Space Coordinates of Computer Model Details using Digital Close-Range Photogrammetry

Mostafa A-B EBRAHIM and Ahmed A. ELSONBATY, Egypt

Keywords: 3D computer modeling, close-range photogrammetry, central projection, computer graphics.

SUMMARY

3D object animation could be very useful for obtaining the space coordinates of the computer model's points. Computer model's points consist of two categories of points. The first contains the points that have been used to create the computer model. The second is the points lie on the model's surfaces but have unknown coordinates.

Creating 3D computer models can be done using the obtained space coordinates from the photogrammetric measurements. Once the 3D computer model has been created, different measurements can be done from this model, but just for the points belonging to the first category. Measuring the space coordinates for the points of second category needs establishing of a new measuring technique. This new method will use 3D object animation technique together with the digital close-range photogrammetric techniques.

The visible and hidden parts of the 3D computer model play an important role in finding the space coordinates of the surface details. Once the hidden surfaces were excluded of the scene, it will be easy to determine the space coordinates of the points lying among the nearest model's points of the surface. The method depends on model animation which changes the position of the surfaces during the motion. During the animation, the model's surfaces will change it's position, from visible to hidden and vise versa depending on their points' space coordinates. Method will be explained intensively through this paper.

الملخص العربى:

فن الرسوم المتحركة للمجسمات الثلاثية الأبعاد قد يكون مفيداً للحصول على الإحداثيات الفراغية للنقاط الواقعة على سطح نماذج الكمبيوتر. تتكون نقاط نماذج الكمبيوتر من فئتين من النقاط. الأولى عبارة عن تلك النقاط التي تم استخدامها لتخليق نموذج الكمبيوتر و التي لها إحداثيات فراغية معلومة. الثانية هي اى نقاط آخرى واقعة على أسطح النموذج وليس لها إحداثيات فراغية معلومة.

ان تخليق نماذج الكمبيوتر ثلاثية الأبعاد يمكن أن يتم باستخدام الإحداثيات الفراغية الناتجة من قياسات المساحة التصويرية. بمجرد تخليق نموذج الكمبيوتر، يمكن عمل قياسات مختلفة للنموذج و لكن للنقاط التي تنتمي للفئة الأولى فقط من خلال صورة للنموذج مأخوذة من فيلم حركي له تم تخليقه في برنامج خاص بإنتاج الرسوم المتحركة ، أما تلك النقاط التي تنتمي للفئة الثانية فلا يمكن قياس إحداثياتها من هذه الصورة إلا بتوفر شرط إضافي للقياس من صورة مفردة.

والهدف الاســاسى لهذا البحــث هو كيفيــة إيجاد الإحداثيات الفراغيــة لاى نقطة آخرى واقعة على السطح وظاهرة في الصورة (*نقاط الفئة الثانية*) الملتقطـة للمجسم في اى وضـع في إطار الفيلم الحركي له. وخلال هذا البحـث تم توضيـح الفكـرة الأسـاسيــة و اشتقاق المعادلات الرياضية المختلفة لاستنتاج تلك الأحداثيات وهى تعتمد فى المقام الأول على الأسقاط المركزى مع تقنيات المساحة التصويرية الرقمية في المجال المحدود. كما تم حل بعض المشاكل التى واجهتنا باستخدام الكمبيوتر جرافيك مثل كيفية تحديد السطح الذى تقع عليه نقطة ما من مجموعة الأسطح التى تظهر فى الصورة وكانت الفكرة الأساسية فى ذلك هو أولا تحديد الأسطح الظاهرة و المختفية في نماذج الكمبيوتر وبعدها يتم استبعاد الأسطح المختفية. حالة الأسطح سواءً كانت ظاهرة أم مختفية تعتمد على وضع ومكان الصورة الملتقطة للمجسم ثم يلى ذلك تحديد احد هذه الأسطح الظاهرة التى تقع عليها النقطة الفراغية ، وبالتالى يمكننا الحصول على الإحداثيات الفراغية لتفاصيل نماذج الكمبيوتر. وخلال هذا البحث سوف يتم شرح ذلك بمزيد من التفاصيل.

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1 INTRODUCTION

It is well known that digital photogrammetry is one of the most important measuring techniques that have been used in documentation of architectural historical building and world heritage (Grimm A., et al 2001 & Hanke K and Ebrahim M, 1997). In 1996 Hanke K. and Ebrahim M. have presented a new approach called "Digital Projector" that can be used in documenting the historical buildings and monuments in their real shape and dimensions. The documentation is in the form of 3D computer models. Full measurements can be done for the obtained computer model, but just for the points that have been used in creating the computer model. What about the other points that lie on the computer models' surfaces but not included in creating the model? It is a very important question that will be answered through this research work. Figure (1) shows the scheme chart that will be followed through this research. This chart will follow the digital projector approach technique as it gives 3D computer model with its real shape and dimensions. Once the computer model is created, it can be imported to the 3D Studio software to create the object animation after applying the "Digital Projector Approach". This measuring system is not limited to the "Digital Projector Approach", but can be applied to any 3D computer model animation.

The easiest way to import the 3D computer model to the animation software is using DXF file format. Drawing exchange format files (DXF file) are vector format files designed with vector data interchange in mind but are vendor-controlled and originated as a format supporting a single application. In addition DXF was specifically tailored for CAD information useful in the construction of mechanical, electrical, and architectural drawings. DXF therefore supports not only common vector elements such as circles and polygons, but also complex objects frequently used in CAD renderings, such as 3D objects and hatching. Each DXF consists of five sections: a header; tables; blocks; entities sections and an end-of-file marker. DXF files are very good tools to show the 3D wireframe because they contain points and lines information (Figure 2). As the DXF files contain also the data of the surfaces between the points, rendering and shading can be done to show the surfaces of the 3D model (Figure 3).

Once the computer model has been imported to the animation software, animation of this computer model can be created. There are four basic techniques used in animation, Site [12]:

- Drawn animation
- Cut-out animation
- Model animation or stop motion animation
- Computer animation or computer generated imagery (CGI)

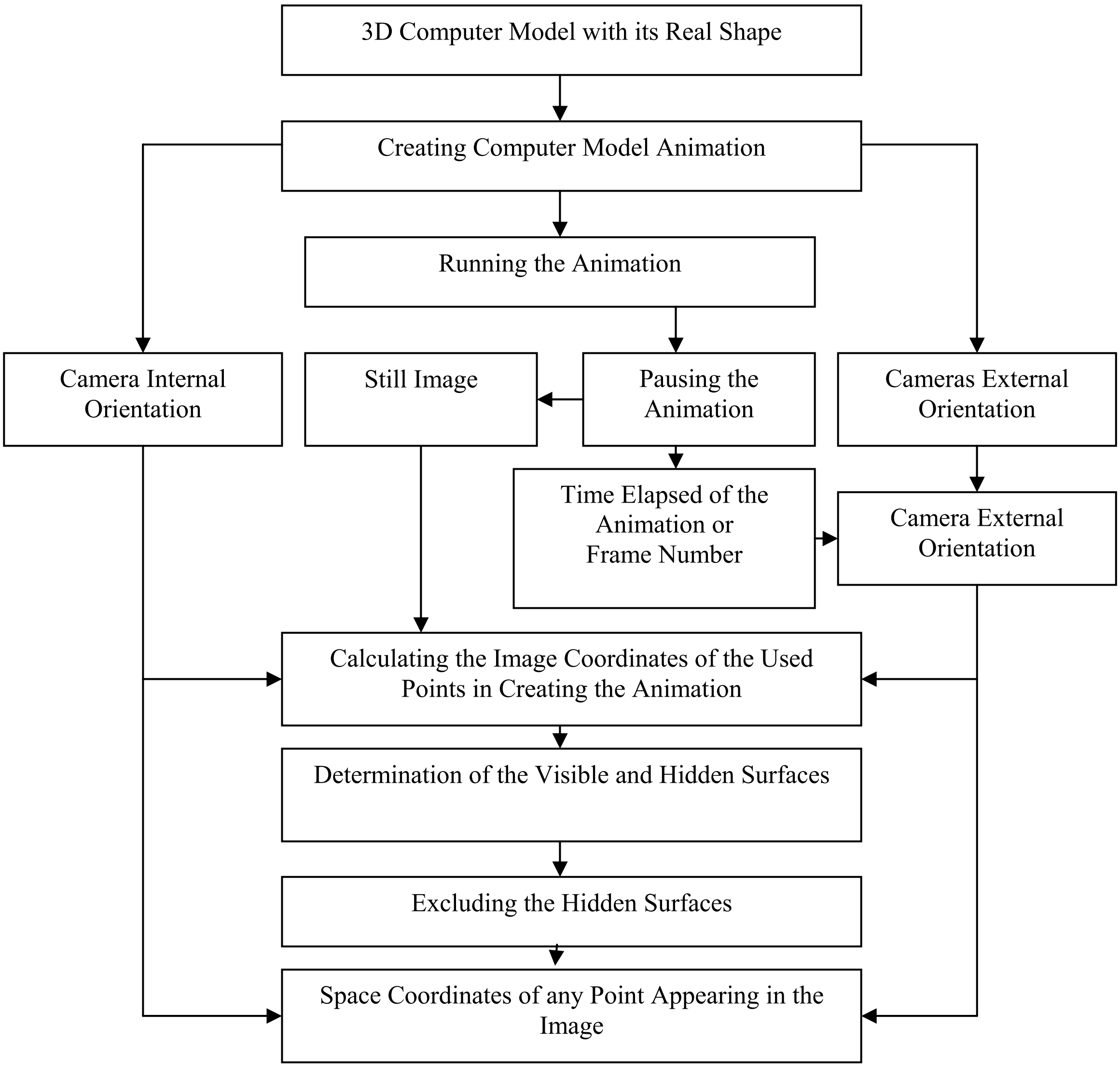
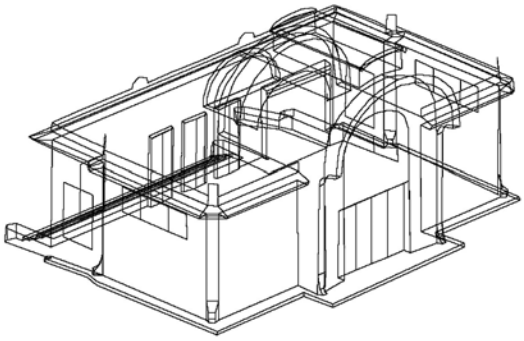


Fig. (1) System Scheme Chart.



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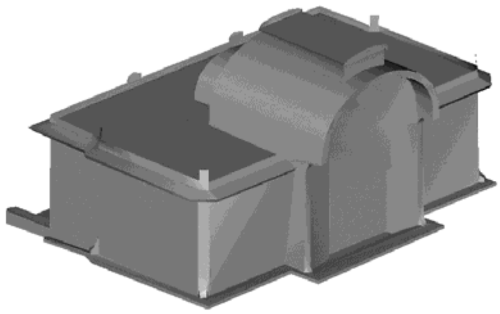

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Fig. (2) Computer model Wireframe (Hidden and Visible surfaces)

Fig. (3) Shaded Computer Model (Visible Surfaces Only)

The last technique will be used throughout this work using 3D Studio software. Animation formats have been around for several years. The basic idea is that of the flip-books one played with as a kid. Rapidly display one image superimposed over another to make it appear as if the objects in the image are moving. Very primitive animation formats store entire images that are displayed in sequence, usually in a loop. Slightly more advanced formats store only a single image, but multiple color maps for the image. By loading in a new color map, the colors in the image change and the objects appear to move. Advanced animation formats store only the differences between two adjacent images (called frames) and update only the pixels that have actually changed as each frame is displayed. A display rate of 10-15 frames per second is typical for cartoon-like animation. Video animation usually require a display rate of 20 frames per second or better to produce a smoother motion.

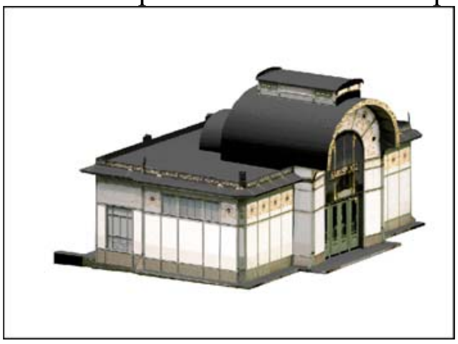

Fig. (4) & (5) Detailed Computer Model

Using animation as a visualization tool, objects can be shown from different direction and point of views (Figure 4 & 5). It runs automatically as it has been created, no control of the object motion unlike the VRML technique which can be manually controlled (Hanke and Ebrahim, 1996).

Ebrahim, 1998 has explained in details the visualization of the 3D computer model with its real shape and details using the "Digital Projector Approach". He used Otto Wagner's Stadtbahn Station buildings on the Karlsplatz in Vienna as a test field which has been selected in 1990 as a small test object, photographed, measured and documented, in order to get well-checked materials to train students and photogrammetrists as well as to valuate internationally

the results of the analytic photogrammetric amount of control information. The test object was a masterpiece of Art Nouveau, built in 1898-1899. (Waldhäusl, P., 1991)
Considering an architectural restitution, first a complete reconstruction of the building's shape has to be done using e.g. any digitally matching method (e.g. Streilein, 1995) or a bundle adjustment program (Kager, 1980) followed by a definition of lines and surfaces in a CAD environment. A few of the already before used images are then chosen to do a "Digital Slide Projection" onto the surface to achieve a restitution of the architectural details on the facades of the building. The surfaces of the different objects are not restricted to planes but were also of regular curved (e.g. cylinder etc.) and even irregular or free formed shape (Hanke and Ebrahim, 1996).
The space coordinates of the points that have been used to create this model can be easily measured, but the other model details' space coordinates are impossible to be measured unless a certain new method is applied. The idea of this new method will be explained in the next section.

2 THE SYSTEM IDEA OF THE NEW TECHNIQUE

As mentioned previously, model animation is a kind of presenting sequence of images with a certain speed. The image sequence is depending on the media that has been used to create the animation. As example, to create an animation through 3D studio MAX, a base stations for the camera must be defined which determine the camera passes. The number of images that will be created depends on the desired number of frames. The camera internal orientations are be known according to the software options. Each frame will have its camera position, so each camera station has its known external orientations. Running the animation will change the camera external orientation according to the showed frame. Pausing the animation will give the frame number or the elapsed time. Any of these will lead to the camera station with known exterior orientations. As the camera's internal and external orientations are known, any details that appear in the image can be measured. The ability of measuring from a single image can be achieved when an additional condition is considered (Ebrahim M and Khalil R 2001 & Elsonbaty A and Ebrahim M 2002). This additional condition in our case will be the surface that the desired point is lying on. The system idea of the new technique depends on the 3D computer model data base which contains the space coordinates of the objects' points, the object's edges, and the object's surfaces information. Using photogrammetric measurements techniques, the space coordinates of the object details can be measured after excluding the information of the hidden part of the surfaces and keeping that of the visible part.

3 THE SYSTEM CALCULATIONS

After photogrammetric solution, a data base of the model will be available which contains all information about the object in space (points, lines and surfaces). Also, the camera's internal and external orientations will be known from the paused animation which will depend on the frame number or the elapsed time. The paused image information are:

1- The camera internal orientation known from the defined camera.
2- The camera external orientation known from frame number.

3- The image coordinates of the visible surfaces' points from the object space coordinates and the camera orientation.

Now, the problem can be summarized into the following 3 items:

1. Calculation of the image coordinates of the object.
2. Which faces of the object are visible.
3. Calculating the space coordinates of any point appearing in the image plane.

To solve the above items, the space object has to be represented in a way that gives a complete and unambiguous definition of the object, not only the shape of the boundaries but also the object's interior and exterior regions. In the following section, a brief explanation about the way of representing objects on the computer will be given.

4 BOUNDARY REPRESENTATION OF OBJECT

The object in space is enclosed by a set of faces, which form a closed and oriental surface. This guarantees that it is possible to distinguish between the interior and exterior region. The orientation is usually established by the direction of a normal vector. This means that the boundary is determined by a set of faces bounded by one or more rings (*loops* consisting of edges and vertices). So, the object in space is approximated into a polyhedron.

5 DATA STRUCTURE

The boundary of each polyhedron consists of three types of geometric elements:
Vertices (*V*), edges (*e*) and faces (*f*). Each vertex bounds an equal number of edges and faces, each edge is bounded by two vertices and two faces. All these elements can be addressed in the internal data base by pointers. Pointers are not data entities, but an attributes of some data entity. The definitions of the geometric elements are presented in the next subsections.

5.1 The points' data structure (Figure 6)

Each point storage has record number of the point (*id*), Space coordinates of the point (*P*), Image coordinates of the point (P^C), and address of the next point (*next*)

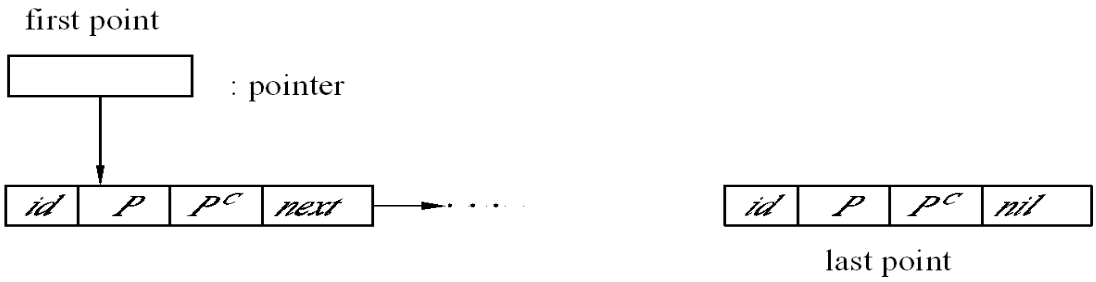

Fig. (6) Points' Data Structure

5.2 Edges' data structure (Figure 7)

An edge is a line segment. It joins two points, the initial point i_p and the end point e_p. Therefore the edges data structure will be as follows:

i_p and e_p are the pointer to the initial point and the end point. f_l and f_r are the pointers to the neighboring faces of the edge, one on the left side, one on the right, if seen from outside in the direction i_p-e_p.

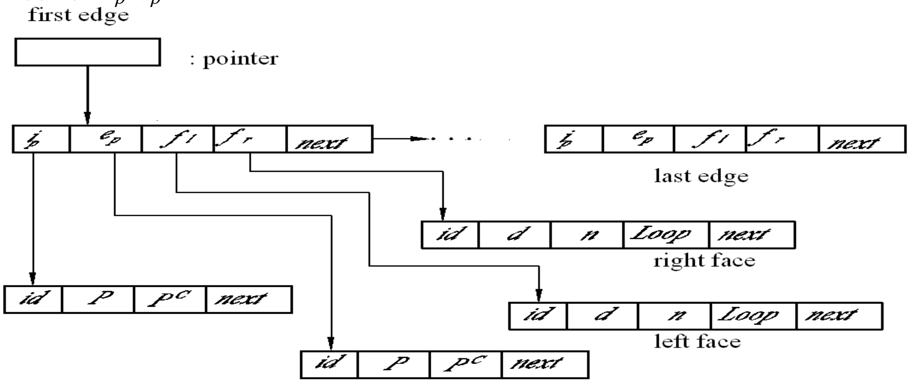

Fig. (7) Edges' Data Structure

5.3 Faces' data structure (Figure 8)

The faces of the polyhedron will be defined by a sequence of the included vertices *(loops)*. If seen from outside, the outer loop of a certain face will be processed mathematically as positive (*anticlockwise*) order, the inner one will be negative (*clockwise*). So, for each face, the following information will be stored:
The record number of the face (*id*), oriented distance between the face and origin (*d*), the normal vector to the face pointing outside (***n***), the pointer to the list of the bounding polygons of the face (*f_loop*) and pointer to the next face (*next*).

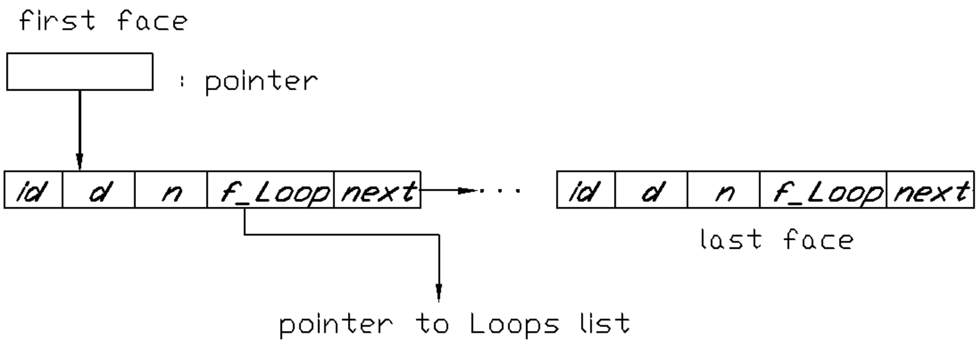

Fig. (8) Faces' Data Structure

Now, a complete database on all objects in space (*points, edges and faces*) is available. Assuming that, the image for that object is obtained from the paused animation with known camera exterior and interior orientations (*camera station and image plane* **p**)).
Next, we are going to discuss the two important items which fulfill the main aim of this paper::

— Formation of a list of faces that will appear in the image plane.
— Calculation of the space coordinates of any point that appears in the image.

6 DISPLAYING THE OBJECT

The visibility of edges and faces for any polyhedral (*approximation of space object*) for parallel and central projection can be determined as follows:
The visibility of faces will be checked by
Calculating the angle θ between the view vector $\boldsymbol{v}$ (*in case of central projection, the view vector will be considered as the line connecting camera station S and any vertex*) of the face and the normal vector $\boldsymbol{n}$ of that face. If the angle θ is acute then the face is invisible otherwise it is visible (Figure 9).
So, the dot product can be used to obtain information about the angle between two vectors. Then $\boldsymbol{v} \cdot \boldsymbol{n} < 0$ will be characterized as visible faces.
An edge is visible if at least one neighbor face is visible. The edges between one visible and one hidden face are silhouette edges. So, the silhouette is formed by the edges that separate visible from invisible faces on the polyhedron.

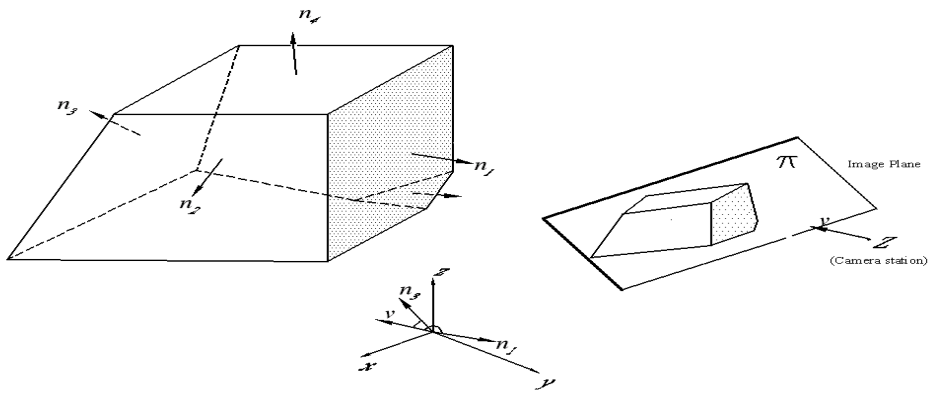

Fig. (9) Perspective Projection of Polyhedron

7 CALCULATING THE IMAGE COORDINATE OF A SPACE POINT

Let the coordinates of a point $P(x_P, y_P, z_P)$ in space be known relative to xyz -system. Now we want to calculate the image coordinates of point $P^c(x, y)$ (*projection of* P *on* π). Let Z be the center of projection with base vector $\mathbf{z}$ and point H (*principal point of* π) with base vector $\mathbf{h}$ (*normal projection of* Z *on* π). Since, point P with base vector $\mathbf{p}$, its central projection P^c (*base vector* $\mathbf{p}^c$) and center of projection Z are collinear, then the base vector of $\mathbf{p}^c$ can be calculated from the following equation:

$$\mathbf{p}^c - \mathbf{z} = \lambda(\mathbf{p} - \mathbf{z}) \qquad \lambda \in R$$

To calculate λ, let point P^n (*base vector* p^n) be normal projection of P on π as shown in figure (10). The points P^n, H and P^c lie on one line, which is the normal projection of the line ZP on π. So, the point P^c divides the two lines ZP and HP^n in the same ratio.

$$\mathbf{p}^c - h = \lambda(\mathbf{p}^n - h).$$

The parameter λ can be determined from the following equation $\lambda = \frac{d}{(\mathbf{p}-\mathbf{h})\cdot\mathbf{s}} + d$

Where $\boldsymbol{s}$ is unit vector parallel to $\overrightarrow{ZH}$ (*i.e. normal on image plane* π), and d is the distance between Z and H (= *focal length)*
Choose rectangular coordinate system $o(x, y)$ in plane π with o coinciding with H and y parallel to the projection of z axis on π as shown in figure (11). Let $\boldsymbol{e}_1$ and $\boldsymbol{e}_2$ be base vectors located on x and y axes in image plane.
The image coordinates of P^c can be calculated from;

$$x = \lambda(\mathbf{p}^{\mathbf{n}} - \mathbf{h})\cdot\mathbf{e}_1 = \lambda(\mathbf{p}-\mathbf{h})\cdot\mathbf{e}_1$$

$$y = \lambda(\mathbf{p}^{\mathbf{n}} - \mathbf{h})\cdot\mathbf{e}_2 = \lambda(\mathbf{p}-\mathbf{h})\cdot\mathbf{e}_2$$

The above equation can be rewritten in the following form:

$$x = \frac{x_1}{x_0}, \quad \text{and} \quad y = \frac{x_2}{x_0}$$

$$x_0 = \frac{1}{\lambda} = 1 + \frac{(\mathbf{p}-\mathbf{h})\cdot\mathbf{s}}{d}$$

with $x_1 = (\mathbf{p}-\mathbf{h})\cdot\mathbf{e}_1$
$x_2 = (\mathbf{p}-\mathbf{h})\cdot\mathbf{e}_2$

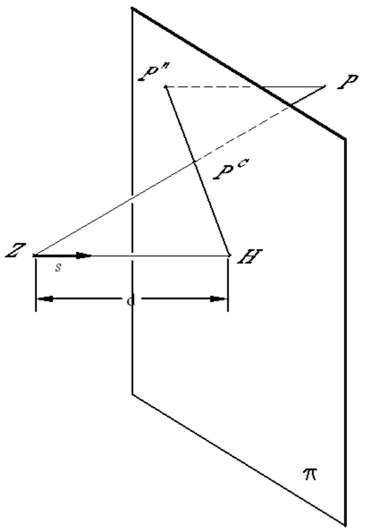

Fig. (10) Central Projection of P

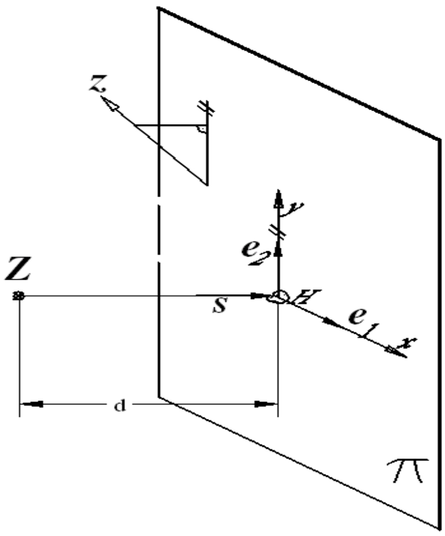

Fig. (11) Image Coordinates System

8 CALCULATING SPACE COORDINATE FOR IMAGE POINTS

Now, how can the space coordinate of any point appear in image plane be determined?
A complete data base is available (*a list of visible faces, a list of vertices whose space and image coordinates are known and a list of edges*). The image of the faces in **p** is planer

polygon. The relation between the image coordinates of point $P^c(x_0, x_1, x_2)$ and the space coordinate of $P(x_P, y_P, z_P)$ can be presented in a matrix form as:

$$\begin{bmatrix} x_0 \\ x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} 1-\dfrac{\mathbf{h}\cdot\mathbf{s}}{d} & \dfrac{\mathbf{s}_1}{d} & \dfrac{\mathbf{s}_2}{d} & \dfrac{\mathbf{s}_3}{d} \\ -\mathbf{h}\cdot\mathbf{e_1} & e_{11} & e_{12} & e_{13} \\ -\mathbf{h}\cdot\mathbf{e_2} & e_{21} & e_{22} & e_{23} \end{bmatrix} \begin{bmatrix} 1 \\ x_P \\ y_P \\ z_P \end{bmatrix}$$

Where s_1, s_2, s_3 , e_{11}, e_{12}, e_{13} and e_{21}, e_{22}, e_{23} are components of the vectors $\mathbf{s}, \mathbf{e_1}, \mathbf{e_2}$.

9 DETERMINATION THE FACE WHICH *P* LIES

To determine which face *f* contains upon point *P*, it is required to test the image plane whether the point P^C (image of *P*) lies inside a polygon *pl* (image of *f*) or not. To explain this, let the image coordinate of point P^C be given. We consider the following cases:

1. Define the bounding box for the set of vertices of *f* as shown in figure (12). A point outside this box cannot be inside the polygon. For the points inside the box, we have:
2. Compute the points of intersection of any line *l* passing through point P^C with the edges (*considered as line segments but not their extension*) of the polygon. There is always an even number of points of intersection, when a case is avoided when *l* passes through any vertex. Point P^C separates this set of points into two subsets. *Point* P^C will be inside the polygon if and only if each subset has an odd numbers of elements.

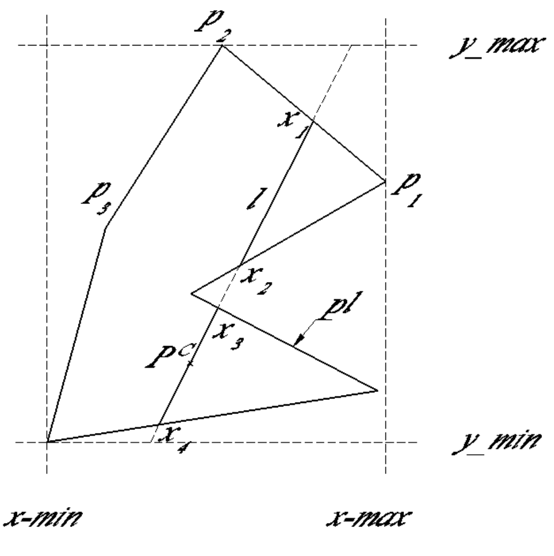

Fig. (12) Relative Position Between Point and Polygon

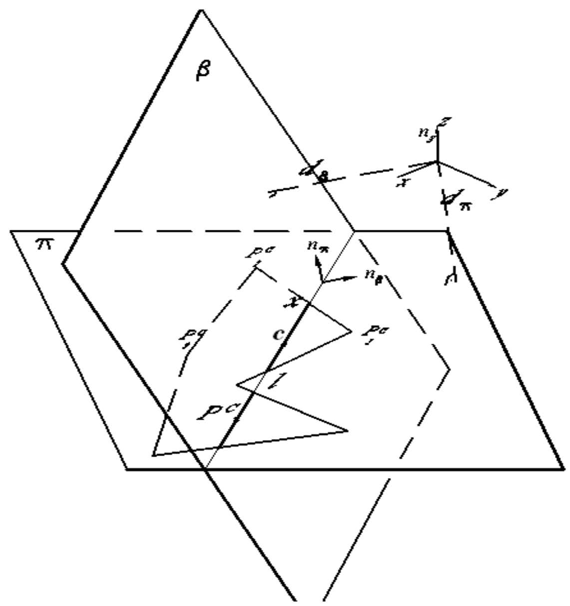

Fig. (13) Intersection of *l* with Polygon

10 FINDING THE POINTS OF INTERSECTION OF l WITH THE LOOPS (FIG. 13)

Let *l* be a line passing through point P^C and a polygon *pl* in image plane be the image of the visible face *f* of the object. The position vector $\boldsymbol{x}$ of can be written in the form:

$$\mathbf{x} = \mathbf{p}^C + \lambda \mathbf{c},$$

where $\mathbf{p}^C$ is the position vector of point P^C and $\boldsymbol{c}$ is a vector in direction of line *l* in image plane. From which, $\mathbf{n} \cdot \mathbf{c} = \mathbf{o}$.

So, the computation of $\boldsymbol{x}$ has been reduced to the computation of any suitable coefficient $\lambda \in R$. After having ordered the values, a sequence of line segments representing the intersection between *l* and polygon *pl* will be obtained.

For this reason we introduce the plane b $\boldsymbol{n_\beta} \cdot \boldsymbol{r} = d_\beta$ normal to image plane **p** through line *l.* .

The equation of plane b is

$\boldsymbol{n_\beta} \cdot \boldsymbol{r} = d_\beta$ Where $\boldsymbol{n_\beta} = \boldsymbol{n} \times \boldsymbol{r}$ with $\| \boldsymbol{r} \| = 1$.

Where $\boldsymbol{r}$ is the position vector for any point located in **b**, and d_β is the oriented distance between the origin *O* and plane **b** and can be computed with any point $\boldsymbol{r} = \boldsymbol{c} \in l$, for any point $P^C \in \pi$ the value $d_p = \mathbf{n_\beta} \cdot \mathbf{p}^C - d_\beta$ gives the oriented distance between P^C and **b**.

The following algorithm explains how the points of the intersection between *l* and *pl* can be computed. Assuming a certain assumption that the line will not pass through any polygon vertices, then each line segment of *pl* intersect line *l* or not must be tested. Supposing that, the test edge has the initial point P_1^C (with base vector $\mathbf{p}_1^C$) and the end point P_2^C (base vector $\mathbf{p}_2^C$), the oriented distance $d_{P_1^C}$ and $d_{P_2^C}$ must be used. Then, if the sign of d_{p_1} differs from the sign previous d_{P2}, the two end points of the test edge are situated on different sides of **b**. Then between P_1^C and P_2^C there will be an intersection point *x* of *l* with the plan **b**. The vector of this point can be expressed as:

$$\mathbf{x} = \frac{1}{d_{p_2} - d_{p_1}} (d_{p_1} \mathbf{p}_1^C - d_{p_2} \mathbf{p}_2^C)$$

11 CONCLUSION

Documenting historical buildings and the world heritage needs to be done with the ability of measuring all details that appear on the object surfaces. 3D computer model with its real shape and dimensions is the best way of such documentation. Using digital close-range photogrammetric techniques in the form of the digital projector method, 3D computer model of the object with its real shape and dimensions can be easily obtained. Creating 3D computer model animation gives the ability to have a still image for the model from the desired point of view which shows the desired details to be measured. The paused animation determines the camera external orientation according to the frame number. Using the used points in creating the computer model with the paused image, the hidden surfaces' points can be excluded from the system data base. Using the digital close-range photogrammetric techniques with known camera orientations and image coordinates of the points, any points lying on the model's visible surfaces can be calculated. This is a promising new measuring system that will enable photogrammetrists to do their job easily and accurate. The advantage of this system is the ability of measuring any details lying on the computer model surfaces just from a single model image.

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BIOGRAPHICAL NOTES

Associate Professor Dr. Mostafa A-B Ebrahim born in 1963. He has been graduated in 1986 from Civil Engineering Department, Faculty of Engineering, Assiut University, Egypt. In 1992, he has been awarded his M. Sc. Degree in close range photogrammetry from Assuit University. In 1996, he has been awarded Eduard Dolezal Award from ISPRS in its XVIII congress, Vienna, Austria. In 1998, he has been awarded his Ph.D degree in Digital Close Range Photogrammetry from Innsbruck University, Austria. In 2005 he has been promoted to Assistant professor Position at Civil Engineering Department, Faculty of Engineering, Assuit University, Egypt. His research interests are in 3D computer modeling, Mobile road mapping systems, close-range Photogrammetry and Geodesy.

Associate Professor Dr. Ahmed A. Elsonbaty born in 1963. He has been graduated in 1986 at Civil Eng. Dept, and obtained his M. Sc. Degree in 1992 from Assiut University, Egypt and Doctorate degree in 1998, from Technical University, Vienna, Austria. His research interests are in Engineering Mathematics, Photogrammetry, Descriptive Geometry, Kinematics and Differential Geometry.

CONTACTS

Associate Professor Dr. Mostafa A-B Ebrahim
Civil Eng. Dept., Faculty of Engineering,
Assiut University,
Assiut,
EGYPT
Tel. +966 553484223
Fax: +20882332553
E-mail: Mostafa.Ebrahim@btinternet.com

Associate Professor Dr. Ahmed Elsonbaty
Civil Eng. Dept., Faculty of Engineering,
Assiut University,
Assiut,
EGYPT
Tel. +966 568455062
Fax: +20882332553
E-mail: asonbaty2@yahoo.com