Regg et al. also included color in the scratch holograms by calculating the color for the scratch traces and printing the resulting color map onto a plastic transparency using an inkjet printer. The color transparency is then put on top of the abrasive hologram giving reflections color. Regg et al. further proposed a technique for animations that involved an input of raster images for each key-frame. Next, a scratch was created for each visible pixel of each key-frame. Finally, the scratches of consecutive key-frames that are lit were combined into one scratch. They improved the image quality by roughening unscratched surfaces to reduce specular reflections in the non-engraved parts of the hologram.

II. BACKGROUND

Freehand drawing is an important tool in many areas. In design, sketching by hand is used to represent ideas quickly so these ideas can be communicated to others. Examples include the sketching of user interfaces [10], typically consisting of 2D representations. 3D sketching is more common in product design and architecture. However, these are usually perspective renderings from a static vantage point.

Attempts have also been made to immerse the user inside a sketch allowing the user to view an object in three-dimensions from inside extending out in all directions. This is achieved by making hand sketches in equirectangular panoramic space [11] where the world is viewed using a longitudinal and latitudinal angle [12, 13]. This space is not straightforward; it has thus been proposed to use supporting gridlines making it easy to trace lines in the x, y and z dimensions [14]. Also, attempts at automatically applying image transformation to move the viewer position have been reported [15] as well as combining panoramic sketches with real world view using an augmented reality display [16].

There is also a relatively vast body of research on techniques for turning two-dimensional sketches into three-dimensional ones such as transforming 2D sketches of 3D

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scenes into three-dimensional data [17], sketching sequences of flat cross-sections [18], using gray-levels to control height contours [19], employing color to control height contours [20]. Still, such three-dimensional models need to be viewed with three-dimensional viewing software such as a point cloud viewer [21] or three-dimensional display.

The first accounts of creating the illusion of 3D scenes on flat surfaces are the spatially multiplexed parallax displays that rely on light blocking or light directing. Ives [22] first used slits to block the part of the image at certain angles. Lippeman [23] employed a grid of spherical lenses to control which part of the image was shown at various viewing directions. The spherical lenses were later replaced by cylindrical or lenticular lenses as it is usually sufficient with the effect along one direction. Several 3D displays utilized lenticular lenses [24] and slits [25].

Denis Gabor is often credited as one of the originator of holography with his advancements in laser technology [26]. Holograms became more practical with the invention of white light transmission and reflection rainbow holograms [27], which allowed holograms to be viewed with normal light. However, the creation of laser hologram requires relatively complex equipment. Computers have also been used to design laser holograms [28]. Traditional holograms have also been used together with interactive computer graphics [29].

III. METHOD

A. Assumptions

The discussion presented herein assumes that the abrasive holograms only work in the horizontal dimension, to wit, the hologram changes when moving from side to side. This is because the most natural way to observe a hologram is moving the head from side to side or walking past the artwork. Problems associated with hologram rotation, as discussed by Abramson [2], are omitted herein.

Next, it is assumed that the abrasive holograms are viewed with a strong light source immediately above the observer, which is a common setup documented in the literature. Also, the animated images must be binary and animations can comprise points in motion, lines in motions, and changing filled shapes. One objective of this work is to facilitate creating holograms with commonly available tools, not having to rely on engravers or milling machines.

B. A Scratch Pattern Taxonomy

In abrasive holography, three-dimensional objects are built from a set of connected specular highlights caused by reflections of arc-shaped scratches. The image can thus be considered a raster image, or discrete points in the spatial domain. The arc defines the path of the specular highlights as the glass plate is moved from side to side. In a sense, these images can also be considered animations as speckles closer to the viewer move along longer arcs with a longer radius than speckles further away from the viewer. The motion of each speckle is continuous, i.e., continuous along the time-domain. We classify these holograms as discrete-space/continuous-time.

TABLE I. ABRASIVE HOLOGRAM TAXONOMY

		Spatial	
		discrete	continuous
temporal	discrete	DISADITI anti-aliased line and point motion	COSADITI line scratches hatched keyframes
	continuous	DISACOTI Horizontal movements Raster key-frames 3D-objects [1, 2]	COSACOTI Solids, not possible with scratched flat surfaces.

We explore four types of holograms where the scratches are continuous in space and discrete in time, discrete in both time and space, continuous in both space and time, and discrete in space and continuous in time. The properties of each class are also examined. The four categories can be considered a scratch pattern taxonomy comprising discrete-space/continuous-time (DISACOTI), discrete-space/discrete-time (DISADITI), continuous-space/continuous-time (CO-SACOTI), and continuous-space/discrete-time (COSADITI) holograms (see Table 1).

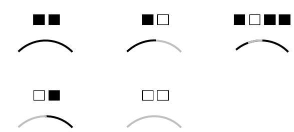

Figure 2. Raster animation with DISACOTI patterns.

C. DISACOTI patterns

An advantage of the discrete-space/continuous-time patterns is that there is a smooth transition when the hologram is viewed from side-to-side. The drawback is that the artist must draw sufficient number of arcs to give the perceived impression of a continuous line. In addition to side-to-side movements, the discrete-space/continuous-time patterns can be used to draw arbitrary animations. Imagine a set of key-frames represented as raster images, namely, pixelated images. Each pixel is thus represented by an arc. Each arc is engraved according to the state of the pixel throughout the key-frames. The example in Fig. 2 illustrates the principle where an arc is divided into two and thus coding two key-frames. If the entire ark is used, the pixel will be always on. If only the first part of the arc is engraved, the pixel will be on the first half of the animation and so forth. By dividing the arcs into more parts, more steps can be coded. The example on the right shows a pixel coded for four key-frames. If the arc is scratched for a given angle segment, the corresponding timeframe will show a lit pixel; if the given part of an arc is not scratched, the pixel will be off. This effect has been exploited to achieve blinking objects in the works of Beaty [1], among others.

Such DISACOTI patterns give animations with smooth transitions between the key-frames. However, a sufficient number of pixels is needed to achieve images with sufficient quality. The scratch patterns can therefore become complicated. Another drawback is that the entire image will move from side-to-side when moved from different direction. Still, all the pixels are moving in unison as long as the same radius is used when drawing the arcs.

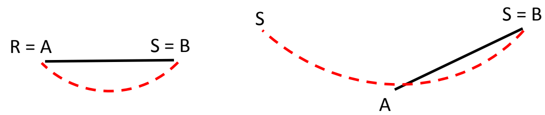

Figure 3. Impossibility of non-level time-travel along curved scratches.

Figure 4. Reducing the height of the arc by splitting the arcs in sections.

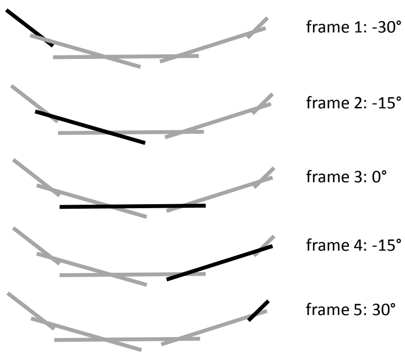

Figure 5. Using straight lines to achieve simple animations.

D. *Limitations of DISACOTI patterns*

Although discrete-space/continuous-time patterns are the most commonly used to construct 3D objects and can be used to generate raster image animations, they are not suitable for arbitrary movements of speckles using only one curve. The speckles in 3D drawings move horizontally side-to-side along the arc. It is impossible to move a speckle along a sloped line or even a vertical line using a single curve. This can be proved as the angles of the scratch patterns when moving the hologram from side to side will add up to zero, for example, starting and ending with specular highlights at -30 degrees. It is impossible to move up or down in elevation if the sum of the slopes of the path travelled leads to the same elevation (see Fig. 3).

Another problem with horizontal lines realized with a single arc is that the curve of the line deviates from the line itself. To overcome this, the arc can be divided into several smaller arcs placed closer to the line (see Fig. 4). The reflection angles are maintained, while the position of the reflections more closely depicts a line. Such curves are not temporarily continuous, as the patterns become DISADITI.

E. *COSADITI patterns*

The only way to achieve a continuous space pattern, viz., a single curve that shows several specular points at the same time, is to use straight scratch lines. Such lines can be scratched using a ruler and a scratching tip. The angle of the lines is used to control at which point a particular line should be visible. Fig. 5 illustrates how a simple set of lines can be used to generate a simple animation. Fig. 6 illustrates a more complex example where sets of lines are used to draw more complex key-frames.

A drawback with COSADITI patterns is that flickers will occur between key-frames if there are too few key-frames. The resulting scratch patterns can quickly become highly complicated and cluttered if many key-frames are included.

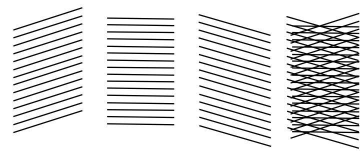

Figure 6. Patterns for advanced animations obtained by combining key-frames engraved with hatched patterns with varying orientation.

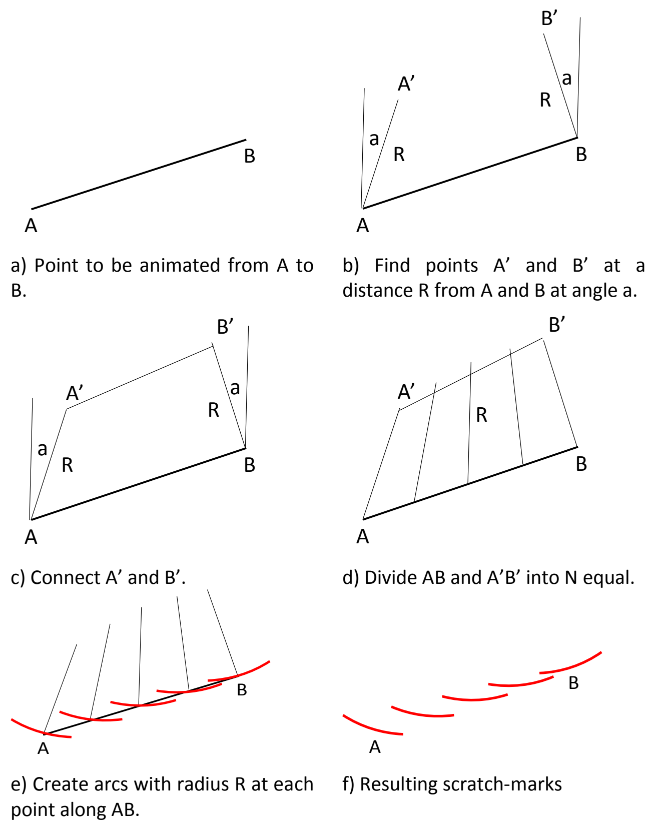

Figure 7. Constructing the struts for DISADITI scratch marks.

F. *DISADITI patterns*

A problem with the DISACOTI patterns is that pixel's changing state makes spatial jumps in the image. Here, an approach based on DISADITI patterns is proposed where single points are followed through its path in the animation with smooth transitions. However, since it is impossible to use a single curve to move a point in an arbitrary direction over time, several discrete overlapping lines are used.

It is assumed that a point travels from point A in the first key-frame along a straight line to point B in the last key-frame. To find the interpolating scratch marks between A and

B, the following procedure is proposed to construct the scratch mark strut. A line is constructed between point *A* and *B*. Next, a point *A*' is constructed by finding the point at distance *R* with an angle *a*. This angle *a* is the viewing angle of the first key-frame. Similarly, a point *B*' is constructed by finding the point at distance *R* with an angle –*a* crossing point *B*. Here we assume that the viewing angle varies from –*a* to *a*; that is, the image is equally offset to each side.

Next, a line is constructed from *A*' to *B*'. The *AB* and *A*'*B*' line segments are both divided into *N* parts, according to the number of desired scratch-marks. For each point along *AB*, a line of length *R* is constructed from the point at *AB* crossing through the corresponding point at *A*'*B*'. Finally, the scratch-marks are drawn using the caliper centered at the end of the newly drawn lines extended from *AB*, with a radius of *R*. All the scratch-marks will thus intersect the *AB* line. Fig. 7 illustrates the construction of the scratch-mark struts.

Note that the points *A*' and *B*' should be placed on the side of the line *AB* so that the *AA*' line and *BB*' line point towards each other, that is, the line segment *A*'*B*' should be shorter than the line segment *AB*. Clearly, if animations are to go in the other direction, the entire construction is mirrored across the *AB* line. Animated lines can then be constructed by overlapping several layers of single points at different positions along the line.

G. *COSACOTI patterns*

A cosocati pattern involves a simultaneous highlight of an area. The curvature of the surfaces allows the light to reflect smooth changing areas of the objects as the viewing angle is changed. Obviously, a true COSACOTI image can only be achieved with solid objects and not by the means of flat scratched reflective surfaces. Such patterns require the slope of the surface to be controlled, and more sophisticated production techniques are required.

IV. Conclusions

Abrasive hologram animations were explored. A taxonomy of animation scratch-marks was introduced, including DISADITI, DISACOTI, COSADITI and COSACOTI patterns. Three systematic approaches to creating abrasive hologram animations were proposed based on DISADITI, DISACOTI, and COSADITI patterns. The techniques open up several new avenues for creating animated holographic artwork.

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