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CASE STUDY OF AUTOSTEREOSCOPIC IMAGE BASED ON SIRDS ALGORITHM

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Abstract

Single Image Random Dots Stereogram (SIRDS) is an interesting algorithm deployed to represent a three-dimensional scene. Results of the algorithm are normal two-dimensional pictures but they do carry the vivid depth information – the third dimension in the real three-dimensional world – that cannot be obtained explicitly with other traditional two-dimensional pictures. The novelties of this paper are twofold: first it gives readers a complete overview of the possibility of 'seeing' reconstructed three-dimensional objects; then the paper focuses on analyzing and improving the implementation of the SIRDS algorithm. Its drawbacks and, especially, its visibility are deeply discussed and tested. Our proposals for generating optimized autostereograms (products of SIRDS) – i.e. they clearly display the depth information of a scene with less artifact and easier to view – are also presented.

Keywords: Single Image Random Dots Stereogram, autostereogram, artifact, hidden-surface, stereopsis.

1. Introduction

The environment around us is a three-dimension world (3-D), i.e. the position of everything is precisely described by its coordinates in the three-dimensional Descartes coordinate. However, up to now the two-dimensional (2-D) presentation of objects is still deployed in most of image processing applications, which tend to simulate, to reconstruct the real world at the maximum level of reality. Obviously such methods with reduction in dimension cause data-loss, nevertheless they still dominate because of their simplicity and portability. Recently the rapid development of computer and hardware manufacturing makes 3-D displaying systems (therefore its applications) possible at a quite 'reasonable' price. A lot of prospective results emerged in this field but the question of finding a displaying method with the best trade-off between the reality of 3-D world and computing complexity as well as the viability of its implementation is still open for researchers.

This paper provides a deep study for a displaying method based on SIRDS (Single Image Random Dots Stereogram) algorithm, which can be considered as a good solution for the aforementioned compromise. Section 2 gives a general view of methods used in three-dimensional displaying systems. The stereoscopic and autostereoscopic representation – two branches of stereo display – are discussed in detail. Section 3 describes the Single Image Random-Dot Stereogram (SIRDS) algorithm, a typical member of autostereoscopic representation family. The issues what SIRDS algorithm is, how to display a SIRDS based image, its limit and visibility are discussed in this section. It also presents some methods and our own programming techniques we use to overcome these problems. Finally, in section 4 the paper is closed with conclusions and further development options for the autostereoscopic representation based on SIRDS algorithm.

2. Classification of Three-Dimensional Representation

Basically there are two methods to display a three-dimensional object. In the scope of this paper, we call them 3-D and stereo representation. There may not exist any relations between the 3-D here and the so-called '3-D' effects used in advertisements for computer games (3-D computer game can belong to either 3-D or stereo representation). To avoid any ambiguities, if there is no extra note, these two methods must be understood in the following way:

2.1. 3-D Representation

In most of cases we hear (or see) the term 3-D, it is not used with the correct meaning. This is the traditional term people use to represent an object in plane. The depth information is perceived by the help of light and shade, relative size, etc. The key point for this method is the subjective judgment of viewers, so we even have no need for the cooperation of the two eyes. It does not show any loss of information in this case when you close one eye when viewing a 3-D scene.

Some simple trivial effects are deployed to give cue for depth information. For instance, artists learn how to make objects look solid or rounded by shading them; bright objects appear to be nearer than the dim ones; objects are considered closer if they cover other ones; etc.

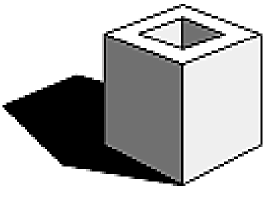

Fig. 1. Light and shade used to describe the depth sense

2.2. Stereo Representation

Just recently mankind has understood that we see different images of the world with each eye. One image is slightly different from the other. But why do not see a double image of the visual world? The mind has an ability to we combine two different, although similar, images into one image. It is called fusion, and the resultant sense of depth is called stereopsis. JULESZ and MILLER (1962) were the first to show clearly that the sense of depth could arise purely from stereopsis, without relying on the other cues mentioned in 2.1.

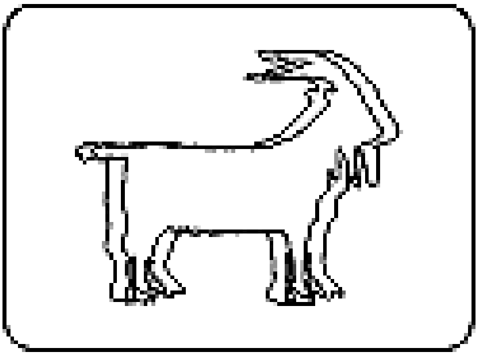

Fig. 2. The image that would be seen on overlaid left and right retinas

Stereo representation provides the aforementioned stereopsis by transmitting different images (stream of images) to each of our eyes. It is not trivial to implement such a system. Depending on how the stereo representation reconstructs the left and right images, we have two types of stereo representation:

2.2.1. Autostereoscopic Display (Free View):

Being barely over a century old, autostereoscopic displays are relatively new concept. Here the stereopsis is perceived without any special equipment. With unaided eyes, we can see the vivid depth dimension of an object in the three-dimensional coordinate system. Hologram, SIRDS are examples for this type of representation.

Taking a closer look into these representations, we can continue categorizing them as below:

1. Holographic: replay the real image of three-dimensional objects, retaining all properties of stereopsis, namely:
    - Motion parallax: a depth cue can be perceived through the rotation of objects. It is noticed that the nearer objects move more rapidly than the distant ones.

- Occlusion: there exist such points (pixels) on the left image which are invisible on the right one and vice versa.
- Natural coincidence of converging and focusing: in natural view two muscles must be activated for controlling the convergence and focusing of the eyes. The former forces the eyes' axes to converge at the point of interest in the three-dimensional coordinate. The latter makes the images of that point appear sharply and clearly on the retinas. This converging/focusing relationship is a habitual response learned by everyone naturally.

Fig. 3. Saturn in the infinite outer space – hologram

Holographic is capable of reconstructing these effects as if they could be obtained in natural view due to the fact that holographic recording is not simply storing the intensities (color components) of a fine-resolution mesh of pixels; the phases of light are also registered at each pixel. The stored amplitudes and phases result from an interference process between a coherent light source and its reflection from the scene in consideration.

2. Volumetric: it is sometimes described as 'space filling', these displays tend not to rely upon flat displays, but generate an image that occupies a volume. The volumetric screen is accomplished by presenting a sequence of 2-D cross-sections of a three-dimensional volume in rapid succession; triggering phosphor elements that occupy a volume rather than a flat surface as in traditional flat screen; or forcing a 'membrane mirror' (on which the image is projected) to alternate between convex and concave extreme.
3. Multiple image: a series of discrete views is presented across the viewing field. Depending on the position of observer, his left and right eyes will catch a different image correspondingly. Special structure of displaying system (e.g. lenticular display) causes this process.

2.2.2. Stereoscopic Display (Aided View):

The variety of stereoscopic displays invariably requires headgear, which ensures that the appropriate view is seen by each eye. Here the special equipment – headgear – can be a polarized glass, anaglyph filter and so on. They belong to the following two main classes:

- Optical equipment: they take an advantage of the incoherence of visible light to separate left and right image. In the case of polarized technique, left and right image are projected with a perpendicular polarized light pair. Glasses worn by viewers are actually polarization filters: letting light, which has parallel polarization with themselves, go through and extinguishing the others. Therefore each eye sees only the image that can be transmitted through its glass. In the case of anaglyph technique, two complement colors (red and green) are deployed to transmit image-pairs.
- Mechanical equipment: an image pair is separated temporarily or spatially. With the power of multimedia computer, this division can be processed in various ways: the interlace approach uses time multiplex, i.e. encodes left and right images on odd and even fields respectively; the White-Line-Code approach defines a white line in the last row of images, which is identical to each eye and used as a signal to synchronize the operation (open or close) of glasses in order to catch the proper images.

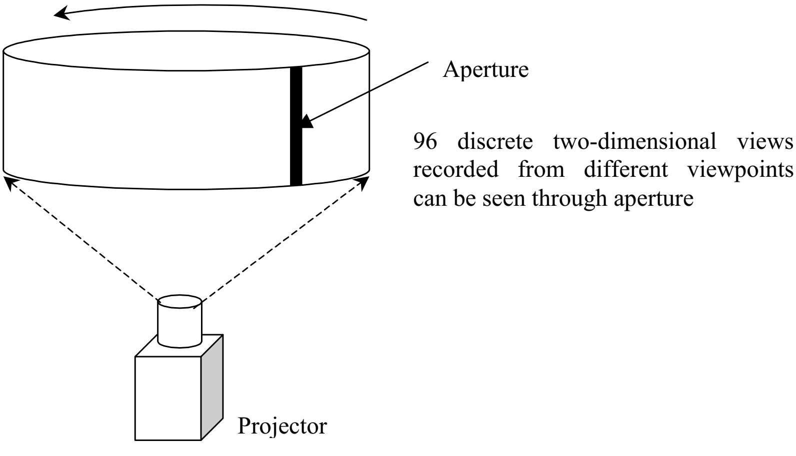

Fig. 4. Collender’s stereoptiplexer; volumetric display from multi 2-D images

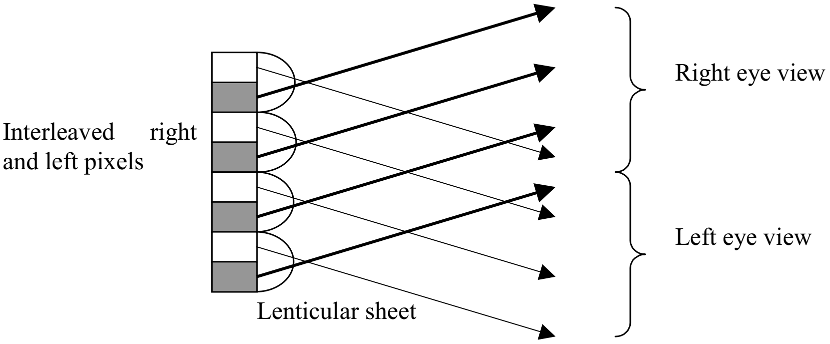

Fig. 5. Two-view lenticular display

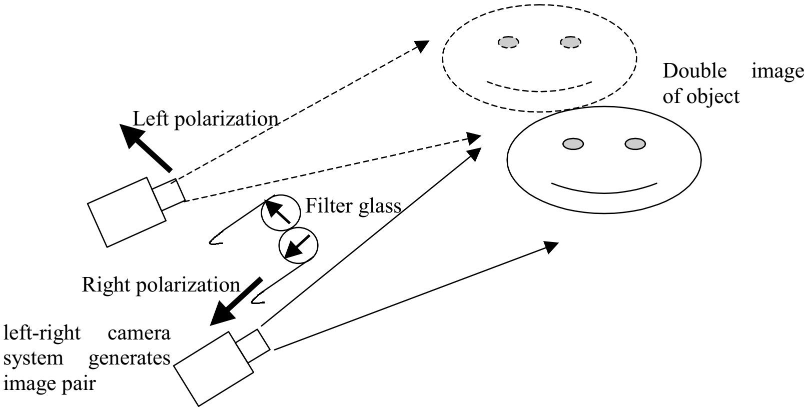

Fig. 6. Optical equipment with polarized glasses

3. Case Study: Autostereoscopic Representation Based on SIRDS Algorithm

3.1. SIRDS Algorithm

In SIRDS we use one stream of images to present the stereopsis. Making use of random dots, we can view a stereoscopic graphic without any special equipment. In theory, random dots here have an extended meaning. Not being restricted to grayscale, they can have colors with randomized intensity. Furthermore their colors can be assigned in accordance with an order of a pattern picture. We then overlay the two separate random dot patterns, carefully placing the dots so that each one serves simultaneously for two parts of the image. Locating the convergence of the eyes at a proper place, we obtain the stereoscopic graphics just as viewing in the nature.

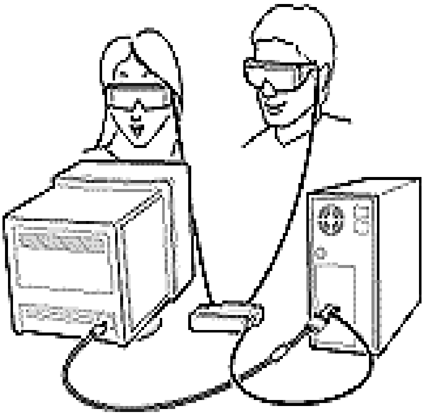

Fig. 7. Mechanical headgear in stereoscopic system

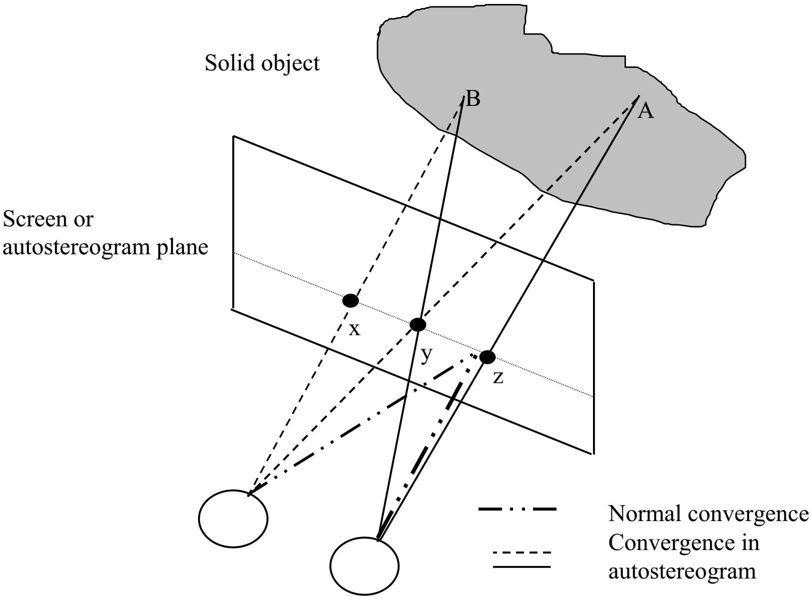

Fig. 8. Left and right image of a three-dimensional point

Fig. 8 shows an image plane placed between the eyes and a solid object. Imagine that it is a sheet of glass (in fact, it could be a computer screen or a piece of paper). Light rays are shown, coming from the object-point, passing through the image plane, and entering each eye. For each object-point, there are two rays – one for each eye – passing through the image plane. If both rays have the same color, they can conveniently reproduce the original object-point in the 3-D coordinate. Keeping every ray-pair entering two eyes from a common object-point identical – constraint on intensity and color – is a crucial key for the success of the algorithm: displaying objects stereoscopically with only one image shared by both eyes so that each eye virtually sees its own left and right image. As seen in *Fig.8*, with 2 three-dimensional points (A and B), three rays and therefore their three intersections with the screen (x, y and z) must be the same in color. At the same time, the pixel y is the right image of the point A and the left image of point B. This solves the problem of seeing a stereoscopic picture with one stream of images, without any special equipment required.

Keep in mind that an unusual method of viewing must be deployed in order to make all tricks mentioned above work properly. Instead of focusing on a pixel of interest in the autostereogram plane and converging the eyes' axes exactly at that pixel, the intersection of the eyes' axes must be positioned at the real three-dimensional point located somewhere behind the screen (the exact position is determined by the constraint pair and the eyes' position) while focusing on the screen is maintained. It requires a little practice to see the depth in an autostereogram with this decoupled viewing, but the experience is very satisfying when first achieved.

The general implementation of SIRDS is based on the geometry shown in *Fig. 9*. The object to be portrayed lies between two planes called the 'near' and 'far' plane. They are located at the distance of (a-b)D and aD, respectively, behind the screen. The separation between the near and far planes determines the depth of the field.

We call the implementation proposed by HAROLD W. THIMBLEBY, STUART INGLIS and IAN H. WITTEN floating eyes algorithm. It is named after the following suppositions:

- Constraints on intensity and color only affect points along a line that lies in the same plane as the two eyes.
- All lines of the screen (the autosteregram plane) successively satisfy the above condition because the eyes' sizes (heights) are relatively large compared to the size (height of the screen). It is due to the fact that most of autostereograms are small-sized and/or viewed at a relatively far place. Hence when calculating the constraints, the program independently processes one scan line at a time.
- It is convenient to define the 'image stereo separation' of a point on the surface of the solid object to be the distance between its image points lying in the image plane. The calculation of this quantity is based on the equal triangle geometry, i.e. the triangle stretched over the eyes and object-point of interest is always equal-sized. Its reason is similar to the one of the previous assumption: the relative size of the autostereogram.

With the parameters shown in *Fig. 9*, the following formulas for calculating constraints are applicable for general floating eyes algorithm:

$$\text{Image stereo separation:} s = \frac{(a - b \cdot z) \cdot E}{1 + a - b \cdot z}. \tag{1}$$

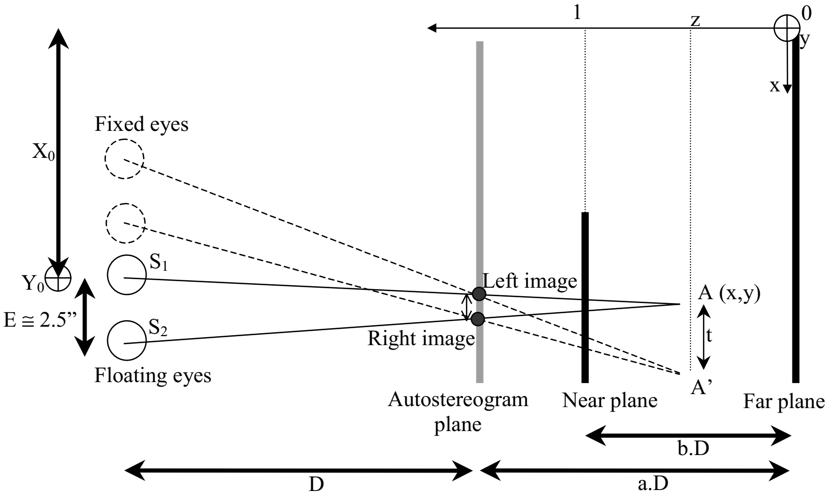

Fig. 9. Geometry of SIRDS

The coordinates of left and right image points in the autostereogram plane:

$$\begin{cases} y_{\text{left}} = y_A \\ x_{\text{left}} = x_A - \frac{s}{2} \end{cases}, \qquad \begin{cases} y_{\text{right}} = y_A \\ x_{\text{right}} = x_A + \frac{s}{2} \end{cases}. \tag{2}$$

Because of a transition in the object (from the near to the far plane, say), a surface in the foreground may obscure one eye’s view of a more distant point. Hidden surface removal is a technical detail. Its advantage is that for any part of the object that is strictly hidden, there are fewer constraints to process. In turn, they give the algorithm greater flexibility in allocating pixel colors, which reduces the problem of artifactual ‘echoes’ as discussed later.

Fig. 10 shows the Harold W. Thimbleby’s technique for hidden surface removal. Point A is a point on the object that would cause two pixels of the image to be linked together in a constraint. The question is to determine whether it is a target of an obscuring object that interrupts one eye’s view. The crucial inequality for hidden surface removal is $Z_{C2} > Z_B$, where quantity Z_{C2} is the depth of a point on the obscuring object and Z_B is the depth of a point on the ray from the eye to the original object. The x-coordinate of $B_{1/2}$ is governed by distance t, and if such an interruption occurs for any value of t greater than 0 and up to the point where $Z_{B1/2} = 1$, then the original point is no longer visible by this eye.

The general inequality is the following:

$$z_{C_i} < z_{B_i} \quad \forall i \in \{1,2\} \text{ i.e. } z_{C_i} < z_A + \frac{2 \cdot t \cdot (1 + a - b \cdot z_A)}{b \cdot E} \quad \forall i \in \{1,2\} \tag{3}$$

After hidden surface removal, only those pixels are linked together (they are local constraint couples), which are the images of visible object-points for both eyes.

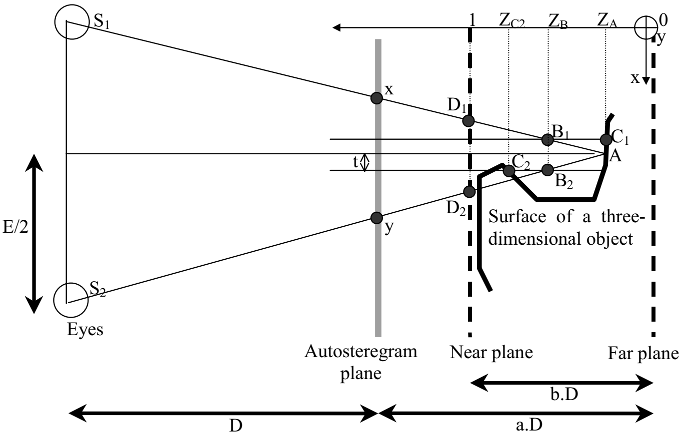

Fig. 10. Geometry for hidden surface removal

Harold W. Thimbleby stored these constraints in a global constraint array for each line, in which each element (corresponding to each pixel on the autostereogram at the same position) stores the position of the nearest right (or left) constraint couple (it may or may not be the couple resulted from the local constraint couple, see *Fig. 11*). It eases the allocating process coming right after this phase.

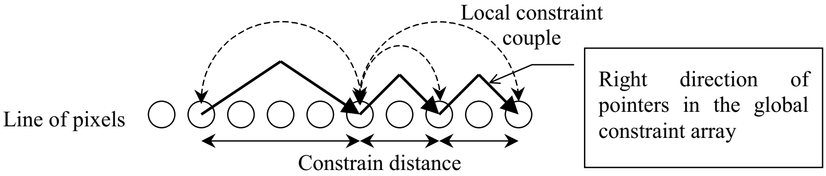

Fig. 11. The construction of global constraint array

Once the constraints have been set for all pixels in a scan line (*Fig. 13*), the line is re-scanned in the inverse direction compared to the direction of the pointers stored in the global constraint; values of pixels in that line are assigned. If the pixel is unconstrained, its value is chosen randomly. Otherwise its value must be constrained to be the same as some pixels whose positions are registered in the global constraint array.

The random value of unconstrained pixels is an important factor. It determines the output type of the algorithm and has effect on false fusion discussed later. Originally its values are taken from gray-scale scalar from 0 up to 255 (*Fig. 14*). They can be extended to any color with different intensity (different saturation degree, see *Fig. 15*) or can be restricted to less random repository of values as in its successors summarized below.

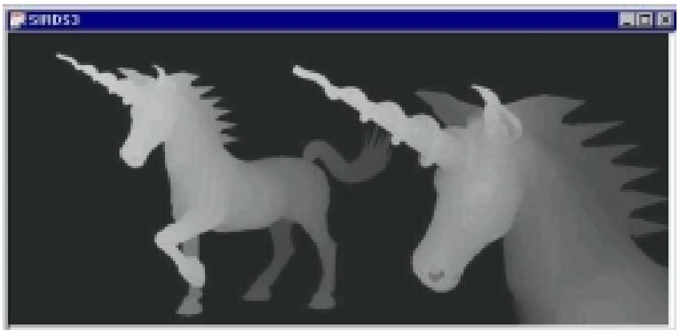

Fig. 12. Input image for our simulation. The intensity carries the depth information: the brighter the pixel, the closer the image to us

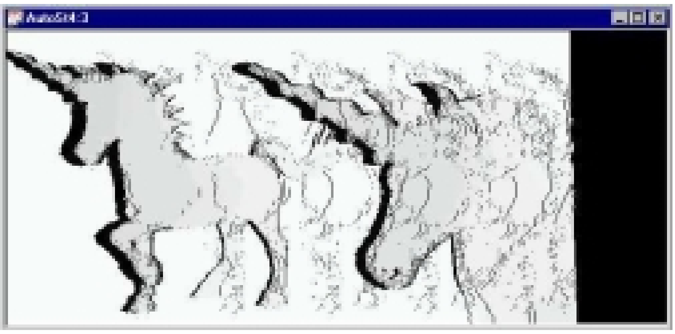

Fig. 13. Global constraint. Black pixel is unconstrained. The brighter the pixel, the farther its constraint couple lies to the right

- Single Image Texture Stereogram (SITS): in order to generate a SITS output, a pattern which is a traditional 2-D image of size MaxX x MaxY is involved. Its size is often smaller than the autostereogram's size itself so that when its colors are applied to the unconstrained pixels, repeated appearance of the pattern (or part of it) occurs on the autostereogram, and the autostereogram appears more interesting. The allocating process assigns only the colors occurring in line l of the pattern to the pixels in line k of the autostereogram (in our simulation, $l = k$ mod MaxY). If pixel (k, m) – the pixel m in line k – is unconstrained, it takes the value of the pixel (l, n) in the pattern (in our simulation $n = m$ mod MaxX); otherwise it is identical to its constraint couple (*Fig.* 16).
- Single Image Random Text Stereogram (SIRTS): a SIRTS output contains ASCII characters instead of 255 values of gray scale. In our simulation,

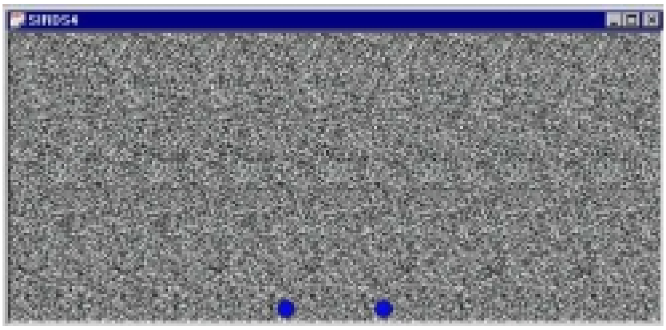

Fig. 14. Sample of traditional SIRDS with black and white dots. The hidden image is *Fig.12*

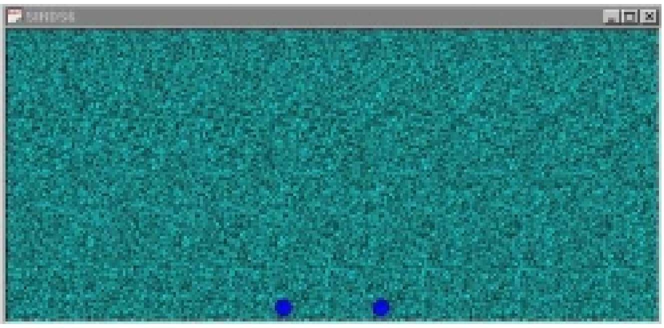

Fig. 15. Sample of color SIRDS. The hidden image is *Fig. 12*

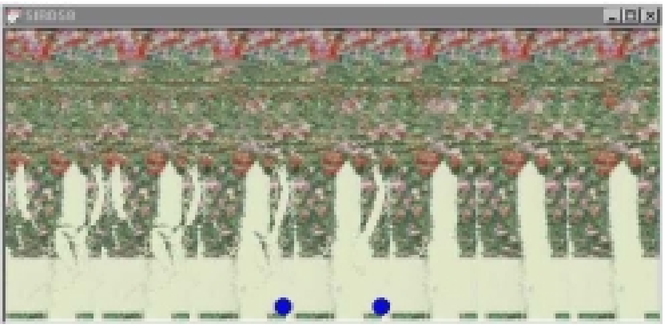

Fig. 16. Sample of SITS. The hidden image is *Fig. 12*

only characters with code laying inside the range from 33 to 127 are set to

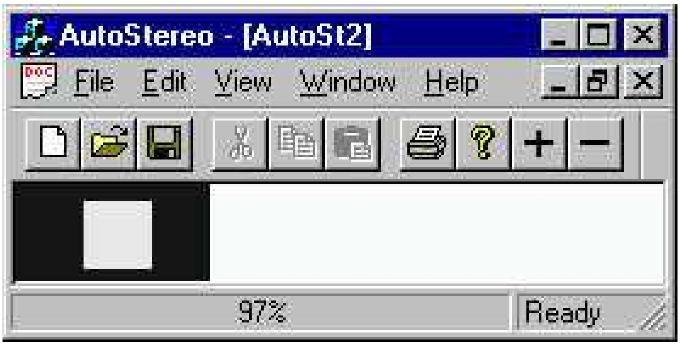

Fig. 17. Input image for SIRTS

unconstrained pixels (they constitute the Latin character set). This allocation expands the original image in both vertical and horizontal direction, because pixel's size is considerable in this case (depend on what size of font being used, see *Fig. 18*).

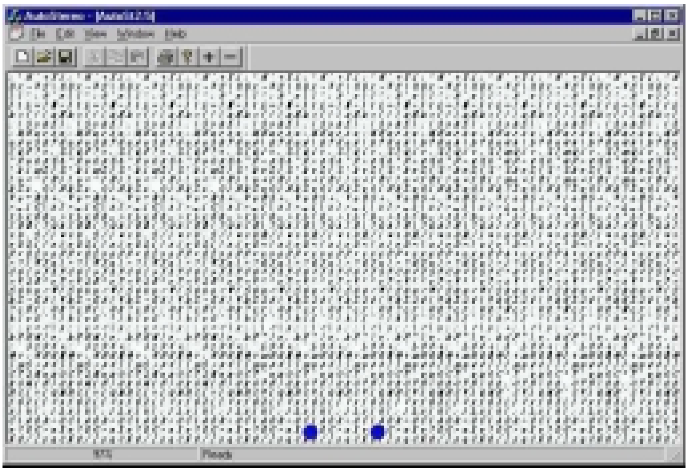

Fig. 18. Sample of SIRTS. Its input is *Fig. 17*. Font settings: italic Times New Roman font of size 7; no space between characters and lines

3.2. Limitations of SIRDS Algorithm and its Possible Elimination

This section describes some of the geometrical limitations of the algorithm. In practice, none of these detracts from the depth effect. We also present our effort to eliminate these effects during our simulation.

3.2.1. Geometry Distortion

Basically the algorithm used to generate an autostereogram is based on floating eyes. It uses the symmetric method to map object's origin points to pixel-pairs in the image plane in accordance with their depth. That is for each point A on the depth field (it is the input image carrying depth in formation for every real three-dimensional point, see *Fig. 12*) we compute the stereo separations accordingly, making use of the equal triangle AS_1S_2 (see *Fig. 9*). However, the stereo separation here should really be governed by point A' instead. Something may intervene between the eyes and A', but not between the eyes and A. There is an analogous distortion in the vertical (or y) direction, perpendicular to the plane containing the eyes.

We also made some trials to correct the above limitations by developing a new algorithm, namely the 'fixed eyes' based algorithm. In this case the calculation of stereo separation for each three-dimensional point A is based on the general triangle stretched over the point A and the two eyes (see *Fig. 19*). Therefore it makes our autostereograms mathematically correct at the unique positions of the eyes. That is, if we choose the left top corner of the depth field as the zero point and the direction of X-, Y-, Z-axis as marked in *Fig. 19*, the object in an autostereogram is seen properly only when viewers' left eye is located at the fixed (X_{eye}, $Y_{\text{eye})}$ point. It implies that also the right eye has the mandatory position ($X_{\text{eye}} + E$, $Y_{\text{eye})}$. *Eqs.* (1) and (2) are rewritten in the following form for this algorithm:

$$s = \frac{(a - b \cdot z) \cdot E}{1 + a - b \cdot z}, \tag{4}$$

$$\begin{cases} y_{\text{left}} = y_{\text{right}} = Y_{\text{eye}} \cdot \dfrac{s}{E} + \left(1 - \dfrac{s}{E}\right) \cdot y, \\ x_{\text{left}} = X_{\text{eye}} \cdot \dfrac{s}{E} + \left(1 - \dfrac{s}{E}\right) \cdot x; \quad x_{\text{right}} = \left(X_{\text{eye}} + E\right) \cdot \dfrac{s}{E} + \left(1 - \dfrac{s}{E}\right) \cdot x. \end{cases} \tag{5}$$

Hidden surface removal also needs to be modified. It is not enough to check the obscuring points only in the line of the object-point, whose stereo separation is currently calculated. Any object-points in the upper or lower lines are capable of interrupting the ray from the point in consideration each of the eyes. Inequality (3) has a new formula:

$$z_{C_i} < z + \frac{A \cdot (a + 1 - z \cdot b)}{b},$$

where

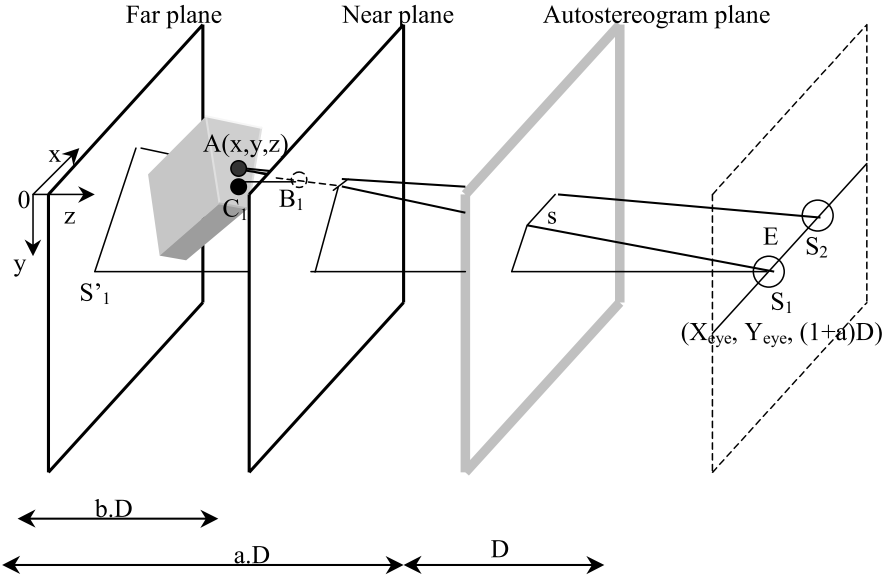

Fig. 19. Fixed eyes based SIRDS algorithm

$$A = \sqrt{\frac{\left(x_{B_i} - x\right)^2 + \left(y_{B_i} - y\right)^2}{\left(x_{\mathrm{eye}} - x\right)^2 + \left(y_{\mathrm{eye}} - y\right)^2}} \quad \forall i \in \{1, 2\}\,. \qquad (6)$$

This inequality must be evaluated at each point $C_{1/2}(x, y)$ in the depth field until the point A is obscured or the depth point $C_{1/2}$ is greater than 1 (it goes farther than the valid depth field).

In fact, the fixed eyes based SIRDS algorithm is a perspective projection. Hence the size-reduction is inevitable (see *Fig.*20). That is, only a part of pixels on the autostereogram plane can be filled with constraint information. Pixels on the edges never have a constraint pair because there are no such three-dimensional points on the input image, whose projected image can reach this area. It causes an illusion as if viewers saw the three-dimensional scene through a virtual window. In our simulation, these pixels can optionally be filled with the constraint of the expanded background, i.e. we pad the left and right of the scan line in the input image with three-dimensional points, which are located in the far plane (background). Similarly, some new lines are added to the top and bottom of the image.

The fixed eyes algorithm is time consuming because the increase in the complexity of the formulas and in the number of object-points must be examined to determine whether a projecting ray is obscured. We defined a threshold for angle resolution: if two three-dimensional points together with the eye construct an angle less than the threshold, only one of them should be taken into account. If the threshold is fine enough, the calculation time is drastically reduced while the visibility of

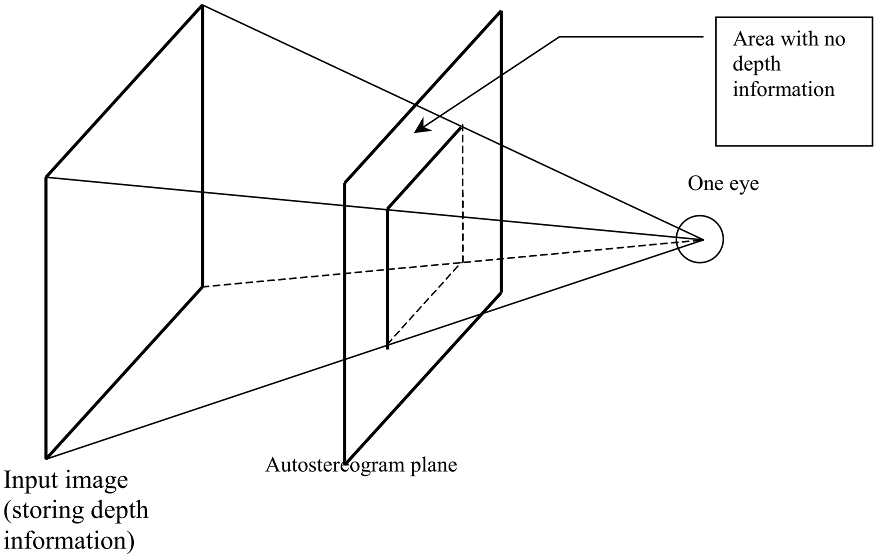

Fig. 20. Size-reduction and need of patching

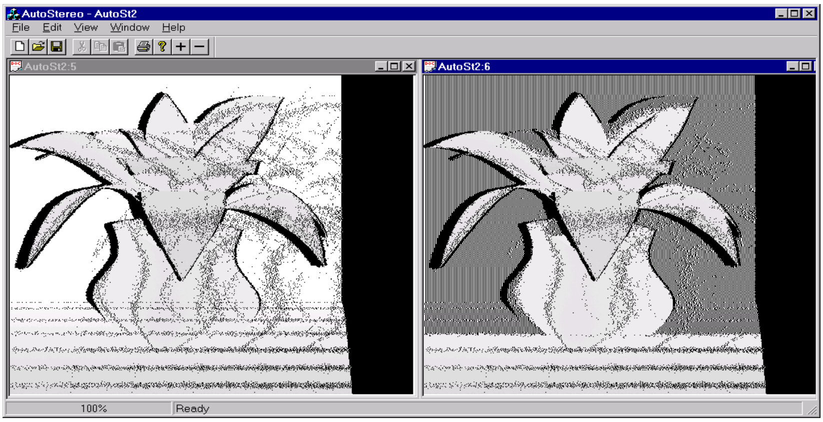

Fig. 21. Constraint couple map. In the left map a finer threshold angle was used than in the right one

the SIRDS image almost remains unchanged (see *Fig.* 21). Measurements of this delay for different implementations of SIRDS are summed up in *Table* 1.

Table 1. Time consuming comparison with different algorithms. The test was run on WindowsNT workstation Pentium Celeron 300 MHz 32Mbyte RAM. The quality and the visibility of all the output images are acceptable. The test shows that fixed eyes algorithm should be used with hidden surface removal (otherwise the output is very noisy). The fact that different geometry is assumed in fixed eyes and floating eyes algorithm causes that different thresholds must be deployed for these two algorithms.

Method		640 × 480 input image (msec)	1024 × 768 input image (msec)
Floating Eyes algorithm	Without hidden surface removal	581	1322
	With hidden surface removal	3665	9904
	Fine angle threshold (0.1659 degree, viewed from distance of 40 cm)	3105	8202
	Rough angle threshold (0.2 degree, viewed from distance of 40 cm)	2744	7210
Fixed Eyes algorithm	Without hidden surface removal	711	1762
	With hidden surface removal	41309	156725
	Fine angle threshold (0.028 degree, viewed from distance of 40 cm)	35891	115797
	Rough angle threshold (0.035 degree, viewed from distance of 40 cm)	20079	74958

3.2.2. False Fusion

As mentioned in the previous section, the secret of successful viewing a SIRDS is to decouple the eyes' focusing and converging. Directed by the constraint couples in the autostereogram plane, viewers must position exactly the intersection of their eyes' axes on the three-dimensional point, whose left and right images are the pixel-pair constructing the constraint. Usually this process does not happen perfectly due to some side effects described below.

- Echoes: suppose there are constraints on pixels such that $a = b$ and $b = c$. It follows that a=c. This last constraint, interpreted geometrically, corresponds to a third point in the three-dimensional space. There may be no such point on the object.
- Artifacts: even though there may be no geometrical constraint that $a = b$, it can happen that a and b are given the same color purely by chance (it

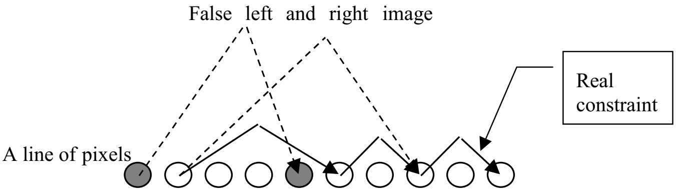

Fig. 22. Echoes and artifacts

depends on the random method we use to generate the colors of the pixels; in the case of SITS, it is due to the color-property of the pattern image used for decoration). The more random way we use, the less likely the chance for artifacts occurs. We have to keep this rule in mind when choosing a sample image to paint the image plane in the SIRDS program.

- Incorrect convergence: false fusion can also occur simply because the eyes incorrectly converge. Then with the effect of artifacts we probably see something that is completely different from the initial intention (even worse, we see nothing). For instance, the constraint couple x, y in *Fig.* 23 can give hint at either real point A or A' depending on the position of the convergent point of the eyes. To verify a correct convergence, make sure you 'see' three guide circles (two blue circles located at the bottom of every autostereogram generated by our software) instead of two.

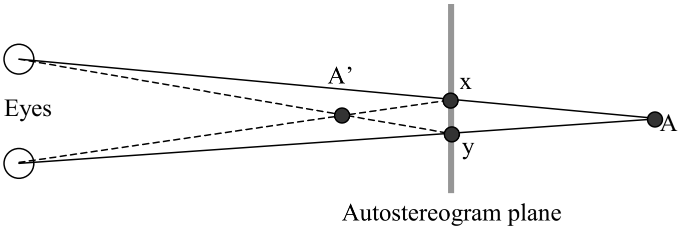

Fig. 23. Incorrect convergence in viewing SIRDS

The false fusion is due to the nature of the SIRDS algorithm. For reducing these limitations to the minimum level, we offer the following experience:

- SIRDS output type is preferable. It is the most random output the algorithm can generate.
- In the case of SITS output, the larger and the more random pattern is used, the better the autostereogram obtained. It may cause the SITS less interesting as the purpose of SITS is presenting repeatedly a pattern to mislead viewers deliberately. But the fact that the pattern is repeated frequently just increases the possibility of the occurrence of echoes and artifact.

- Pixel has considerable size in SIRTS output type, so it is not advised to generate an autostereogram with fine resolution, containing complex scene.

4. Conclusions

We consider the SIRDS algorithm a hot topic because of its simplicity, portability in representing three-dimensional objects with vivid depth information. The only one disadvantage of the algorithm is the initial view. With different combinations of geometrical parameters, we examine their effect on the visibility of an autostereogram. Results can be seen in *Table* 2.

Table 2. The visibility of an autostereogram versus different geometrical parameters. The autostereogram was viewed with 15” monitor at the resolution of 1024 × 786.

‘a’ value	Visibility
0.3	The autostereogram is noisy, the depth field is shallow. Constraint distance is small (see formula (1), so periodical colorization can be seen in lines, hence echoes and artifacts are inevitable.
1	With $b = 0.33$ vivid depth information can be perceived. It is the advised value.
2	Depth field is deep, three-dimensional effect is promoted. The autostereogram consists of true random dots (constraint distance is large).
60	The object is no longer visible. It may hurt the eyes because of the large diversity in decoupling focusing and converging.

It is experienced that the autostereogram can be seen in less time if viewers first try to locate the intersection point of their eyes’ axes in the far plane. That is why we, on purpose, draw the two guide circles for each autostereogram generated by our program. The autostereogram will be viewed correctly if three circles can be seen on the autostereogram: the binocular middle and the two monocular side ones (the middle circle will be seen in the far plane). These guide circles also take part in eliminating the false convergence as much as possible.

We believe that the unusual view of the SIRDS algorithm can be learned, and it is no longer an unreachable thing for viewers, we put a new step far ahead for SIRDS algorithm: apply SIRDS to moving objects. We are in the last phase of solving the most crucial problem in this new field: how to store and reconstruct the random texture of moving objects from frame to frame and how to retain colors for certain pixels which have unchanged constrained couple (background points). The success of moving objects with SIRDS will complete the full picture of the algorithm in the field of displaying three-dimensional information.

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