Chapter 5

Proposed models for reconstituting/ adapting three stereoscopes

5. Proposed models for reconstituting/adapting three stereoscopes

This chapter offers three contributions in the Stereoscopy area, which are described in the three following sections:

Section 5.1 contains a description of a method to obtain stereo graphics using a two-monitor system and four mirrors. This method is based on the ideas of the Cazes-type stereoscope. The result of this research is published in the 18th International Conference on Electronics, Communications and Computers CONIELECOMP, 2008. (Aguilera, et al., 2008) and Virtual Concept 2006 (Aguilera, et al., 2006).

Section 5.2 describes the construction of a virtual environment created using two parallel walls and two mirrors. This research is based on the ideas of the Wheatstone-type stereoscope. The result of this research is published in the "Revista Iberoamericana de Computación. -Computación y Sistemas", (Mora, et al., 2009).

In Section 5.3 there is a method to build a boxed-type stereoscope. The result of this research is published in the journal CiBIyT of the Universidad Autónoma de Tlaxcala (Mora, et al., 2008-2)

In section 5.4 there is a chapter summary.

5.1 Cazes -type computer-based Stereoscope

This section shows the design and building of a Cazes-type digital stereoscopic device using a computer with two monitors and four mirrors.

Let h, w, and d be the *height*, *width*, and *diagonal* lengths of each monitor respectively. Two identical monitors are used with an aspect ratio of 4:3, see Figure 5.1

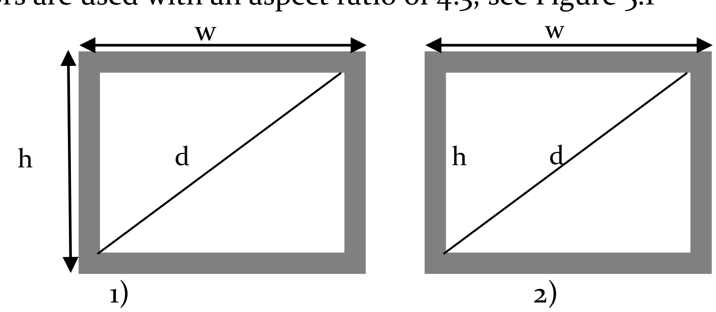


Figure 5.1. Two identical monitors

It has been demonstrated that a good working eye-monitor distance for a Cazes-type stereoscope through the mirrors is roughly d (Vali, 1966), that is, the same as the diagonal length of the screens. The first design is for the left eye. For the right eye, a similar procedure is used. Therefore Figure 5.2 *a* represents the position for the left eye.

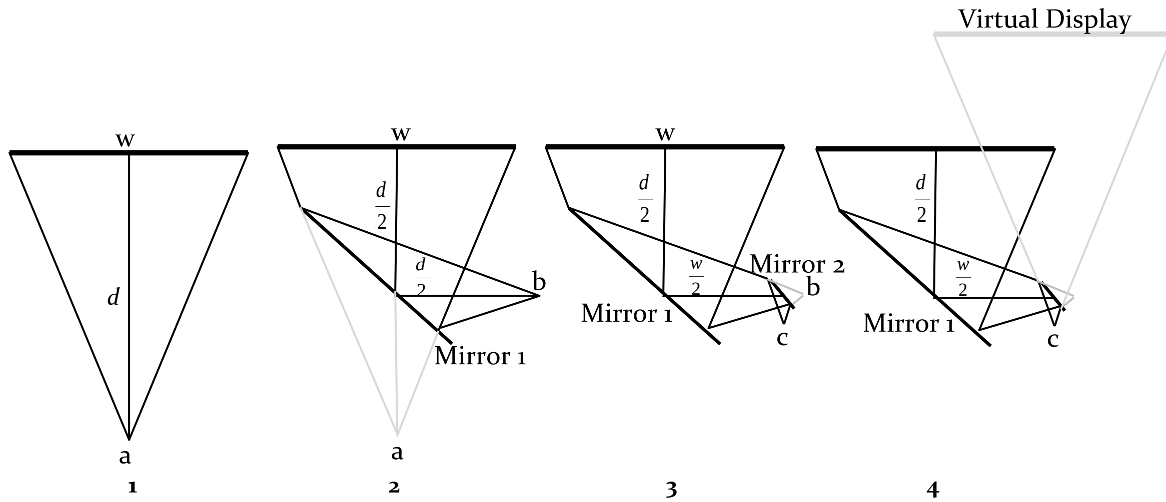


Figure 5.2 1)Eye position at *d* from the monitor. 2) Placement of a first mirror, defining a new eye position. 3) Placement of a second mirror, defining the final eye position. 4) Location of a virtual monitor, as seen from the final eye position.

Figure 5.2.2 shows the placement of *Mirror 1* at 45° ($\pi/4$) and at half of the eye-monitor distance from the monitor (that is, *d*/2), which defines point *b* to the right. Point *b* represents a new eye location, also at *d* from the monitor through this mirror, but the image will be laterally inverted (this would the basis for a Wheatstone-type stereoscope).

Figure 5.2.3 shows the placement of *Mirror 2* at 45° ($\pi/4$) and at half of the monitor width from *Mirror 1* to the right (that is, *w*/2). This defines point *c* at $(d-w)/2$ from *Mirror 2*, which represents the final position for the left eye.

Figure 5.2.4 shows the position where the monitor will be seen from point *c*, as seen by the viewer, and labeled as *Virtual Display*. Note that point *c* is

a) at a distance *d* from the monitor through both mirrors,
b) at a distance $w/2$ to the right from the monitor center, in other words, it is aligned at the right edge of the monitor.

Figure 5.3 shows the Cazes-type stereoscope.

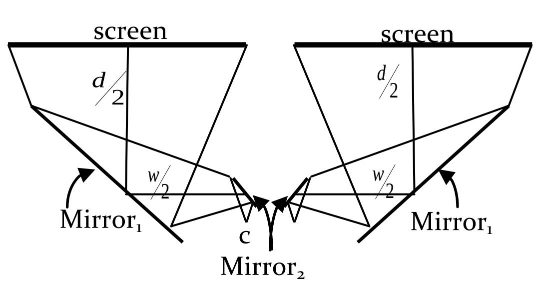


Figure 5.3 Cazes -type computer-based stereoscope

The triangle formed by the screen width (*w*) and the position *a* allows computing the sizes of mirror 1 and mirror 2. See Figure 5.4, both mirrors are rotated the same degrees, therefore α, β_1, β_2, γ_1, and γ_2 are the same values in both mirrors, the difference is the distance between them and position *a*.

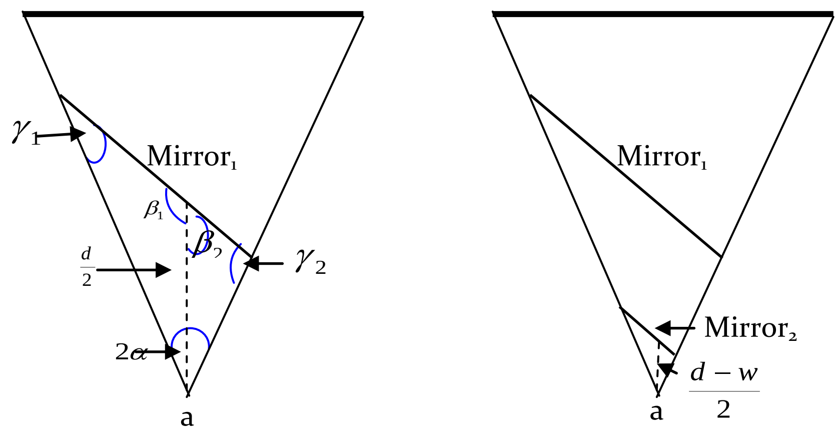


Figure 5.4 Mirror_1 and Mirror_2

The following equations calculate the size of both mirrors $Mirror_1$ and $Mirror_2$.

Eq. 5.1 $$\alpha = a\tan\left[\frac{w}{2d}\right]$$

Eq. 5.2 $$\beta_1 = \frac{3\pi}{4}$$

Eq. 5.3 $$\gamma_1 = \frac{\pi}{4} - \alpha$$

Eq. 5.4 $$\beta_2 = \frac{\pi}{4}$$

Eq. 5.5 $$\gamma_2 = \frac{3\pi}{4} - \alpha$$

Eq. 5.6 $$m\_1_{width} = \frac{d\sin(\alpha)}{2\sin(\gamma_1)} + \frac{d\sin(\alpha)}{2\sin(\gamma_2)}$$

Eq. 5.7 $$m\_1_{height} = \frac{3}{4} m\_1_{width}$$

Eq. 5.8 $$Mirror_1 = m\_1_{width} \times m\_1_{height}$$

Eq. 5.9 $$d_2 = \frac{d-w}{2}$$

Eq. 5.10 $$m\_2_{width} = \frac{d_2 \sin(\alpha)}{\sin(\gamma_1)} + \frac{d_2 \sin(\alpha)}{\sin(\gamma_2)}$$

Eq. 5.11 $$m\_2_{height} = \frac{3}{4} m\_2_{width}$$

Eq. 5.12 $$Mirror_2 = m\_2_{width} \times m\_2_{height}$$

5.1.1 Stereoscope structure

As previously stated, the set of mirrors for the right part of the stereoscope can be set up in an analogous, yet symmetrical way. Figure 5.5 shows two views of the full Cazes-type stereoscope set up.

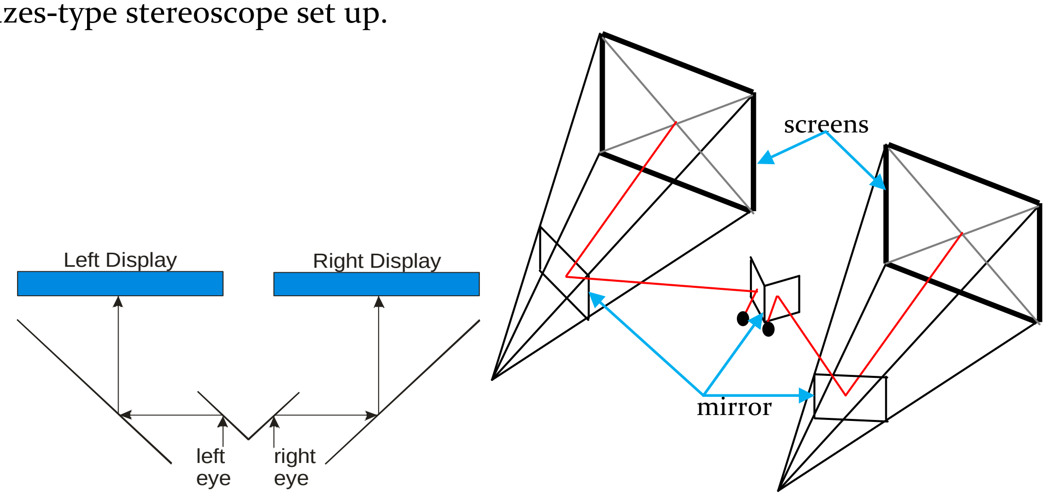


Figure 5.5 A Cazes-type stereoscope.

The system used is a Dell XPS computer with a 512 MB nvidia GeForce 6800 video card, which includes outputs to two monitors. Nevertheless, smaller computer systems can also be used[1].

The following list delineates the actual sizes of the components used in this project. All of them are actually larger than needed for the given monitors size, as stated in the previous section. However, bigger sized components allowed us to more finely tune all distances and angles in a nice way, with no restriction at all.

Table 5.1 Part listing of the Cazes-Type Stereoscope

Part listing:	Size	Remarks
2 Identical 20” monitors	(40 cm x 30 cm)	with stand
2 Large mirrors	(44 cm x 35 cm)	with stand
2 Bicycle mirrors	(12 cm x 6 cm)	with clamp for handlebars
1 Wood block	(20 cm x 20 cm x 2 cm)	the stand base

[1] For example, a laptop computer with an external monitor attached to it.

1 Large wooden stick	(50 cm x 2 cm diameter)	the stand column
1 Small wooden stick	(15 cm x 2 cm diameter)	the stand arms
2 Clamps	(10 cm x 1 cm)	to hold both sticks together

Our monitors include a stand which is height adjustable; it also allows for adjustment of the horizontal and vertical viewing angles. This allowed for easier monitor orientation, but it is, of course, not an absolute necessity. Place both monitors next to each other forming no angle between them, as shown in Figure 5.6. Place both large mirrors in their position, see Figure 5.7. The mirrors need to be kept in a vertical position. Each of the large mirrors has been attached to a stand which keeps it that way.

For small mirrors bicycle mirrors were used, and a simple cross-like stand was constructed to allow for vertical adjustment. This stand is made using the wooden parts and the clamps in the following way:

1) Take one of the two clamps and unravel it completely, then assemble it again chained to the other clamp in an interlocking way, see Figure 5.6. Keep both clamps loose enough to insert and move both sticks freely until their final adjustment.
2) Insert the small wooden stick horizontally into one of the clamps, half of its length, so that the clamp rests at the center of the stick.
3) Insert the large wooden stick vertically into the other clamp around half of its length too, however, its final position will be adjusted later.

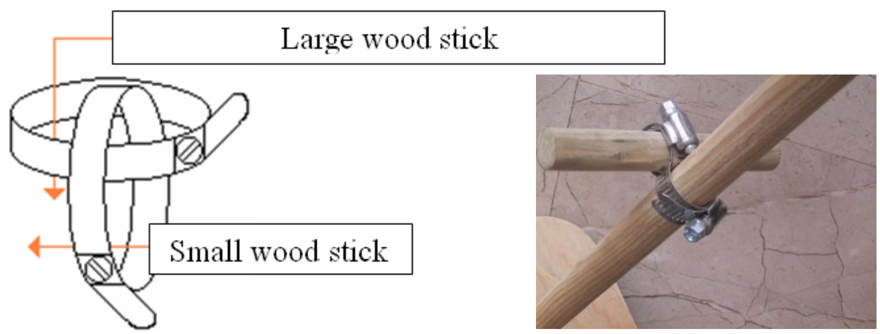


Figure 5.6 Interlocking clamps.

4) Drill a 2 cm hole in the wood block center, then glue and insert one end of the large stick into this hole.
5) Mount both bicycle mirrors on both sides of the small wooden stick as if it were the handlebars of a bicycle. These mirrors should be placed close enough to touch each other's edges, forming a right angle. Place this mounting to put the small mirrors in their position, see Figure 5.7.1.
6) Start tightening up everything as you fine-tune the stereoscope. This fine-tuning process is explained in the next section.

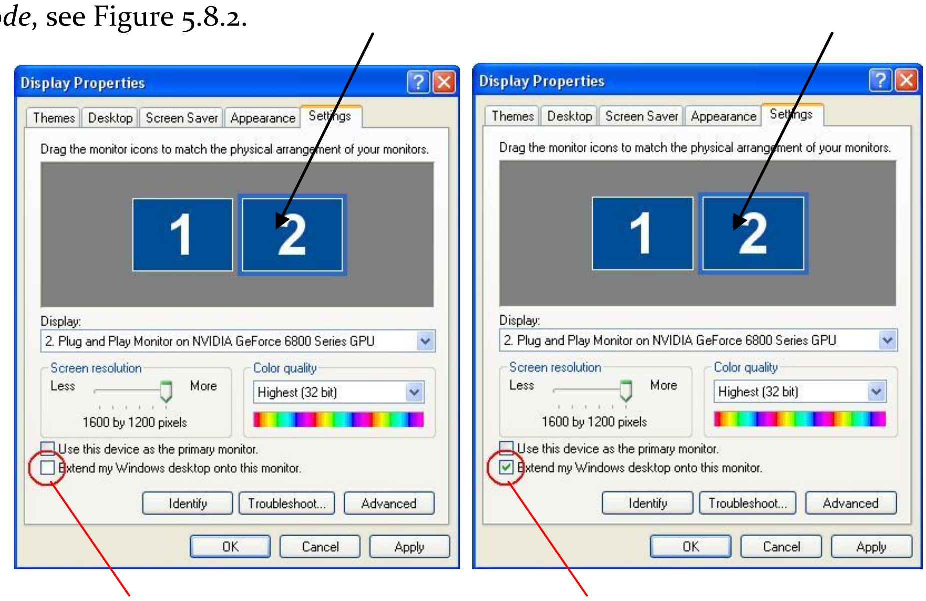
Figure 5.7 : 1) Placement of the small mirrors. 2) The Cazes-type digital stereoscope.

5.1.2 Fine-tuning the Stereoscope

To use this stereoscope, the viewer should practically touch the small mirrors with his nose, so that each eye only looks through one mirror. Therefore, the vertical position of these mirrors should be adjusted along the large wooden stick using the corresponding clamp.

Next, all mirrors should be oriented so that each eye sees its corresponding monitor in such a way that both monitors are perceived as one. In order to accomplish this, it is very convenient to set the second monitor to display the same image as the first one (*clone monitor mode*), so that both images will fuse as one. This can be done by right-clicking the desktop, selecting the *properties* item in the contextual menu, and clicking on the *Settings* tab, which brings the *Display Properties* window, as shown in Figure 5.8. Select *monitor 2* by clicking on it (see the arrow in Figure 5.8.1), and uncheck the *Extend my Windows desktop onto this monitor* option (see the circle in Figure 5.8.1).

Once all mirrors are correctly oriented, and each eye sees its corresponding monitor, be sure to check the *Extend my Windows desktop onto this monitor* option to set the *dual monitor mode*, see Figure 5.8.2.



1) Clone monitor mode. 2) Dual monitor mode.

Figure 5.8 The Display Properties window.

5.1.3 Software Implementation.

Once the system and all mirrors are properly adjusted, have the left image of a stereo pair be displayed on the whole screen of the left monitor, and the right image on the right monitor. There is an easy trick for doing this: maximize your window to span both monitors, and let your software draw the left image of your stereo pair at the left half of the window, and the right image at the right half, side by side. Thus each image will occupy one monitor exactly. This can be carried out in eight steps, using OpenGL:

1) Clear the color and depth buffers.
2) Define the (*left*) viewport as the left half of the window.
3) Use *gluLookAT*() to set the camera at the left eye position.
4) Draw your OpenGL scene (without swapping or flushing buffers).
5) Define the (*right*) viewport as the right half of the window.
6) Use *gluLookAT*() to set the camera at the right eye position.
7) Draw your OpenGL scene again.
8) Swap buffers.

The following is a Pascal code (using Delphi) which implements this. Note that procedure *FormPaint* is called every time your window needs to be redrawn. You can also call it every time your scene changes. Also, procedure *FormResize* is called every time your window is *resize*. This code assumes some global variables, like *ViewerFrom, ViewerAt, ViewerUp*, and similar ones for the left and right eyes. Procedure *CalcFromAtUp* computes all the required vectors for the left and right eyes, in a way that the resulting lines of view for both eyes are parallel to the original *From-At* segment at a distance *sep*, and perpendicular to the *Up* direction.

```
procedure TForm1.FormPaint(Sender: TObject);
var
  w, h: Integer; // width and height viewports
  sep : Double;  // (half of) amount of separation
begin
  GetSeparation(sep); // user adjusted separation value
  CalcFromAtUp(sep,  ViewerFrom,   ViewerAt,   ViewerUp,
                 LeftEyeFrom,  LeftEyeAt,  LeftEyeUp,
                RightEyeFrom, RightEyeAt, RightEyeUp);
  glClear(gl_color_buffer_bit or gl_depth_buffer_bit);
  w := Form1.Width div 2; // width  for viewports
  h := Form1.Height;      // height for viewports

  glViewPort(0, 0, w, h); // set left viewport (Note 1)
  glLoadIdentity;
  gluLookAT(LeftEyeFrom.x, LeftEyeFrom.y, LeftEyeFrom.z,
          LeftEyeAt.x  , LeftEyeAt.y  , LeftEyeAt.z,
          LeftEyeUp.x  , LeftEyeUp.y  , LeftEyeUp.z);
  DrawScene();

  glViewPort(w, 0, w, h); // set right viewport (Note 2)
  glLoadIdentity;
  gluLookAT(RightEyeFrom.x, RightEyeFrom.y, RightEyeFrom.z,
```

```
          RightEyeAt.x  , RightEyeAt.y  , RightEyeAt.z,
          RightEyeUp.x  , RightEyeUp.y  , RightEyeUp.z);
  DrawScene();

  SwapBuffers(FDC);
end;

procedure TForm1.FormResize(Sender: TObject);
var
  aspect: Double; // aspect ratio
begin
  glMatrixMode(gl_Projection);
  glLoadIdentity;
  aspect := (Form1.Width/2)/ Form1.Height;
  gluPerspective(45, aspect, near, far);
  glMatrixMode(gl_ModelView);
  glLoadIdentity;
  FormPaint(Sender);
end;
```

Note that the call to *glViewPort*() has been moved from procedure *FormResize* and placed twice into procedure *FormPaint*, since the scenario requires redefining the view port at the left and right positions every time the scene is updated. Also note that only one buffer swapping is performed after both halves are drawn, which prevents flickering.

5.1.4 Evaluating Cazes-type digital stereoscope

A Cazes-type digital stereoscope built with two monitors and four mirrors was evaluated by a group of 20 students.

Each user manipulated the stereoscope and watched four dynamic virtual worlds and several stereoscopic photos. The trial duration for every user was 10 minutes.

The topics evaluated were:

Table 5.2 Topics for discussion on evaluating the Cazes-type digital stereoscope

System	System-user interaction
3D images quality	Stereoscope comfort
3D illusion on moving stereo scenes	Ease in image fusion
Environments with solid, wired and mixed (solid and wired) objects.	Seasickness sensation

5.1.5 Results of the evaluation of the Cazes-type digital stereoscope

The results of the evaluation are shown in Figure 5.9 and confirm that Cazes-type digital stereoscope shows high quality 3D images. Different virtual environments and photographs were evaluated, all users perceived depth. 95% of the users could see depth in moving scenes, 100% of them perceived depth in solid object and 90% saw depth in wired objects.

On evaluating the system-user interaction 95% of the users considered comfortable the stereoscope. 90% of the users had no difficulty in fusing both images. 5% of the users had seasickness sensation.

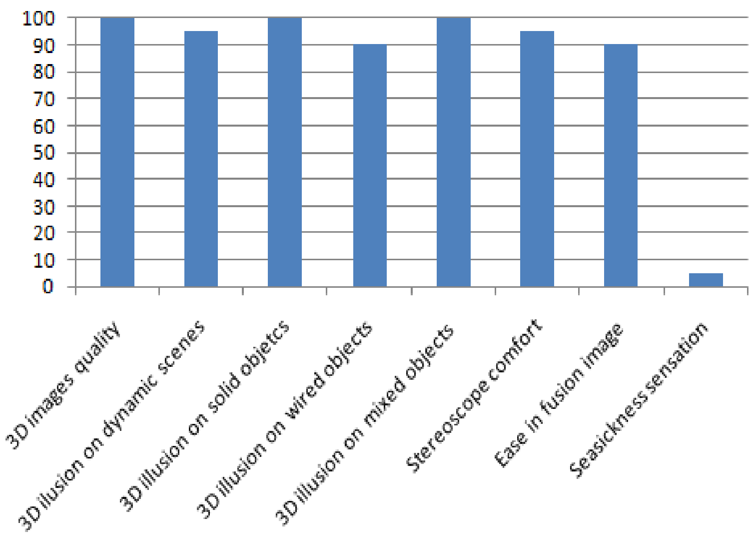


Figure 5.9. Evaluation of Cazes-type digital stereoscope

5.2 Wheatstone-type computer-based Stereoscope

This section shows the building of a stereoscope, which is formed with two parallel walls. The building of this stereoscope is based on the Wheatstone-type stereoscopic device. Due to the incorporation of some characteristics, this stereoscope is considerate as a virtual environment.

This section describes the building of stereoscopic environments in different sizes, where each wall can be built with projection screens, TV screens, and/or computer-controller monitors connected via network.

Furthermore, in this section the incorporation of different means to perform an unrestricted navigation in a 3D scene is proposed, which can be controlled through several different input devices including a keyboard, a tracker, and a remote control.

5.2.1 Digital Stereoscope Design

In section 2.2.2.1 it was mentioned that Wheatstone built a stereoscope for seeing drawings made on two paper cards. The idea in this section is the building of a stereoscope using two monitors to see a virtual world.

The digital stereoscope uses the following equipment:

1) Two monitors (preferably identical)
2) Two flat mirrors, the mirrors' structure described in section 5.1.1 can be used.
3) A stereo environment generated by computer and/or stereo images such as photos, drawings, etc.

In this section *h*, *w*, and *d* also are the *height*, *width*, and *diagonal* lengths of each monitor, see Figure 5.10.1.

Generally, it is better to use two identical monitors. When the monitors used are of different sizes, it is necessary to take into consideration that the final image size on each monitor should be equal, that is, if one screen is larger, then some portion of it will be wasted.

It is possible to use the mirrors' structure described in section 5.1.1 or to build a simple structure with two flat mirrors, which have to form an angle of 90° with each other and placed vertically upon a horizontal board, see Figure 5.10.2.

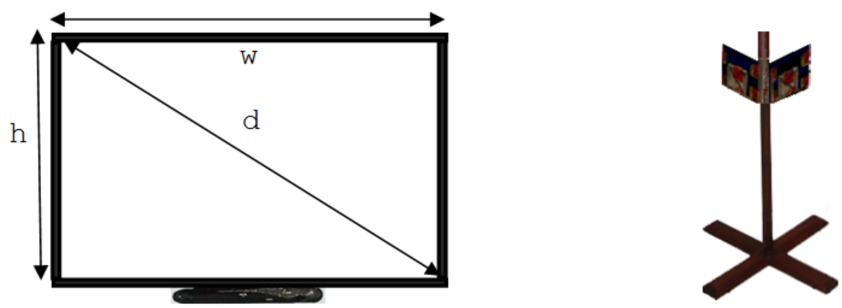


Figure 5.10 1) A monitor with height h, width w and diagonal d. 2) Two fixed mirrors

Section 5.1 mentioned that a good eye-monitor distance for a digital stereoscope through the mirrors is roughly *d* (Vali, 1966). With this distance each eye should see roughly a whole screen, that is, neither more nor less. This implies that a good distance in this stereoscope is twice *d*.

Figure 5.11 thick lines representing the monitors, the dotted lines as mirrors, the horizontal lines indicating to us the distance between the mirrors and the screens and finally, the arrows indicating the eyes' position.

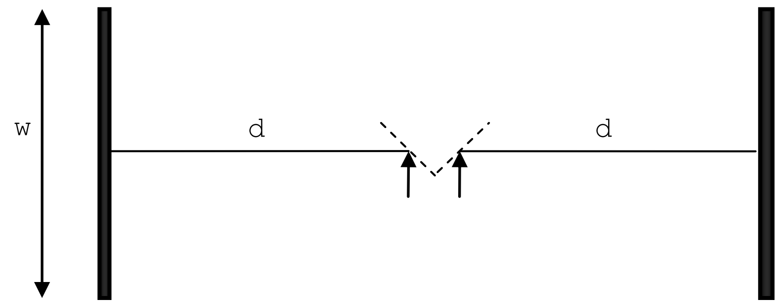


Figure 5.11. **Wheatstone-type computer-based stereoscope**

The size of the Wheatstone-type computer based stereoscope using two monitors is:

Eq. 5.13 $$Size_{W\_S} = 2d \times w$$

Figure 5.12 shows a stereoscope built with two laptops interconnected via network, the monitors are of different sizes, but both images are the same size. The laptops are set one in front the other and the mirror frame is in the middle of them. The viewer eyes should be set in front of the mirrors. The virtual environment is displayed on both monitors and it is possible to navigate it. A remote control is proposed to manipulate the world movements when two laptops are used and a keyboard when the stereoscope is built with two PCs.

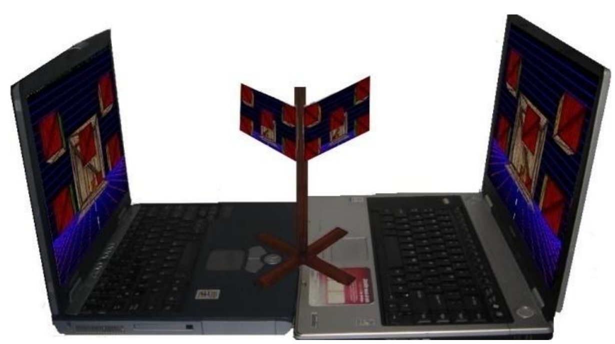


Figure 5.12 Wheatstone-type digital stereoscope built with two monitors

5.2.2 Virtual Environment Design

It was already mentioned in chapter 2.2 that the Wheatstone-type stereoscope allows us to work with big graphics. This facilitates the building of a large stereoscope for creating a new type of environment. This environment allows us to see 3D images without any color loss, flickering or ghosting and using equipment of a mid-range cost.

When building the environment, it is important to consider the following:

a) The walls of this environment can be built with monitors, projection screens or flat TVs. In this work, the word “screens” will refer to any of these computer-controlled devices. The screens size could be different, but the walls size has to be similar. In Figure 5.13 the left wall is formed with four screens, which together are as large as the right wall.
b) The number of screens on each wall depends on the virtual environment size.
c) The viewer should see both images all the time, to avoid losing the 3D illusion.

d) Every screen should be driven by a computer. Therefore, to drive all screens in the environment, a cluster of computers is needed.
e) The left and right screens should display a stereoscopic world, which has the characteristic of being slightly different.
f) Two mirrors have to be set on a large support, which could be approximately of 1.80cm. The mirrors should be adjusted to the viewer height, see section 5.1.1.

Figure 5.13 shows the environment on four flat TVs and a projection screen. A careful procedure must be followed in order to achieve a similar brightness level on both walls.

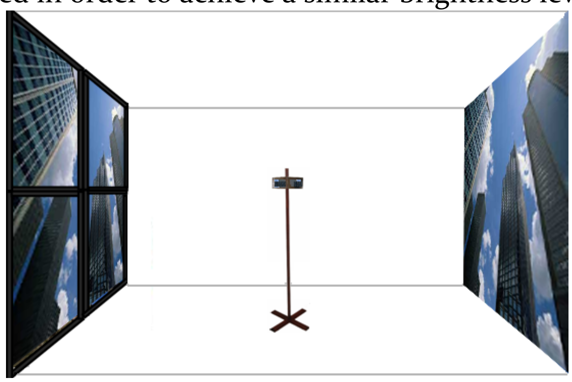


Figure 5.13. Wheatstone-Mora environment built with four plane screens and a projection screen

5.2.3 Wheatstone stereoscope using projectors

Figure 5.14 shows the Wheatstone-type stereoscope built with two projectors. The mirrors (m_1 and m_2) and projectors technique is used, see section 4.2.4.

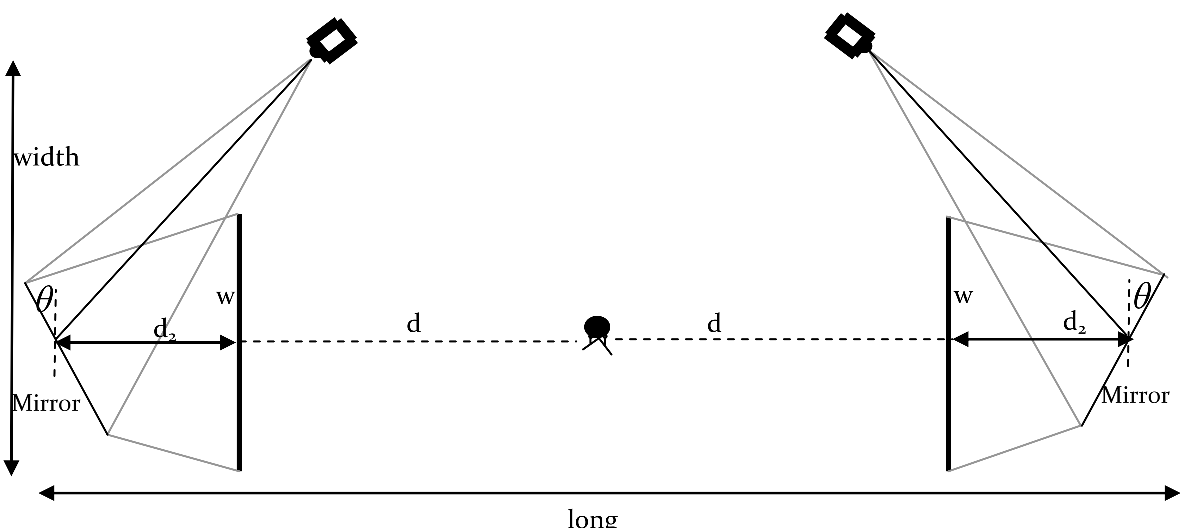


Figure 5.14Wheatstone stereoscope using two projectors

Using Eq. 5.14 and Eq. 5.15, it is possible to determine the required space in a Wheatstone-type digital stereoscope.

Eq. 5.14 $$width_{W\_S} = \frac{w}{2} + \cos\left(\frac{\pi}{2} - \theta\right)(2w - d_2)$$

Eq. 5.15 $$long_{W\_S} = 2(d + d_2 + m_2 \sin(\theta))$$

Eq. 5.16 $$size_{W\_S} = with_{W\_S} \times long_{W\_S}$$

Where *distance* and θ can be changeable.

5.2.4 Interacting in the Stereoscopic Environment

Figure 5.15 represents the interaction between a viewer and the stereoscopic environment. The black point is the viewer, who has two small mirrors; the thick lines represent two projections.

To have a correct visualization, the viewer should see both walls at the same time and the small mirrors have to remain at the same distance of both walls. The left wall displays the left stereo image, while the right wall displays the right stereo image. Therefore, the viewer can walk forwards or backwards, depending on the walls size, but he should not move away from the middle imaginary line of the room, see Figure 5.15.1 If he does move away, the mirror would reflect one wall smaller than the other one.

In order to see the world with the movements allowed, two mobile viewports are suggested, which should move in the same viewer direction and just when the viewer walks a few steps forwards or backwards.

Figure 5.15.2 shows an incorrect viewer movement; in this example the 3D effect is lost.

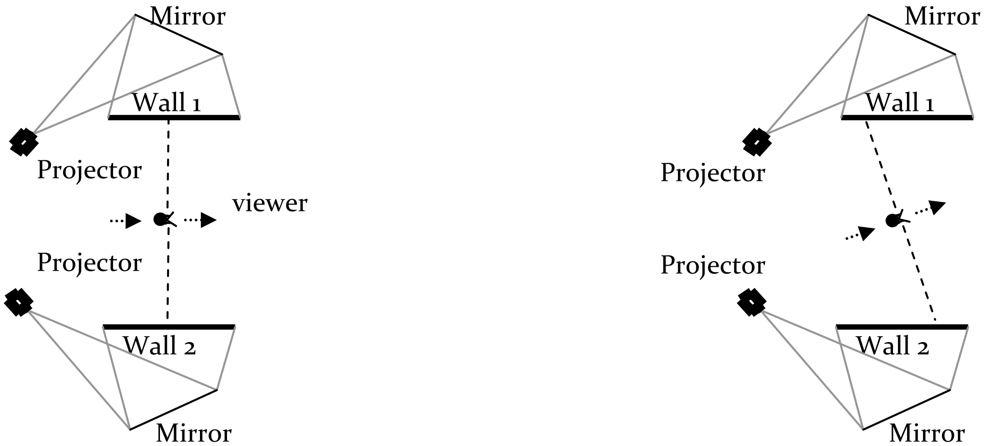


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Figure 5.15 Viewer interacting in the parallel world. A) **Correct movement.** B) **Incorrect movement**

Due to the fact that viewer movements are restricted within this environment; an unrestricted virtual navigation is suggested. This combination of physical/virtual movements provides a great sense of immersion to the user. The virtual navigation includes forward, backward, upward, downward, leftward, and rightward displacements, as well as rotations. The virtual world can be controlled through several different input devices including a keyboard, a tracker, or a remote control.

5.2.5 Evaluating Wheatstone-type digital stereoscope

In order to evaluate this environment, two stereoscopes of different size have been evaluated by a group of 50 non-expert users.

- The first stereoscope was built with two laptops, see Figure 5.12.

- The second stereoscope was created using two projectors. This stereoscope was built of 3mX2.25m and d=3.75m, the distance between the projections was 7.5m.

The trials consisted of the following. Each user manipulated the systems and watched a set of stereoscopic photos, images, and dynamic environments, which were solid, wired (done with lines), and mixed (solid and wired). The static images were presented with slides; the dynamic environments were done with an unrestricted virtual navigation. The trial duration for every user was 20 minutes, 10 minutes for each stereoscope. The following input devices were used:

-The first stereoscope was evaluated using a remote control and a keyboard.

-The second stereoscope was evaluated using a head-tracker, a remote control and a keyboard.

In the trials some topics were focused on the environment and others were focused on the environment-user interaction, see Table 5.3.

Table 5.3 Topics for discussion on evaluating the Wheatstone-type digital stereoscope

System	System-user interaction
3D images quality	Input devices used in the environment: a head-tracker, a remote control and a keyboard
3D illusion on moving stereo scenes.	Stereoscope comfort.
Environments with solid, wired and mixed (solid and wired) objects.	Viewer movements allowed and not allowed.
	Ease in image fusion
	Immersion level
	Seasickness sensation

These topics were chosen to determine the feasibility of seeing different moving and static images with comfort, immersion and ease. In addition, the input devices preference used in the environment was evaluated.

5.2.6 Results

The results of the evaluation are shown in Figure 5.16.

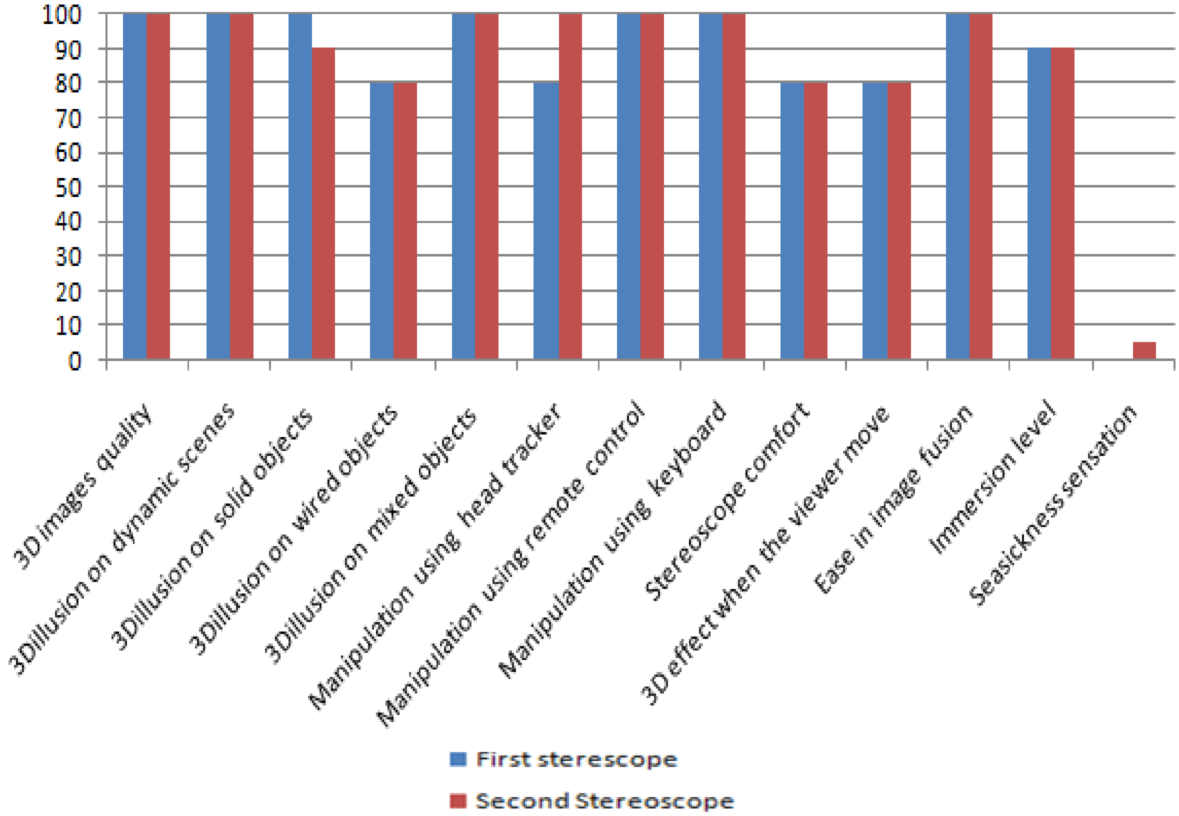


Figure 5.16. Results

After analyzing the chart, it is concluded that the viewers had no difficulty in fusing both images. This stereoscope allows real-size high-resolution images to be seen. The viewers had a clear depth perception in an environment with both moving and static images. When the different objects were tested, the solid and mixed (solid and wired) objects were seen without any problem. The perception of the 3D illusion was somewhat more difficult in the wired objects. The remote control and the keyboard use proved to be more comfortable for the users than the tracker, due to the restricted user mobility. Due as a result of restricted movement, the viewers lost the 3D effect when they moved to the right or to the left during the tests. The viewers could move forward and backwards without noticing any loss of the 3D effect. Therefore, this stereoscope is comfortable and produces high-level immersion.

5.3 Boxed-type Digital Stereoscope

This section describes the construction of a boxed-type digital stereoscope with accessible materials for many people. This stereoscope allows us to see small stereo graphics on a monitor.

The boxed-type stereoscope hides the image that corresponds to the opposite eye, using a central wall. This section describes how to build special lenses that allow for seeing a 3D world on a monitor. These lenses can be assembled and disassembled to facilitate its transportation.

5.3.1 Building the Boxed-type Digital Stereoscope

The materials used for doing these lenses are cardboard sheets and the model shown in Figure 5.17, which is to a scale 1:4. Figure 5.18.1 shows the assembled lenses and their final measurements. Figure 5.18.2 shows our Boxed-type digital stereoscope.

With this stereoscope 3D images can be seen, such as: photos, solid and wired objects and moving scenes. It can be used for doing tests in prototypes that employ stereo graphics.

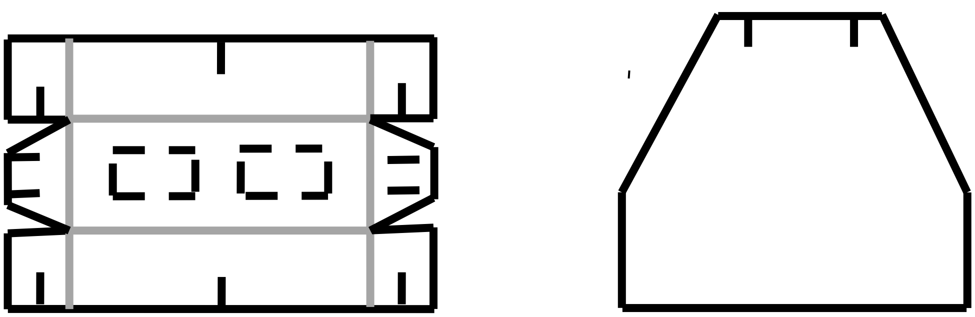
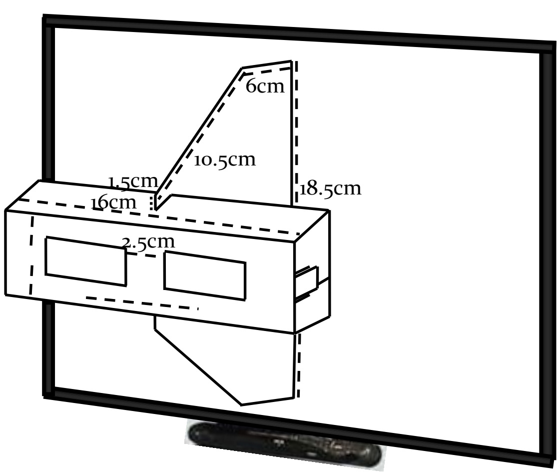
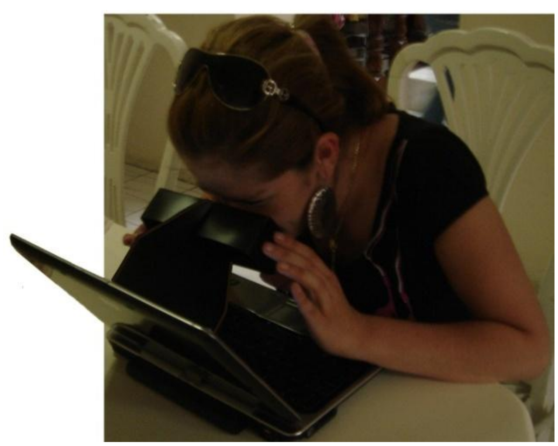


Figure 5.17 Pattern of the lenses, scale 1:4



1



2

Figure 5.18 Boxed-type stereoscope

5.3.2 Evaluating Boxed-type digital stereoscope

A Boxed-type digital stereoscope built with a monitor was evaluated by a group of 20 students. Each user manipulated the stereoscope and watched different virtual worlds and stereoscopic photos. The trial duration for every user was 5 minutes. The topics evaluated were:

Table 5.4 Topics for discussion on evaluating boxed-type digital stereoscope

System	System-user interaction
3D images quality	Stereoscope comfort
3D illusion on moving stereo scenes	Ease in image fusion
Environments with solid, wired and mixed (solid and wired) objects.	Seasickness sensation

5.3.3 Results of the evaluation of the Boxed-type digital stereoscope

The results of the evaluation are shown in Figure 5.19. 100% of the users could see high quality 3D images. 95% of the users could see depth in moving scenes, 95% of them perceived depth in solid and wired objects; 100% of user saw depth in mixed objects.

On evaluating the system-user interaction 95% of the users considered comfortable the stereoscope. Nobody had difficulty in fusing both images or had seasickness sensation.

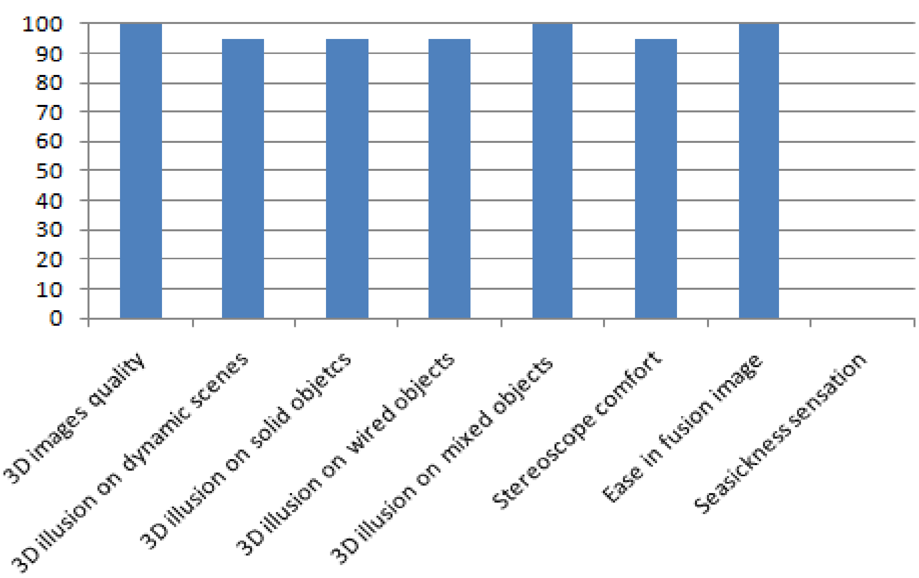


Figure 5.19. Evaluation of Boxed-type digital stereoscope

5.4 Summary

This chapter described the adaptation of three digital stereoscopic devices. It is concluded that although the original stereoscopes are antique, it is possible to use them with very good results. Some important observations about our digital stereoscopes are:

Cazes-type computer-based stereoscope

- It can be built with four mirrors and two PCs, which shows a 3D world.
- This implementation enjoys bright colorful stereo images, and requires no dark room or special environments
- This digital stereoscope was evaluated and the results show the users perceived high quality 3D images. 95% of the users could see depth in moving scenes and 90 of them perceived depth in wired objects.
- On evaluating the system-user interaction 95% of the users considered it comfortable. 90% of the users had no difficulty in fusing both images. 5% (a user) had seasickness sensation.

Wheatstone-type digital stereoscope

- It has been built in different sizes using different digital devices and two mirrors.
- The Wheatstone-type stereoscope was analyzed and is used for building a large stereoscope. This digital stereoscope is considered as a new virtual environment due to the characteristics that it has.
- The environment size can be as large as the walls themselves can be built.
- The virtual environment does not have any color loss.
- The construction of the environment can be carried out with the equipment that any institution normally has; this is a didactic method. If the environment is small, the cost decreases.
- The number of viewers depends on the environment size. But the viewers should not cover the projection wall from other viewers. For example, in our first evaluated stereoscope only one viewer can use it at a time, while in the second one, two viewers can use it, although only one of them can manipulate it.
- The walls can be built with different screen sizes, such as the one shown in Figure 5.13, but the walls have to be totally built for experiencing a good visualization. This means walls without any holes.
- This implementation produces high quality stereo images, which can be static or in movement. This technique does not use any overlapped image on the same screen. Due to this, it does not produce any ghosting or flickering; the color depends on the projectors, monitors or devices used.
- The disadvantages include restricted movements and loss of the 3D illusion when the viewer does not see both images.
- This world can be used in teaching, in stereoscopic museums, in videogames for enjoying 3D worlds and for people that enjoy creating stereoscopic imagery.
- This stereoscope was built in two sizes and was evaluated by 50 users. The results show that it allows seeing real-size high-resolution images without any problem. Different input devices were tested, the remote control and the keyboard proved to be more comfortable for the users than the tracker, due to the restricted user mobility.

Finally a boxed-type digital stereoscope is shown in this chapter.

- This stereoscope allows us to see a small 3D environment, which can be static or in movement in an easy way. It also produces high quality images and without any color loss. This stereoscope is very accessible for most people.
- This stereoscope was evaluated by 20 users and the results of the evaluation show the users could see high quality 3D images. 95% of the users could see depth in moving scenes and solid objects. All users saw depth in mixed objects.
- In the system-user interaction 95% of the users considered comfortable the stereoscope. Nobody had difficulty in fusing both images or had seasickness sensation.