CAD-SUPPORTED DETERMINATION OF SENSOR ATTITUDE IN TERRESTRIAL PHOTOGRAMMETRIC APPLICATIONS

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ABSTRACT

The purpose of this work is to derive an easy-to-use interactive method, using simple CAD software, for the determination of good initial values for camera positioning (Xo, Yo, Zo) and orientation (ω, φ, κ rotations). It is actually a control-point-free method intended for terrestrial photogrammetric applications, mainly in Architecture and Archaeology, dealing with facades.
Nowadays CAD vendors and current software provide the possibilities of entering raster images as well as easy manipulation of 3-D vector graphics. Furthermore in CAD environments, friendly user interfaces using pop-up windows and dialog boxes give the user the ability to view photographs and 3-D design files (e.g. a 3-D file for a facade) - in top, front, isometric and side views - at the same time. The proposed system profits from these advances taking ideas and utilities in an attempt to solve a classical photogrammetric problem, such as the determination of sensor attitude without control points, using CAD tools and programming techniques. In terrestrial photogrammetry the calculation of approximated values for exterior orientation parameters is a difficult and time consuming task.
The system is to some degree automatic, since it analytically computes discrepancy vectors and examines possible solutions to minimise a penalty function. These different solutions are animated on the screen and the procedure is simply stopped by the user when he feels the solution was achieved. When the solution deviates user interaction is possible. As a supplement to automatic procedure a manual approach is provided for micro-corrections and enhancements. This manual approach is based on mouse movements and appropriate push-button selections according to a predefined step.

1. INTRODUCTION

Unlike the aerial case, where the sensor rotations are normally small, in terrestrial applications, due to the complexity of the cases, the rotations can range to any possible values. This creates a major problem in defining good initial values for the ω, φ, κ angles to be entered to the subsequent photogrammetric adjustment.
The problem is even worse in Architectural and Archaeological applications, where normally the use of low-end equipment is desirable or simply used. Under these circumstances the number of control points is relaxed, the cameras are of many types (from amateurs to camcorders), surveying instruments may not be used, and generally control information is reduced to simple distance measurements for scale determination. Thus **ω, φ, κ** rotations are rarely recorded and the determination of their initial values becomes an empirical, time-consuming and often very difficult job, many times performed by people (like architects and archaeologists) with little photogrammetry experience.
The developed system is based on **Bentley's MicroStation V5 PC CAD** environment, enhanced by dialog boxes and hook functions implemented in an even-driven manner using the **MDL** programming language. The main MDL enhancements have been gathered in an easy-to-use dialog box [Fig. 2] offering a friendly graphical user interface (Young K., 1991).
The whole operational procedure is based on two facade's models attempting to match each other on screen (CAD environment): The **red TARGET model** is built according to provided image co-ordinates, and the **generic CAD model** is built according to any available distance measurements on the facade. This matching is achieved after a continuous stepwise CAD camera's positioning and orientation. This CAD camera is actualy a virtual camera provided by the CAD platform and controlled by MDL-software in order to achieve good approximated values for exterior orientation giving minimum overall discrepancies for these two models.

2. THE CAMERA-VIEW PROJECTION SYSTEM

To work successfully in 3-D CAD environments there is a necessity to view the models from any direction. In these environments a very good practice is: in order to change the direction, from which a CAD model is looked, the design cube offered by the environment is rotated to the required orientation instead of the model itself. The result is visually the same. So, instead of the model the 'world' of the model is rotated. This 'world' is CAD environment's **design cube** and **virtual camera** (Wilkinson D., 1991).

The camera-view projection system introduced in this paper profits from CAD environment facilities like design cubes and virtual cameras, trying to match the shearing photograph model by changing the position and orientation of the virtual camera whilst the actual 3-D model is fixed. In this way a simulation of camera's position orientation and internal geometry is achieved (Streilein A., 1994).

Elements in 3-D computer modeling must be drawn on the screen that is planar. Hence a projection is needed. The two principal methods of projection used in CAD systems are: **parallel** (or cylindrical) projection and **perspective** (or conical) projection.

2.1 Parallel Projection

In **Parallel projection** the rays or projectors are all parallel and intersect the image plane at the same angle. A parallel projection can be thought of as like a perspective with an infinitely distant eye-point. A special case of parallel projection is produced when the rays meet the image plane at right angles. This kind of parallel projection is known as **orthographic projection** and is used in 3-D computer modeling for engineering and architectural applications. The visual images generated by an orthographic projection are called **multi-views**. Examples of such as multi-views are the widely used in engineering Top, Left, Right, ISOmetric and Front views offered by well-known 3-D CAD systems (e.g. Bentley's MicroStation, Autodesk's AutoCAD). In our system the whole computer screen is divided into four viewports with three of these are used to show the Top, Right and ISOmetric multi-views of the facade. For a planar and vertical facade (the usual case) its image appears to be a horizontal line in Top view and a vertical one in Right/Left view. So, these multi-views serve as a control error-checking system to camera's approximating positioning procedure. The ISOmetric view is used for increasing visualisation purposes. The fourth viewport, which is the bigger, is devoted to the visual image of the facade generated by the camera view projection [Fig. 4, 5, and 6].
The main disadvantage of the **parallel projection** is that there is no perspective associated with objects. Parallel lines appear parallel on the screen and distant objects appear at the same scale as near ones of the same dimensions. In real life the thinks are different. The more distant objects appear smaller to viewer (Rooney J. et al., 1987).

2.2 Perspective Projection (Camera-View Projection)

The **Perspective projection**, known as well as **Camera-View projection**, enhances realism of modeling and mimics the way a conventional camera works. This projection system is used in current paper for facade-model visualisation.
The geometry of photography is essentially equivalent with the perspective projection geometry (Fig. 1). In camera-view projection the position of the eye is being taken by virtual camera's lens center, and the plane of the image corresponds to camera's plate or film. The "difference" of perspective and camera-view projection is that for the late the 'eye-point' (lens center) is between the object (facade) and the image plane (film), and as a consequence the image is formed down-upside (negative case) instead of upside-down (diapositive case). Otherwise these two projections are geometrically similar (Baker P. et al., 1994).

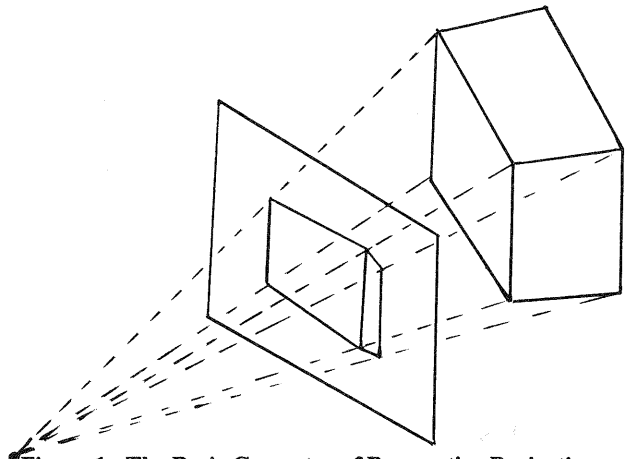


Figure 1. The Basic Geometry of Perspective Projection.

2.3 Projection Relationships between the Camera, the Photo and the 3-D Object (facade)

Using the **central projection** logic, which is the base for the camera-view projection system, there is always just <u>one particular perspective</u> regarding the camera position, the exposed photo and the spatial 3-D object.
In other words in central projection a 3-D object-image has been taken using a particular interior and exterior orientation for the camera used.
Generally, there are as many as <u>eight different settings</u> of the camera used (according to Patias P. et al., 1995a) that could lead to a particular image. Four of these camera settings refer to transparent objects and can be avoided. The selection of the remaining four settings is a problem, that could be avoided if approximate values are taken empirically (see: the automatic procedure of the system in next chapter).

The Camera-View Projection System used in this paper follows the next conventions:

In a FRONT View

- We are looking into the design cube from the front.
- The XZ plane is parallel to our screen.
- X is positive from left to right (horizontally).
- Z is positive from bottom to top (vertically).
- Y is positive <u>away</u> from the viewer and perpendicular to the screen.

In a TOP View

- We are looking down on the design cube from the top.
- The XY plane is parallel to our screen.
- X is positive from left to right (horizontally).
- Y is positive from bottom to top (vertically).
- Z is positive towards the viewer and perpendicular to the screen.

In a RIGHT View

- We are looking into the design cube from the right.
- The YZ plane is parallel to our screen.
- Y is positive from left to right (horizontally).
- Z is positive from bottom to top (vertically).
- X is positive toward the viewer and perpendicular to the screen.

3. APPROXIMATE CAMERA POSITIONING USING A VIRTUAL CAMERA

General graphics programming packages provide an extensive set of graphics functions that can be used in a high level programming language. Such examples are the GL (Graphics Library) system on Silicon Graphics equipment, Bentley's MDL on MicroStation PC platform and the graphics standards GKS and PHIGS+. In these environments customised software extensions are possible to deal with the virtual camera.

In the proposed system - based on MicroStation PC platform - by graphical means and MDL programming techniques, it is possible to **"position"** and **"aim"** the virtual camera anywhere into the 3-D design session space. In this CAD system there is a virtual camera associated with each view and this camera can be turned on or off at will. Various settings associated with this camera allow user to vary the type of lens and the camera's exterior orientation, i.e. the position of the camera in current design session according to design cube and where the camera is aimed to. The projection used is a camera-view projection, and the camera position (Xo, Yo, Zo) and orientation (Up-vector or ω, φ, κ) for this particular view can be found precisely without using control points.

The camera can be placed anywhere in the design session, looking in any direction. In addition, by moving the camera and its target point progressively through a model, while the rendered views are saved each time, a **"walkthrough"** presentation of the 3-D object is produced.

The whole operational procedure follows the next steps:

First a screen-window segmentation is performed, and then the placement of both models (CAD and TARGET) is followed.

The placement of the TARGET model is done in red (**red TARGET model**) according to provided image co-ordinates (pixel co-ordinates) for the four facade's vertices. For this purpose a low-cost image processing software could be used (e.g. Adobe's Photoshop, Aldus Photostyler, Paint Shop pro).

The placement of the generic CAD model is done in black (**generic CAD model**) according to any available measurements for facade's edges. The facade object must be planar and is assumed approximately orthogonal.

The design session used has m, cm and pu-positional units (pixels) as working units, with resolution 1m=100cm and 1cm=10 pu.

The virtual camera is placed by default in front of the planar facade [Fig. 3] in a vertical distance according to the nominal photo scale.

$$Yo = S * c \qquad \text{(Eq. 1)}$$

Where:

S: the nominal of the photograph.

c: the camera constant.

The CAD-based procedure for camera position approximation, is based on adjustment methods trying to minimise the differences between the **"red TARGET model"** and the **"generic CAD model"** whilst the virtual camera is moved into the design session. For this purpose either an automatic or a manual approach can be used [Fig. 4, 5, and 6].

3.1 The Automatic Approach

This approach is an empirical one and such as is based on attempts for approximating camera position and orientation.

It is well known (Patias P., 1991) that the optical-mechanical rectification procedure has to be performed in three steps. Similarly the empirical automatic procedure follows these steps in a (semi)automatic way. Three push-buttons are available in application's dialog box for these steps (see on figure 2 the Automatic section).

At first, the red TARGET model is magnified so that to coincide the generic CAD model on two upper vertices [Fig.4]

At second, the generic CAD model is rotated about the X-axis, so that both down edges are equal in length [Fig. 5]. During this step some manual operations in generic CAD model scale are needed in order the two upper vertices to stay coincide.

Finally, the generic CAD model is rotated about Y-axis, so that both right edges are equal in length [Fig. 6]. During this step some manual operations in generic CAD model scale are needed in order the two down edges to continue being coincide.

During this automatic procedure the current values of Xo, Yo, Zo, ω, φ, and κ are displayed for monitoring and feedback purposes [Fig. 2]. When the automatic approach finishes some good approximated values for **Xo, Yo, Zo, ω, φ,** and **κ** have been found.

3.2 The Manual Approach

These approximated values of **Xo, Yo, Zo, ω, φ,** and **κ** are used in the manual approach method as the initial values of the exterior orientation. Push-buttons control micro-rotations for ω, φ, κ and micro-movements for Xo, Yo, and Zo, according to a user-defined step. These window-buttons allow changes to be made to the six degrees of freedom for the virtual camera separately [see on figure 2 the Manual section].

During both approaches the topological differences of both models are recorded and these differences define the achieved accuracy of the approximation procedure. When this accuracy is not adequate, new approximated values are calculated and used as feedback to an adjustment algorithm until a predefined accuracy level is achieved. The adjustment algorithm positions the virtual camera whilst the aim, that is the "red TARGET model", is fixed. During this procedure when an attempt leads to model differences smaller than a given accuracy, the camera position and camera settings' parameters are displayed and saved for future use.

The final values of **Xo, Yo, Zo, ω, φ,** and **κ** are actualy approximate the exterior orientation parameters of the camera used to take the particular photo. When these values are found, the rotation matrix elements (Rij) and the rectification parameters (a1, a2, a3, b1, b2, b3, d1, d2) are calculated and saved for future use.

The camera settings (lens: Field of Vision angle (FoV), focal length (f) / camera constant (c)) used in this procedure to control projection are fixed and they could be found empirically or they are known from the documentation.

It is important to notice that the **virtual camera** used in CAD environments has some advantages over **conventional cameras**. Hence in virtual cameras:

a) Everything is in focus; no matter how close to or far from the camera,

b) There are no problems related with depth of fields, astigmatism, curvature of field and aberrations.

Finally, as a conclusion to this chapter, it could be said that:

"The approaching procedure consists of consequently generated **generic CAD models** trying to match the **red TARGET model** according to a predefined accuracy".

4. THE GRAPHICAL USER INTERFACE - GUI

A friendly GUI-Dialog Box with a number of push-buttons provides a user-friendly window-manager interface and powerful event-driven functions for facade's modeling manipulation.

All the actions taken place from these dialog box push-buttons are related to both models (i.e. red TARGET and generic CAD) and they are performed in a particular view (a screen viewport) similar to front-view; whilst the remaining views used for facade's multi-views visualisation.

This dialog box is divided in three parts: The first is devoted to the **Automatic** procedure, the second to **Manual** enhancements and the third to some useful **Utilities** like "Delete All Elements", "Unload Application", "set Camera data-file", "set Facade data-file", "place Red TARGET model" and so on.

Interfaces are designed to carry on a continual interactive dialogue for current values concerning virtual camera's exterior orientation so that the user is informed of actions in progress at each step. This is particular important for feedback purposes. Good diagnostics and error messages are designed to help determine the cause of an error.

The figure 2 demonstrates the dialog box used to control the process.

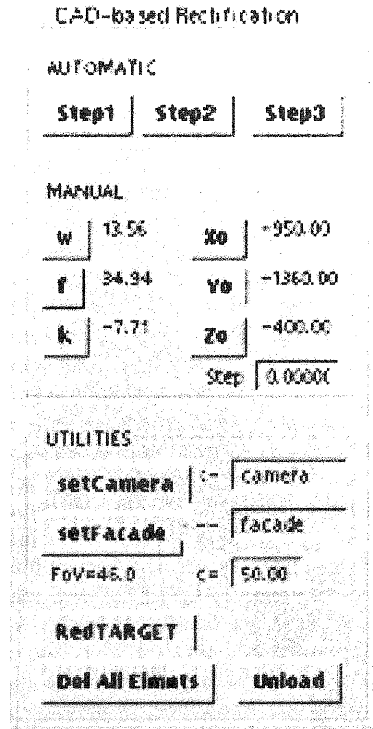


Figure 2. The Dialog Box used to control Exterior Orientation Rectification.

5. A CASE STUDY - PRACTICAL EXAMPLE

The developed CAD-based method has been verified practically on a neo-classical historical building. This building, built in 1890, is situated in Kozani-Greece and the rectification parameters, of an available facade's photograph, are known by analytical methods. These parameters' values as well as the corresponding values calculated by the proposed CAD-based rectification, were used in a cross-reference test concerning the length of two perpendicular facade's edge-distances.

From an existing documentation an orthogonal and planar facade's part found having the wide-edge=7.5 m and the height-edge=2.8 m. Using Adobe's Photoshop 3.0 and the available photograph of the facade, the image co-ordinates of this part's four corners, in pixels, were found as (x/y): 92/153, 373/221, 373/348, and 88/311.

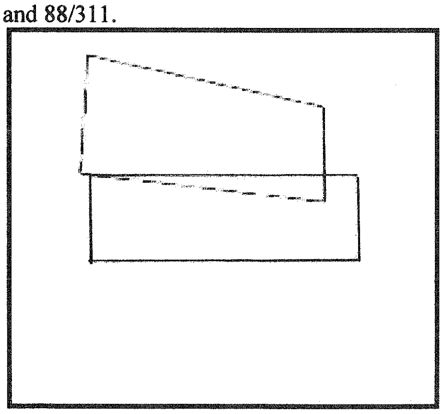


Figure 3. Red TARGET Model and Generic CAD Model at initial state before Rectification.

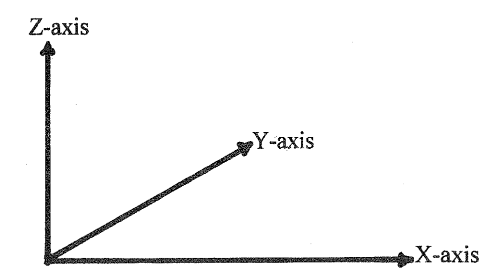
As visual display unit-VDU a 17' screen has been used and a resolution 500x500 pixels was defined for the view where the camera's position approximation procedure was performed.

The design file settings/working units were in **m**, **cm** and positional units (**pixels**) with resolution:1m=100cm=1000pu.

Initially the virtual camera was at the ideal position just over the facade, with co-ordinates: Xo=0.0, Yo=-14.0 m, Zo = 0.0 and camera constant: c=50 mm [Fig. 3]. Using the automatic and manual approaches described in chapter 3 the final best fitting virtual camera position, for the particular photo, found as: Xo=-9.78 m, Yo=-11.36 m, Zo=-3.19 m, with the angular orientation parameters as: ω=12.71 degrees, φ=40.32 degrees, κ=-8.18 degrees. The camera constant, of the visual camera producing this coincidence, found as: c=64.1mm. (FoV=36.6 degrees).

On figure 4 facade's TARGET and CAD models are displayed as they are just after the first step of the automatic procedure. On figure 5 the models are displayed as they are in a middle-procedure state, and particularly after the second step of the automatic procedure. On figure 6 both models are displayed in a coincide state achieved by the end of the CAD-based rectification.

All the values are related to following XYZ co-ordinate system:



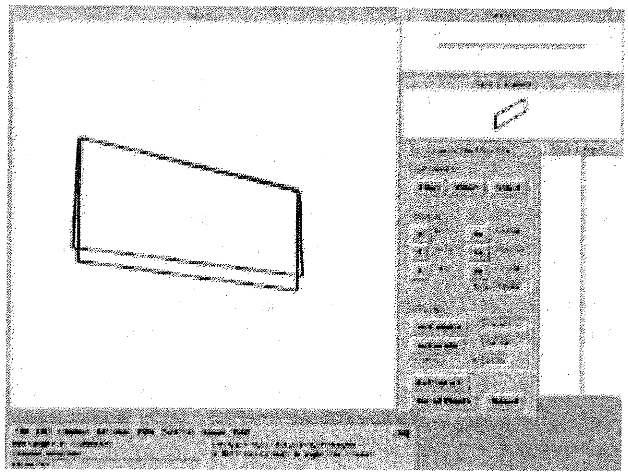


Figure 4. Red TARGET Model and Generic CAD Model after Step1 in Automatic Approach (c=64.1 mm) (ω=14.72degrees, φ=34.74degrees, κ=-8.33degrees, Xo=-8.89m, Yo=-12.82m, Zo=-4.10m)

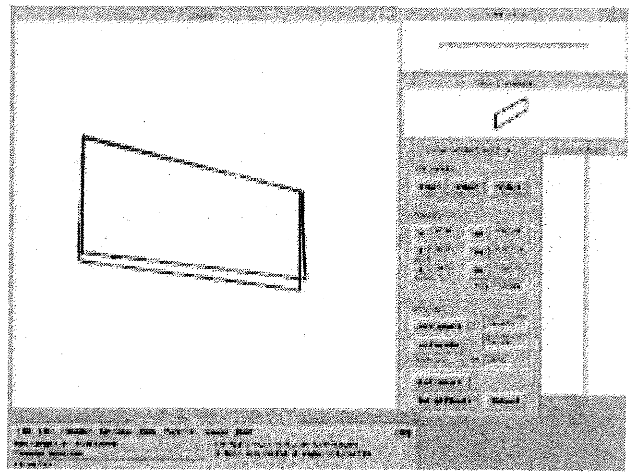


Figure 5. Red TARGET Model and Generic CAD Model after Step2 in Automatic Approach (c=64.1 mm) (ω=14.96degrees, φ=38.75degrees, κ=-8.53degrees, Xo=-9.50m, Yo=-11.70m, Zo=-3.94m)

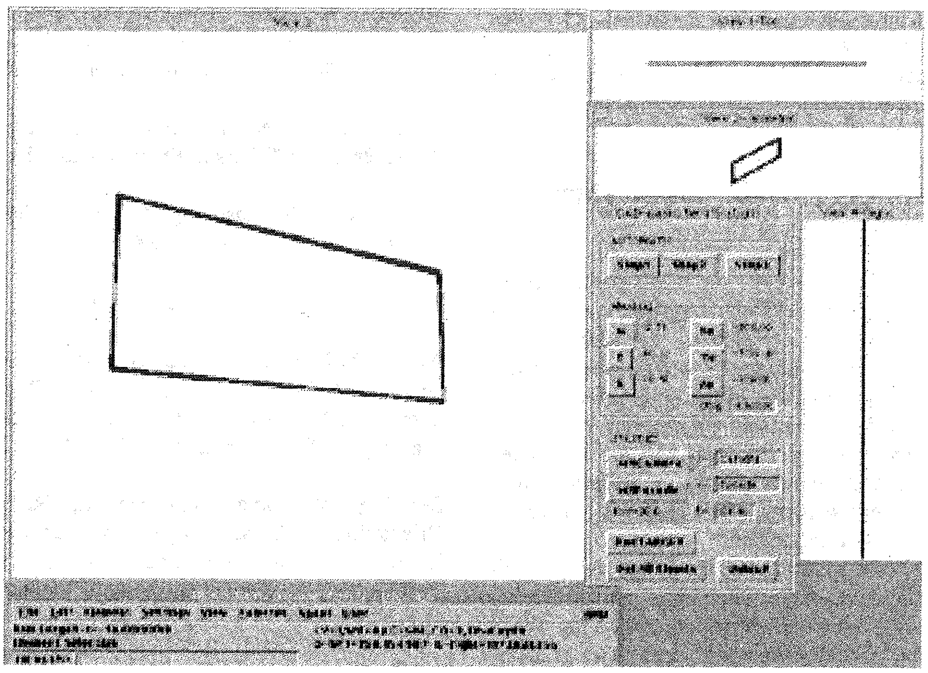


Figure 6. The Final Image after Rectification (red TARGET model = generic CAD model) (c=64.1mm, Xo=-9.78m, Yo=-11.36m Zo=-3.19m, ω=12.71dgrs, φ=40.32dgrs, κ=-8.18dgrs)

5.1 Accuracy Evaluation

The developed system has been verified using as test-object the facade of previous chapter's case study. Table 1 shows values of rotation matrix elements and rectification parameters produced by this CAD-based method.

CAD-based Rectification Method	
Rotation Matrix Elements	Rectification Parameters
R11= 0.754705	a1= -0.185066
R12= 0.002038	a2= -0.156449
R13=-0.656061	a3= 0.013760
R21= 0.108531	b1= 0.018976
R22= 0.985829	b2= -0.035481
R23= 0.127912	b3= -0.002683
R31= 0.647025	d1= -7.005009
R32=-0.167739	d2=-12.079406
R33= 0.743789	

Table 1. Rectification Parameters.

The accuracy of this CAD-based rectification was determined by comparing the values of two perpendicular object's edge-distances calculated using both sets of rectification parameters; i.e. the rectification parameters produced by this system, and the available rectification parameters which have been calculated using the classical analytical photogrammetric method (collinearity method) (Abdel-Latif M.S. et al, 1992). Table 2 shows values of exterior orientation parameters and the facade's edge-distances found using both methods. In this accuracy test the inner orientation was: c=64.1 mm, xo=0.0 mm, yo=0.0 mm.

Exterior Orientation Parameters (CAD-based Method)			
Xo= -9.78 m	ω = 12.71 degrees		
Yo= -11.36 m	φ = 40.32 degrees		
Zo= -3.19 m	κ = -8.18 degrees		
Lengths calculated by:	CAD-based Method	Collinearity Method	D=
Horizontal Edge:	801.902.cm	801.105 cm	0.797 cm
Vertical Edge:	853.298 cm	852.590 cm	0.708 cm

Table 2. Accuracy Evaluation using a practical approach.

6. PRINCIPLES OF THE PROCEDURE

The development of this semi-automatic digital rectification has the following principles:

- Determination of apparent focal length (camera constant) especially in old printed photos, where the camera and/or magnification factor is unknown.
- Interactive manipulation of both facade's models (red TARGET and generic CAD) for an on-screen CAD-based rectification. This is actually a simulation of the classical optical-mechanical rectification.
- Automatic and manual procedures for this rectification with a friendly easy-to-use GUI.
- Analytical rectification support (i.e. automatic calculation of rectification parameters: a1, a2, a3, b1, b2, b3, d1, d2).
- Stereo rectification support (i.e. performing the bundle adjustment for subsequent 3-D modeling).
- As-built Facade's 3-D Modeling using design utilities from the supporting CAD platform.
- Modeling accuracy suitable for Architectural and Archaeological applications.
- Educational teaching-photogrammetry utilities, for on-screen real time rectification.
- Open-design logic for possible future extensions. For instance, software extensions regarding multimedia.

7. CONCLUSIONS AND FUTURE ENHANCEMENTS

This paper reports on a software extension of Bentley's MicroStation PC V5 environment, for CAD-based sensor attitude approximation. The developed system has proved adequate in accuracy for terrestrial photogrammetric applications referred to object facades. The only pre-requisites are the planar and orthogonal status of the object (facade), the length of its edges and an available photograph of it. The orientation parameters (Xo, Yo, Zo, ω, φ, κ) are calculated (approximated) using a three-step automatic procedure with manual interventions (i.e. a semi-automatic method). No control points are needed for these calculations.

The proposed CAD-based system provides a first step towards the integration of photogrammetric knowledge for an exterior orientation parameters' evaluation without control points. When this procedure will be full automated and when better accuracy will be provided, then the whole reconstruction of 3-D objects without manual measurements will be performed.

Future enhancements will be on using interactive virtual-reality environments, that is headsets and data gloves, or even stereoscopic glasses and video monitors. In these environments the tracking device is placed on top of the video display and is used to monitor and record head-eye movements with six degrees of freedom like stereo-rectifier hardware. As head-eye position changes the viewing position for the facade is changed as well. A sensing system in the headset keeps track of the viewer's position and orientation. For conservation purposes and in a meta-documentation logic, camera positioning for particular documented photos can be approximated and then to be used for 3-D modeling in any CAD environment. This method is well operated when an existing meta-documentation for a photograph offers the interior orientation parameters and qualitatively object information like: "*every side is parallel to the side opposite it for this four-sided geometric figure (facade) on the photo*", "*facade's edges are equal in length and perpendicular*", etc.

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