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TÍTULO:	3D line drawing from point clouds using chromatic stereo and shading	:TITLE
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<b>Resumen</b>	
TITULO:	Dibujo de líneas tridimensional sobre nubes de puntos mediante estéreo cromático y sombreado.
RESUMEN:	<p>Los sistemas de escaneo laser se han convertido en una herramienta habitual en la documentación geométrica del patrimonio. Como uno de sus resultados, se obtienen nubes de puntos que incluyen información adicional como la reflectancia o el color procedente de una textura fotográfica. Sin embargo, su manejo implica la gestión de ficheros brutos de gran tamaño y no es sencillo obtener algunos de los productos que se demandan por los técnicos habituados al trabajo patrimonial como son los dibujos de líneas.</p> <p>Nuestra contribución consiste en enriquecer la componente temática mediante el sombreado y el estéreo cromático, resaltando los detalles de la superficie documentada y mejorando la identificación y dibujo de las líneas.</p> <p>Con el fin de ilustrar la utilización de capas temáticas para el dibujo 3D, se describe, paso a paso, un procedimiento simple para el dibujo tridimensional a partir de nubes de puntos.</p>
DESCRIPTORES NATURALES:	nube de puntos, dibujo 3D, Chromadepth, estéreo cromático, patrimonio
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<b>Abstract</b>	
TITLE:	3D line drawing from point clouds using chromatic stereo and shading
ABSTRACT:	<p>Terrestrial laser scanners (TLS) have become a common tool in geometric documentation of heritage. As output, they can produce point clouds along with thematic information such as reflectance or photographic texture. Some of their drawbacks are that the products which have been directly obtained from raw point clouds imply massive data handling, besides, standard products demanded by organizations and technicians such as wireframe models and line drawings are not readily computed from them; therefore, human supervised point cloud processing is still mandatory.</p> <p>Our contribution is to enriching the point cloud thematic component using shading and Chromadepth® information, which allows to enhance the point cloud surface details and to improve the identification and drawing of the lines defining the elements over the point cloud.</p> <p>In order to illustrate the utility of these thematic layers, we describe, step by step, a simple procedure to draw 3D lines from point clouds.</p>
NATURAL KEYWORDS:	point cloud, 3D line drawing, Chromadepth, chromatic stereo, heritage
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# 3D LINE DRAWING FROM POINT CLOUDS USING CHROMATIC STEREO AND SHADING

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**KEY WORDS:** point cloud, 3D line drawing, Chromadepth, chromatic stereo, heritage

## ABSTRACT:

Terrestrial laser scanners (TLS) have become a common tool in geometric documentation of heritage. As output, they can produce point clouds along with thematic information such as reflectance or photographic texture. Some of their drawbacks are that the products which have been directly obtained from raw point clouds imply massive data handling, besides, standard products demanded by organizations and technicians such as wireframe models and line drawings are not readily computed from them; therefore, human supervised point cloud processing is still mandatory.

Our contribution is to enriching the point cloud thematic component using shading and Chromadepth® information, which allows to enhance the point cloud surface details and to improve the identification and drawing of the lines defining the elements over the point cloud.

In order to illustrate the utility of these thematic layers, we describe, step by step, a simple procedure to draw 3D lines from point clouds.

## 1. INTRODUCTION

POINT CLOUDS, enriched with thematic information such as laser reflectance or photographic texture, have found widespread usage in several engineering fields; among them, the geometric documentation of heritage can be highlighted. The ability to readily acquire models and products, such as orthoimages or sections, has contributed its acceptance. Nowadays, however, some of the commonly demanded products such as line drawings are not readily available from point clouds.

It is interesting to emphasize that, besides the drawing, the extraction of edges from the point cloud within the three-dimensional space has been applied in many areas, such as: image segmentation, 3D scan alignment or photographic image alignment with respect to the point cloud. We are not reporting those works exhaustively, but focusing on those which are relevant for our purpose of line drawing over point clouds.

The high quality line drawing demanded in cultural heritage makes the human interaction with the 3D model unavoidable. As the interaction interface is a computer screen, the operator does not interact directly with the 3D point cloud but with its 2D projections along with the available thematic information on the computer screen. Figure 1 details the interaction process, 3D information is projected in 2D enriched with thematic information to produce the image on the screen, the operator makes the drawing on the computer screen, and hence the line drawing is backprojected on the 3D point cloud, yielding finally the 3D line drawing model.

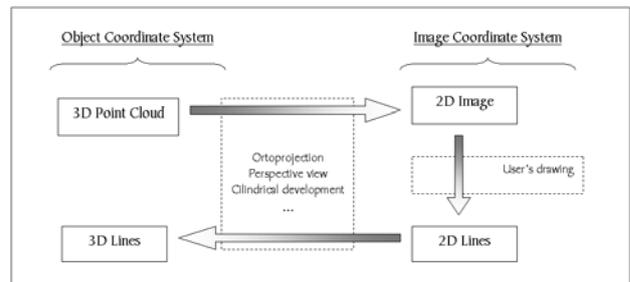


Figure 1: Manual line drawing workflow

Line drawing is highly dependent on the thematic information available. Sometimes this information is degraded during the alignment of several scans, specially when the coded information is laser reflectivity that varies according to the distance and orientation with respect to the imaged object. Because of that we propose to synthesize thematic information from the 3D shape of the object. In our experience we have found particularly useful shading and Chromadepth information.

In the case of the shading, the user can select the relative location of the point cloud with respect to the light source, and hence making visible details of the 3D point cloud worth to direct the drawing.

The usage of Chromadepth® system (this technology is owned by American Paper Optics, Inc.) allows to visualize depth from a single 2D image under a controlled point of view. This visualization of the 3D information has also proven quite effective in guiding the line drawing process in order to achieve the high quality results demanded in heritage documentation applications.

## 2. INTERFACING 3D POINT CLOUDS BY 2D PROJECTIONS

In general the data format for a 3D raw point cloud is  $(X, Y, Z, N_D)$ , where the first three values are the coordinates defining the 3D location of a point, and  $N_D$  is the thematic vector containing visualization information for the 3D point, fields typically defining the thematic components are:

- Data captured with the sensor directly, like reflectivity or distance.
- Assigned data from external sources: such as the radiometric information gathered with a digital camera normally located close to the 3D sensor central point. There are even (Reulke, 2006) some sensors like the PMD (Photonic Mixer Device) cameras which can record image and range at the same time.
- Calculated data, for instance: curvature, shading or Chromadepth.

In Ardissonne et al. (2005) it is illustrated a multilayer approach by showing all together: the reflectivity image (obtained from the scanner), the range image (calculated, while the viewpoint has been shifted) and the photographic image (from a different source).

It has to be noted that, in general, the point cloud is composed from a set of 3D scans gathered from rather different sensor locations, and it has to be possible to compute the two-dimensional projection from any point of view, by any kind of projection and showing any thematic data. In general we can apply the perspective projection to compute the 2D image from the point cloud. Nevertheless, for the considered points clouds, points corresponds to the surface of the object and hence, it could be—at least locally—possible to represent the point cloud by means of a 2D parameterisation, which implies the projection method can be extended to include perspectives, orthographic views or cylindrical developments. The concept has been extended to fitted surfaces like the series of cylinders and planes as proposed in Bonino et al. (2005). These extended range of projections enable to select the one where the thematic information is shown clearly for the line drawing

According to Ressel et al. (2006), right from the beginning, it was seen the interest of merging scanner data and photographic image. Given that the image resolution is usually greater than the point density, one possible solution consists in orientating the image and adding an additional channel with the distance in each pixel from the origin of the photograph. The user works over the two-dimensional image but the output is in the three-dimensional object space (Alshawabkeh and Haala, 2004; Bornaz and Dequal, 2004; Abdelhafiz et al., 2005; Neubauer et al., 2005).

Nonetheless, our proposed solution, regarding the photographic texture, consists in assigning the thematic values to the points; as it was said above, it is common for the photographic image to have greater resolution than the point cloud, therefore, some information will be lost in this process. This drawback can be eluded, to some extent, by adding new 3D points obtained by interpolation in the photographic image and, as points store attributes, these new points can be ticked so that they are used only if the generated two-dimensional image, over which the user works, is compatible with the photographic one.

## 3. LINE DRAWING FROM POINT CLOUDS

All the algorithms from image analysis might be used on the 2D thematic images we are working with, moreover, as it is possible to emulate user's criteria when extracting edges, it will be feasible to define automatic algorithms. The use of these techniques in photogrammetry was set by Schenk (2000) however it is still an open issue that does not produce the required accuracy for heritage documentation.

A review of the related works where linear elements are employed illustrates that they fit the scheme previously set (figure 1): Dorminger and Briese (2005) represent the shading image on a cylindrical development, Briese (2006) shows more examples including reflectivity images, in Deveau et al. (2005a) the profiles of some surfaces of revolution are extracted from the range image, orientation and curvature images can be found in Martínez et al. (2005) and, even if it has been designed for meshes, the automatic contour drawing method from normal vectors of Boehler et al. (2003) can be tailored for point clouds without meshing as well, since there are algorithms to calculate the normal vectors directly from the point as it is described below.

Obviously, the presented scheme can be extended (figure 2) by obtaining several two-dimensional images from different viewpoints (what allows the conventional stereoscopic vision) or the simultaneous management of several thematic layers by means of multi-criterion algorithms for the automatic edge extraction. In Alshawabkeh et al. (2006) the linear elements from images generated by the scanner (range and reflectivity) are compared with the elements extracted from the photographic images to improve the geometric relationship between photography and scanner data, on the other hand, the outputs from different layers are fused in a unique final edge map, Deveau et al. (2005b).

For automated processing, the need of a view no longer exists so the scheme (figure 2) has also the possibility of obtaining the lines directly from the three-dimensional space. In Gross and Thoennessen (2006), a calculated 3D neighbourhood for each point is used to obtain the eigenvalues which permit to identify the edge points, then, in a second step these points are converted into line elements. Another example can be found in Lerma and Biosca (2004), although the last conversion to lines is not performed, they recognize the edge points by analysing the curvature directly calculated in the 3D space.

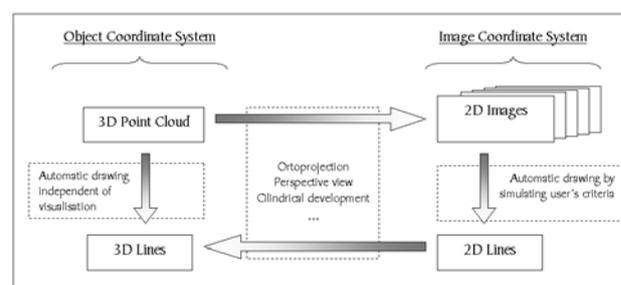


Figure 2: Extended workflow including the automation process

## 4. LINE DRAWING OVER A ORTHOGRAPHIC PROJECTION. AN EXAMPLE OF IMPLEMENTATION

This section is devoted to developing in detailed an example of line drawing for the orthographic projection. More than a

conceptual approach, it is intended as example explaining step by step how to obtain the three-dimensional lines.

#### 4.1 From 3D point cloud to 2D image

Point clouds are lists of coordinates  $(X,Y,Z,N_D)$  where  $N_D$  means the thematic component, gray scale, reflectivity or colour, to cite a few.

According to the general outline presented in the introduction, it must be defined a relationship between the tridimensional object coordinates and the coordinates (column, row):

$$\begin{cases} \text{column} = f(X, Y, Z) \\ \text{row} = g(X, Y, Z) \end{cases} \quad (1)$$

Where  $f(X,Y,Z)$  and  $g(X,Y,Z)$  mean whatever mathematic function. The lines will be drawn over these bidimensional coordinates, then an inverse relationship will provide the tridimensional coordinates of each pixel, these corresponding functions are indicated by  $h(\text{column}, \text{row})$ ,  $j(\text{column}, \text{row})$  and  $k(\text{column}, \text{row})$ :

$$\begin{cases} X = h(\text{column}, \text{row}) \\ Y = j(\text{column}, \text{row}) \\ Z = k(\text{column}, \text{row}) \end{cases} \quad (2)$$

As a practical application, we will develop the obtaining of an orthographic view, similarly to (Jansa et al., 2004), defined by the vector  $\mathbf{u}(X_0, Y_0, Z_0)$  from which, the angles  $H$  (azimuth from the  $Y$  axis in direct direction, that is, anti-clockwise) and  $V$  (colatitude, angle from the  $Z$  axis) are calculated as:

$$\tan H = \frac{X_0}{Y_0} ; \tan V = \frac{\sqrt{X_0^2 + Y_0^2}}{Z_0} \quad (3)$$

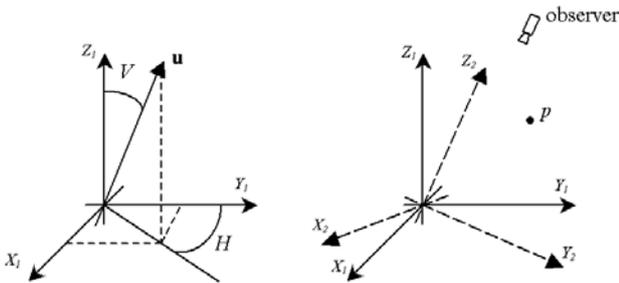


Figure 3: On the left, the vector  $\mathbf{u}$  is drawn in the coordinate system 1, on the right the new coordinate system 2 whose  $Z$  axis follows the  $\mathbf{u}$  vector

A new coordinate system is defined, with the same origin but whose  $Z$  axis follows the same direction as vector  $\mathbf{u}$ . These angles permit converting the object coordinate system  $(X_1, Y_1, Z_1)$  to the system  $(X_2, Y_2, Z_2)$ :

$$\begin{bmatrix} X_2 \\ Y_2 \\ Z_2 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos V & \sin V \\ 0 & -\sin V & \cos V \end{bmatrix} \cdot \begin{bmatrix} \cos H & \sin H & 0 \\ -\sin H & \cos H & 0 \\ 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} X_1 \\ Y_1 \\ Z_1 \end{bmatrix} \quad (4)$$

$$\begin{bmatrix} X_2 \\ Y_2 \\ Z_2 \end{bmatrix} = \begin{bmatrix} \cos H & \sin H & 0 \\ -\cos V \sin H & \cos V \cos H & \sin V \\ \sin V \sin H & -\sin V \cos H & \cos V \end{bmatrix} \cdot \begin{bmatrix} X_1 \\ Y_1 \\ Z_1 \end{bmatrix} \quad (5)$$

In this new system, the observer is placed at infinity in the  $Z_2$  axis so, for each point  $(p)$ , the higher the value in  $Z_2$ , the closer to the observer. For the searched purpose, it is not needed a third rotation orienting the  $XY$  axes with any specific direction.

In order to obtain the image, we need integer numbers for coordinates  $(X_2, Y_2)$ , hence, they are rounded to a defined size (1 cm, 5 mm, ...). This size is a key value; therefore, it must be chosen carefully to obtain the better resolution without leaving gaps between pixels with data. Once the resolution  $-r-$  is defined, the new set of coordinates is defined:

$$\begin{cases} X_3 = \text{round}\left(\frac{X_2}{r}\right) \\ Y_3 = \text{round}\left(\frac{Y_2}{r}\right) \\ Z_3 = Z_2 \end{cases} \quad (6)$$

We go through the list of points  $(X_1, Y_1, Z_1)$  and calculate their  $(X_3, Y_3, Z_3)$  coordinates, at the same time we generate two two-dimensional arrays:  $\mathbf{M}(X_3, Y_3) = Z_3$  which stores the highest values (the closest to the observer) of  $Z_3$  for each pair  $(X_3, Y_3)$ , that is to say, the  $Z$ -buffer, and  $\mathbf{N}(X_3, Y_3) = N_D$  which stores the digital level held by the point with a bigger value of  $Z_3$ . When finishing, we will have a reduced version of the point cloud with a single point for each pixel, the one with a higher value of  $Z_3$  among all which have the same  $(X_3, Y_3)$  coordinates. It is also necessary to store the extreme values of every coordinate  $(X_{3\min}, X_{3\max}, Y_{3\min}, Y_{3\max}, Z_{3\min}, Z_{3\max})$ .

We propose to use this rather simple method to select the image point when several 3D point are viewed in the same pixel. Some examples for more elaborated methods can be found in Azariadis and Sapidis (2005), Liu et al. (2006), Ressler et al. (2006), in any case, the important point is to establish the existence of an only value in each pixel.

Some special features of the computer language must be taken into account: the origin of the image can be either the pixel  $(0,0)$  or  $(1,1)$ , on the other hand, it is usually placed at the upper-left corner and the  $Y$  values (rows) grow downward; on the contrary, the origin of the system  $(X_3, Y_3)$  is at the lower-left corner and the  $Y$  values increase upward and for the  $(0,0)$  origin.

$$\begin{cases} \text{column} = X_3 - X_{3\min} \\ \text{row} = Y_{3\max} - Y_3 \end{cases} \quad (7)$$

The corresponding colour in each pixel comes from the value  $N_D$ . Besides the image file, a text file stores the values of resolution, the bounds obtained when scanning the point cloud, the image size (number of rows  $n_{row}$  and columns  $n_{col}$ ) and the values from the array  $\mathbf{M}$ .

The figure 4 presents an axonometric view of a simplified point cloud and the orthoimage calculated according to the described method (the grey scale shows reflectivity values).

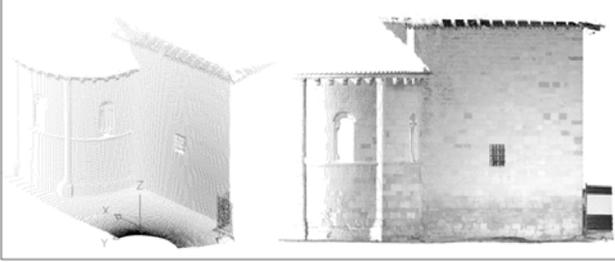


Figure 4: On the left, 3D view of the point cloud (decimated), on the right, orthoimage generated

#### 4.2 Line drawing in 2D and backprojection 2D to 3D point cloud

Then, we can draw the two-dimensional lines of the interesting elements over the image after having inserted it in a CAD software (figure 5, left).

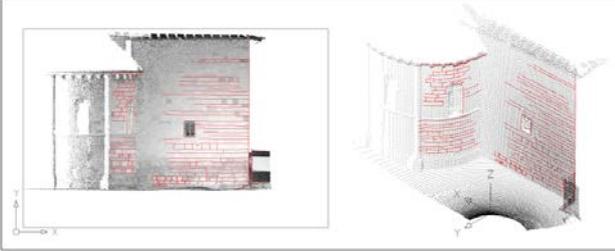


Figure 5: 2D lines over the orthoimage (left), and the same lines after projecting them over the point cloud (right)

Lines are series of coordinates  $(x_{CAD}, y_{CAD})$  with their topology, that is, the links between them. Once we have the two-dimensional lines, they are transformed to the object space by obtaining the corresponding three-dimensional  $(X_1, Y_1, Z_1)$  coordinates of each  $(x_{CAD}, y_{CAD})$  pair and by keeping their topology.

If the image file has been inserted arbitrarily (place and scale) in the CAD space, we will need to know the coordinates of two corners to transform from  $(x_{CAD}, y_{CAD})$  to  $(column, row)$ , for instance the lower-left  $(x_{LLCAD}, y_{LLCAD})$  and the upper-right  $(x_{URCAD}, y_{URCAD})$  ones, the values must be integer.

$$\begin{cases} column = \text{int} \left[ \frac{n_{col}(x_{CAD} - x_{LLCAD})}{x_{URCAD} - x_{LLCAD}} \right] \\ row = \text{int} \left[ \frac{n_{row}(y_{URCAD} - y_{CAD})}{y_{URCAD} - y_{LLCAD}} \right] \end{cases} \quad (8)$$

In this equation, the origin has been set to  $(0,0)$ , so the transformations follow like that:

$$\begin{cases} X_3 = X_{3\min} + column \\ Y_3 = Y_{3\max} - row \end{cases} \quad (9)$$

From the  $(X_3, Y_3)$  values, we can find in the array  $\mathbf{M}$  what is the corresponding  $Z_3$  value. Then, the coordinates  $(X_2, Y_2, Z_2)$  are computed:

$$\begin{cases} X_2 = X_3 \cdot r \\ Y_2 = Y_3 \cdot r \\ Z_2 = Z_3 \end{cases} \quad (10)$$

Finally, the three-dimensional coordinates in the object space are obtained by transposing the array used in (5), so we can go from  $(X_2, Y_2, Z_2)$  to  $(X_1, Y_1, Z_1)$  as follows:

$$\begin{bmatrix} X_1 \\ Y_1 \\ Z_1 \end{bmatrix} = \begin{bmatrix} \cos H & -\cos V \sin H & \sin V \sin H \\ \sin H & \cos V \cos H & -\sin V \cos H \\ 0 & \sin V & \cos V \end{bmatrix} \cdot \begin{bmatrix} X_2 \\ Y_2 \\ Z_2 \end{bmatrix} \quad (11)$$

The figure 5 shows the 2D lines drawn over the image in the CAD system and the same lines in the object three-dimensional space over the point cloud.

This process can be repeated with the same point cloud from different directions (vector  $\mathbf{u}$ ) until completely cover the elements to draw. The generated images are orthoimages so they can be useful for cartographic purposes as they are metric outputs.

#### 5. SYNTHESIZING SHADING THEMATIC LAYER

If a reliable  $N_D$  is not available, line drawing in 2D would be rather difficult and inaccurate. As most of the sensors capture both intensity and range data and the former can be displayed like a grey-scale image, this information is not ready available after having merged several scans gathered from different viewpoints. The reason is that  $N_D$  value depends on the distance, the incidence angle and the observed material, as a result, if the final image just obtained by averaging values most of the texture will be blurred. The photographic texture might offer richer information, however, external lighting conditions, shadows and radiometric differences might degrade this information.

In poor  $N_D$  cases, we can resort to compute an artificial shading to show the relief of the objects represented by the point cloud. Considering the classic *lambertian reflection model* (for instance, in Folley et al., 1990) in which the brightness value in each point depends only on the cosine of the angle ( $\theta$ ) between two vectors: the normal vector ( $\mathbf{n}$ ) to the surface from the point itself and the vector which define the direction of the lighting source ( $\mathbf{l}$ ), one important feature of this model is that the value is independent of the position of the user, hence, it can be assigned to the point (figure 6, left).

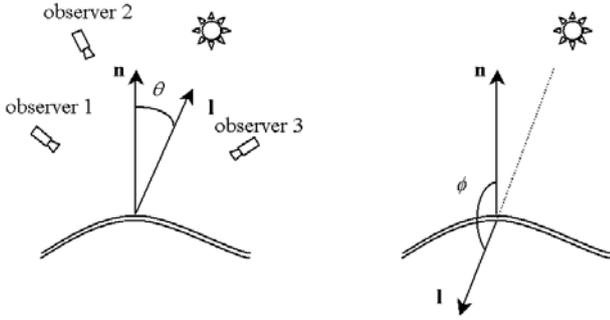


Figure 6: In the Lambertian reflection model (on the left) the brightness depends only on the angle ( $\theta$ ), wherever the observer is. The proposed model (on the right) the Lambertian but considering  $\theta$  values ranging in the  $[0, \pi]$  interval

The model we are to use is a slight variation (figure 6 right), first the lighting vector is defined from the source to the surface, on the other hand, in the Lambertian model, points whose angles are greater than  $\pi/2$  are not illuminated, whereas we will permit all the values in order to assign values to all the point cloud.

If we have two vectors  $\mathbf{v}(X_v, Y_v, Z_v)$  and  $\mathbf{w}(X_w, Y_w, Z_w)$ , the cosine of the angle between them is calculated by the following expression:

$$\cos \phi = \frac{X_v X_w + Y_v Y_w + Z_v Z_w}{\sqrt{X_v^2 + Y_v^2 + Z_v^2} \sqrt{X_w^2 + Y_w^2 + Z_w^2}} \quad (12)$$

The user selects the lighting source location but the normal to the point cloud surface has to be computed. There are many methods to calculate the normal vector, in general, either they are based on the definition of local surfaces or they mesh the point cloud. Anyhow, at each point, normal depends on neighbour points. The stages of this process are (Ou Yang and Feng, 2005):

- Firstly, for each point, it is decided what points in its neighbourhood are to be used.
- Secondly, these points are employed to estimate the normal vector.
- Finally, the inner and outer directions have to be established.

Setting which points are the nearby ones in the object space, in the coordinate system  $(X_1, Y_1, Z_1)$ , can be difficult, however, in the system  $(X_3, Y_3, Z_3)$  it is immediate since the points are regularly arranged along  $X$  and  $Y$  coordinates.

We use a method similar to the one proposed by Yokoyama and Chikatsu (2006) to calculate the normal vector. For each pixel, a mean plane is calculated using their nearby pixels (with a neighbourhood of 1 pixel, 2, 3, ...). The equation of a plane including the point  $p(X_p, Y_p, Z_p)$  is:

$$A(X - X_p) + B(Y - Y_p) + C(Z - Z_p) = 0 \quad (13)$$

Once the plane has been defined, the components of the normal line  $(a, b, c)$  should meet the following condition:

$$\frac{a}{A} = \frac{b}{B} = \frac{c}{C} \quad (14)$$

When setting the normal from a plane, the line is obtained but it is also necessary to define the inner and outer directions, to solve this, we set  $C=1$ , like this, the vector is oriented towards the observer.

A loop goes through all the elements in array  $\mathbf{M}$ , for each one, the coordinates  $(X, Y, Z)$  are got and there is a new loop which goes through the nearby points, with each neighbour we calculate the difference of coordinates and with the summations we pose the following equation which permits obtaining the parameters  $A$  and  $B$  of the plane:

$$\begin{bmatrix} \sum \Delta X^2 & \sum \Delta X \Delta Y \\ \sum \Delta X \Delta Y & \sum \Delta Y^2 \end{bmatrix} \cdot \begin{bmatrix} A \\ B \end{bmatrix} = \begin{bmatrix} \sum \Delta X \Delta Z \\ \sum \Delta Y \Delta Z \end{bmatrix} \quad (15)$$

After having the values  $A$ ,  $B$  and  $C$ , we calculate the components of the normal unit vector:

$$\begin{cases} a = \frac{A}{\sqrt{A^2 + B^2 + 1}} = X_{N3} \\ b = \frac{B}{\sqrt{A^2 + B^2 + 1}} = Y_{N3} \\ c = \frac{1}{\sqrt{A^2 + B^2 + 1}} = Z_{N3} \end{cases} \quad (16)$$

In these identities the coordinates  $(X, Y, Z)$  are marked with the sub-index  $-N-$  to indicate that it is the normal vector and with a  $-3-$  because they are in the coordinate system  $(X_3, Y_3, Z_3)$ .

On the other hand, the lighting vector (sub-index  $-L-$ ) will be defined in the object coordinate system, that is  $(X_1, Y_1, Z_1)$ , to calculate the angle, both of them had to be in the same system, consequently, it is necessary to transform the lighting vector to the system  $(X_3, Y_3, Z_3)$ :

$$\begin{bmatrix} X_{L3} \\ Y_{L3} \\ Z_{L3} \end{bmatrix} = \begin{bmatrix} X_{L2} \\ Y_{L2} \\ Z_{L2} \end{bmatrix} = \begin{bmatrix} \cos H & \sin H & 0 \\ -\cos V \sin H & \cos V \cos H & \sin V \\ \sin V \sin H & -\sin V \cos H & \cos V \end{bmatrix} \cdot \begin{bmatrix} X_{L1} \\ Y_{L1} \\ Z_{L1} \end{bmatrix} \quad (17)$$

If both of them are unit vectors (if not they must be normalized), the angle can be calculated by the equation (12):

$$\cos \phi = X_{N3} X_{L3} + Y_{N3} Y_{L3} + Z_{N3} Z_{L3} \quad (18)$$

The normal vector has its origin in the point to analyse but the lighting vector comes from an external point, so the greatest value happens when  $\cos \phi = -1$  (angle  $\pi$ , vectors with opposite

directions), and the lowest when  $\cos \phi = 1$  (angle 0, the same direction); fitted to the range 0-255 we will supply the array  $N(X_3, Y_3) = N_D$  with the digital level.

$$N_D = 255 \frac{1 - \cos \phi}{2} \quad (19)$$



Fig. 7. Example of image obtained directly from the reflectivity values after having merged several scans (left) and the shading image (right)

## 6. SYNTHESIZING CHROMATIC THEMATIC LAYER

Another method to improve the usage of  $N_D$ , is the Chromadepth® system. The advantage of this system is that it does not use two separated images, what would require two coordinated pointers to identify a single point in the three-dimensional space. In Chromadepth®, the sensation of relief is obtained by modifying the colour, therefore, it is not suitable for real colour images because the original colour going disappears, but it is very interesting for grey scale images.

This system uses glasses with special prisms which diffract with a different angle according to the wavelength, so that, hot colours (red) are showed closer than the cold ones (blue). This stereo is easy to implement in the described process because we have the whole range of distances stored in the array  $M$ .

There are some chromatic scales which works well in Chromadepth®, a very simple one divide the range in four flights sorted by the distance to the observer from the closest to the furthest. The next table shows how each chromatic channel changes (values from 0 to 1), (Schumann and Schoenwaelder, 2002).

	Red -R-	Green -G-	Blue -B-
flight 1	1	from 0 to 1	0
flight 2	from 1 to 0	1	0
flight 3	0	1	from 0 to 1
flight 4	0	from 1 to 0	1

Table 1. Multipliers of the chromatic channels in the Chromadepth® image

The Chromadepth® image makes the sensation of relief, but the object are not sharply defined, the better is to merge it with the shading image. In figure 8 it can be seen the chromatic image, the shading and the merged ones.

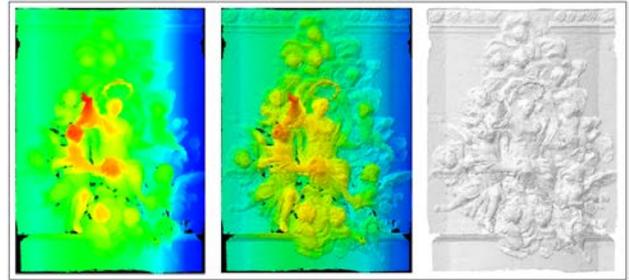


Figure 8: The image chromatic (centre) is the sum of the Cromadepth® image (left) and the shading image (right)

To obtain the merged image, we have both arrays  $M(X_3, Y_3) = Z_3$  and  $N(X_3, Y_3) = N_D$ . Each pair of coordinates  $(X_3, Y_3)$  provide with a value of  $Z_3$ , from this value we obtain a chromatic combination RGB, on the other hand, the array  $N$  supply with the digital level  $N_D$ . The new chromatic values  $R'G'B'$  can be obtained according to:

$$\begin{cases} R' = N_D \cdot R \\ G' = N_D \cdot G \\ B' = N_D \cdot B \end{cases} \quad (20)$$

The figure 9 shows four orthoimages from a sculpture over which it has been drawn a set of lines (in black), in the figure 10 this lines has been projected over the three-dimensional model.

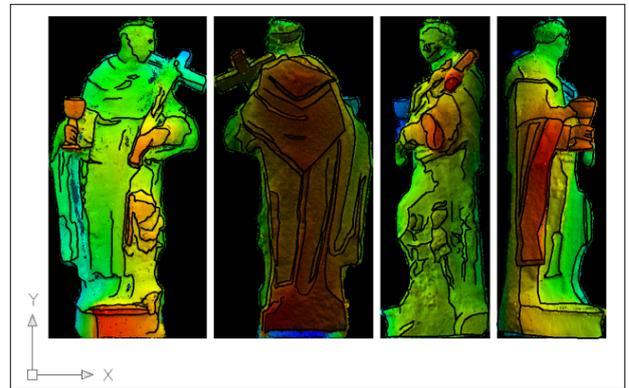


Figure 9: 2D drawing over the Cromadepth® image



Figure 10: 3D lines over the point cloud

It must be emphasized that this kind of stereo permit seeing relief, so the ability to extract information is enhanced, nevertheless, the stereoscopy is not homogeneous through the whole range and the colour range seems strange to the sight. With respect to the comfort and the ability to detect some elements, this method is not comparable with the polarized glasses used in photogrammetry, it must be considered more like a variation of the well-known red-blue anaglyphs.

## 7. CONCLUSIONS

Line drawing is one of the key products used in heritage documentation. The production of a line drawing from a 3D point under the current automated methods do not meet the quality standards required in heritage documentation, so human interaction is mandatory. We have described the interaction between the user and the 3D point cloud by means of 2D computer display providing an example of detailed equations both for the projection from 3D to 2D, and the back projection from 2D to 3D. We believe this compact coding of the process, helps in understanding this interaction with 3D point clouds in heritage documentation production.

One of the key factors in producing 3D line drawings from 2D projections is the availability of a thematic component, normally containing the photometric information guiding the 2D line drawing step. When the thematic component available is poor, it can be enriched producing synthetic thematic information coming from 3D information. We have focused on shading and in Chromadepth®. Practical line drawing experience has proven this additional thematic information rather useful for producing 3D line drawing from 3D points with poor thematic information.

Based on the proposed model for 3D point cloud interaction, our future work is being directed to automate the line drawing in 2D in order to improve productivity in cultural heritage documentation production.

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