Amateur Photographic Recording Used to Rescue Works of Cultural Heritage

Introduction

The application of photogrammetry to the recording of historical monuments dates almost from the invention of photography itself. Architectural photography became a specialism and is presently a category in the history of photography.

It is clear that the recording and documentation of cultural heritage, specifically of monuments and sites, is important for all cultures, because it provides the world with a historical record of mankind’s past achievements. Such recording of existing items allows us not only to understand the development of mankind and its historical and cultural roots, but also to restore, reconstruct or archive for future reference. The information the picture represents cannot be overestimated. Also, the complexity of the information allows us to give a general treatment to the subject of safety including values of nature and landscapes.

The idea of putting every work of art or historical structure on the List of World Heritage is unrealistic. However, due to the increasing damages to monuments (vandalism, armed and political conflicts, natural disasters or atmospheric pollution) it is essential to record existing items for future generations. Realizing that some works of art and historical monuments cannot wait for a professional heritage recorder, authors think that amateur pictures and non-professional descriptions of objects enable us to preserve monuments. We could take advantage of the growing popularity of taking pictures as a cultural behaviour.

Amateur picture as a data source for common memory

The aim is heritage documentation and recording by everyone who travels or undertakes expeditions. Such attitudes give us new perspectives for saving cultural heritage. Our idea is to save for future reference not only the objects that are already on the well-known List of World Heritage but also other valuable objects. They can be outstanding in relation to the district, the village, the town or the municipality they belong to. Non-professionals can help to record the mass of cultural heritage (more or less systematically) and create something like a continuously updated, living archive which can be considered as a common memory of details and examples of historical, artistic and engineering achievements. Amateur pictures can be treated as the first, rough approximation of the archive, and the starting point for future decisions. The advantage of imaging
techniques is that they are permanent records, which can be made quickly and cheaply for subsequent processing.

The recording of our cultural heritage also enables individuals to appreciate monuments and sites of past cultures without actually visiting them, thereby enabling many more people to experience their beauty and wonder. By having more than one photograph of the same object, the creation of realistic virtual three-dimensional scenes becomes possible. Such VR reconstructions have cognitive, historical and cultural values. As a result of computer visualizations sightseeing of the historical sites is possible even when they are in poor condition and in danger of further damage. Additionally, we can take advantage of virtual reality to visit the places that no longer exist. Please, don’t be indifferent, unconcerned or insensitive to the historical monuments that are being destroyed before our eyes.

Metric exploitation of single images

In our short introduction we wanted to emphasize the role of pictures in the recording phase. Now we would like to present the way to use these pictures for measuring and three-dimensional model creation. To reconstruct the object shape we need the complete working plans. To create these specifications we can use some geodetic data (if any exists) or we can use the photogrammetric data from existing photographs. In the majority of cases there is nothing available but one single photograph or some completely different ones. Under such circumstances, photogrammetry is expected to make best use of recordings in order to extract any possible data of metric quality. We all realize that every practical example has its own unique character, thus indicating the multiformity of possible combinations to be treated, including camera, object, external control, product, purpose and accuracy:

- The image can be an original or enlargement; metric or amateur; analogue or digital; full format or only part of frame; with known or unknown interior orientation.
- We can have a full set of external control points or only some or they may not be available.
- The object can be (at the moment of data processing) fully destroyed, partly damaged or have a modified surface.
- We need to prepare different products: vector drawings, raster (orthophotography) or 3D models.
- Depending on the purpose (reconstruction / restoration / general documentation / theoretical study) one can require a high degree of accuracy or just a rough outline of the object.
Building shape reconstruction on the basis of a single amateur photograph

Below, we briefly present the mathematical foundation of our own approach together with its requirements, assumptions, limitations, and accuracy assessment. In order to illustrate these statements the practical task is also presented.

In general, it is impossible to reconstruct a spatial object from only one photograph, because for every image point there are infinitely many possible object points (compare the relation between two dimensional and three dimensional space). We need either a second photograph of the same object or some additional information (on the Z-coordinates). That’s why we narrow our analyses to the case where the object can be treated as physical realization of an external 3D coordinate system. We come across such cases mostly when we take an architectural photograph of the object whose facades and edges are parallel to a properly chosen \{X, Y, Z\} local ortho-Cartesial coordinate system. That system will be used to describe the position in the original (object) space. It is worth mentioning that the accuracy of such physical realization of the coordinate system is not accurate—mostly out by about one decimetre. Nevertheless, regarding the fact that old buildings are often characterised by modified surfaces, we think our simplification is still reasonable and sufficient.

We build the object space in a typical way as for the metric photographs. It means that we will use only these amateur photos that fulfil the following assumptions:

- The inevitable errors of the lens, the camera and the photograph itself is not considered; this means that we treat our photograph as an exact central projection;
- The image (original or enlargement) is in its full format (not only part of frame); this enables us to build an \{x, y, z\} image coordinate system where: 1) the principal point (namely, the orthogonal projection of the projection centre) lies in the centre of the picture and has got the (0,0,0) coordinates; 2) the datum xOy plane is parallel with the image plane which is equivalent to plane equation \( z = c \), where \( c \) stands for the principal distance.

In cases where we are looking at an architectural photograph, we should take such a picture while the camera axis is almost horizontal. What’s more, if we assume the vertical direction for axis OY then we achieve very small angles of rotation of the \{x, y, z\} image coordinate system relative to the \{X, Y, Z\} local ortho-Cartesial coordinate system.
Parameterisation

The relation between the image coordinate system and object coordinate system is called homothety and can be expressed by the following equation

\[ r = \lambda A(R - R_s) \]  

(1)

where

- the point of the image \( r^T = [x, y, c] \)
- the point of the object (original) \( R^T = [X, Y, Z] \)
- the projective centre \( R_s^T = [X_s, Y_s, Z_s] \)

The rotation matrix \( A \) is orthogonal \( (A^T A = I) \) and can be described by three Euler’s rotation angles i.e.: \( k_3 \) - rotation about the \( Oz \) axis, \( k_2 \) - \( Oy \), \( k_1 \) - \( Ox \).

\[
\begin{align*}
    a_{1,1} &= \cos(k_2) \cdot \cos(k_3) \\
    a_{1,2} &= -\cos(k_2) \cdot \sin(k_3) \\
    a_{1,3} &= \sin(k_2) \\
    a_{2,1} &= \sin(k_1) \cdot \sin(k_2) \cdot \cos(k_3) + \cos(k_1) \cdot \sin(k_3) \\
    a_{2,2} &= \cos(k_1) \cdot \cos(k_3) - \sin(k_1) \cdot \sin(k_2) \cdot \sin(k_3) \\
    a_{2,3} &= -\cos(k_2) \cdot \sin(k_1) \\
    a_{3,1} &= \sin(k_1) \cdot \sin(k_2) \cdot \cos(k_3) - \cos(k_1) \cdot \sin(k_2) \cdot \cos(k_3) \\
    a_{3,2} &= \sin(k_1) \cdot \cos(k_3) + \cos(k_1) \cdot \sin(k_2) \cdot \sin(k_3) \\
    a_{3,3} &= \cos(k_1) \cdot \cos(k_2)
\end{align*}
\]

(2)

By eliminating the \( \lambda \) parameter from the (1) equation we can obtain direct seven-paramaters central projection equations \((X_s, Y_s, Z_s, c, k_1, k_2, k_3)\):

\[
\begin{align*}
    x &= a_{1,1} (X - X_s) + a_{1,2} (Y - Y_s) + a_{1,3} (Z - Z_s) \\
    &\quad + a_{3,1} (X - X_s) + a_{3,2} (Y - Y_s) + a_{3,3} (Z - Z_s) \\
    y &= a_{2,1} (X - X_s) + a_{2,2} (Y - Y_s) + a_{2,3} (Z - Z_s) \\
    &\quad + a_{3,1} (X - X_s) + a_{3,2} (Y - Y_s) + a_{3,3} (Z - Z_s) \\
    c &= a_{3,1} (X - X_s) + a_{3,2} (Y - Y_s) + a_{3,3} (Z - Z_s)
\end{align*}
\]

(3)
Photogram orientation

We must notice that the original parallel lines converge on every perspective image. We are interested in the specified convergence points, namely the convergence points of horizontal axes of the local coordinate system as follows:

The $OX$ axis convergence point

$$\lim x = \frac{a_{1,1}}{a_{3,1}} c = x_c \quad \lim y = \frac{a_{2,1}}{a_{3,1}} c = y_c$$

$$X \to \infty \quad X \to \infty$$  (4)

The $OZ$ axis convergence point

$$\lim x = \frac{a_{1,3}}{a_{3,3}} c = x_z \quad \lim y = \frac{a_{2,3}}{a_{3,3}} c = y_z$$

$$Z \to \infty \quad Z \to \infty$$  (5)

Considering the image coordinates of convergence points one can derive the principal distance and rotation angles.

$$c^2 = -x_c * x_z - y_c * y_z$$  (6)

$$k_1 = -\arctan \left( \frac{y_z}{c} \right)$$  (7)

$$k_2 = \arctan \left( \frac{x_z}{c * \cos(k_1)} \right)$$  (8)

$$k_3 = \arctan \left( \frac{y_x \cos(k_1) + c \sin(k_1)}{y_x \sin(k_1) - c \cos(k_1) \sin(k_2)} \right)$$  (9)

To obtain the position of the above mentioned image coordinates of convergence points we can take advantage of the two very specific points, namely the origin of the local coordinate system and the $H$ point lying on the $OY$ axis. Substitute $R = 0$ in (1) we then obtain the following equation

$$r_o = [x_o, y_o, c]^T = -\lambda_o A R S_o$$

After some conversions with regards to some characteristics (i.e. the orthogonality of $A$ matrix) and eliminating the $\lambda_o$ parameter we can determine the following coordinates:
where \( U \) vector is defined as \( U = A^T r_0 = [U_1, U_2, U_3]^T \). Similarly, substitute \( R = R_H = [0, Y_H, 0] \) in (1) we then obtain \( r_H = [x_H, y_H, c]^T = \lambda_H A(R_H - R_S) \).

After multiplying by \( A^T \) and the \( \lambda_H \) elimination the \( \lambda_O \) parameter we can determine the last coordinate:

\[
Z_s = Y_H \frac{U_3 W_3}{U_2 W_3 - U_3 W_2}
\]

It’s easy to notice that the \( Y_H \) value describes the scale of the projection centre vector. If it isn’t possible to obtain the terrain measurement of that value, we can use some rough approximation instead. It influences only the scale, not the object shape itself.

**3D coordinates determination**

To obtain the exact position of the object points we first have to derive the \( \lambda \) parameter. It can be done by bisecting the just reconstructed spatial bundle of projective rays with the exterior object surface (object facade) as following:

\[
\lambda \begin{bmatrix} X - X_s \\ Y - Y_s \\ Z - Z_s \end{bmatrix} = \begin{bmatrix} P_1 \\ P_2 \\ P_3 \end{bmatrix} = A^T \begin{bmatrix} x \\ y \\ c \end{bmatrix}
\]

Such approach is similar to mono-plotting with one exception: here the plane is vertical (not horizontal).

The simplest case is when we have any pre-determined object point. Then we can easily obtain the planes parallel to the planes described by corresponding axes of the local coordinate system. For the points belonging to these planes we have:

\[
\lambda = \frac{P_1}{Z_p - X_s} \quad \text{in case of the plane } X = X_p
\]
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\[ \lambda = \frac{P_2}{Y_p - Y_S} \quad \text{in case of the plane} \quad Y = Y_p \quad (14) \]

\[ \lambda = \frac{Z_2}{Z_p - Z_S} \quad \text{in case of the plane} \quad Z = Z_p \quad (15) \]

The more general case is the determination of the position of the point belonging to any plane. Therefore, we first have to find the coordinates of the three points defining that plane and then calculate the 4 parameters of the plane equation. Substitute (16) by

\[ X = X_s + \lambda P_1, \quad Y = Y_s + \lambda P_2, \quad Z = Z_s + \lambda P_3 \]

we then obtain

\[ \lambda = \frac{aX_s + bY_s + cZ_s + d}{aP_1 + bP_2 + cP_3} \quad (16) \]

To determinate the coordinates of the point belonging to the curved plane we should start by describing this plane using general equation \( F(X, Y, Z) = 0 \). Then substituting (23) in it we can obtain the new equation \( f(\lambda) = 0 \) which allows the determination of unknown parameter.

Conclusions and the practical example

The above-described approach enables the preparation of building documentation on the basis of a single amateur photograph and some project assumptions. One of the most important ones is the assumption that the facade is a vertical plane and we bisect it with the rays of the bundle. In the first place, we have to identify the axes parallel to the local coordinate system axes as in the following example (Fig. 1). Note: These are colour illustrations originally – see CD GIS SILESIA 2003 for full version!
Fig. 1 Identification of the axes parallel to the local coordinate system axes

The next step is the stereodigitalization of the structural lines and other details of the architectural object (Fig. 2).

Fig. 2 Stereodigitalization of the structural lines and other details of architecture object
Using the above-derived equations one can obtain the set of coordinates of the measured points (facade coordinates) even if facades vary to any extent in depth. In our example we obtained the following results:

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Amateur Photographic Recording Used to Rescue Works of Cultural Heritage

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Amateur Photographic Recording Used to Rescue Works of Cultural Heritage

Summary

The paper includes two main sections: 1) amateur picture as a data source for cultural heritage object recording; 2) building shape reconstruction on the basis of single amateur photograph.

Ad.1. Regarding the increasing damage to monuments, it is essential to record existing items for future generations. Authors claim that amateur pictures and non-professional description of objects enable us to preserve monuments from destruction. We should take advantage of imaging techniques such as the use of pictures as permanent records which is quick and cheap for subsequent processing in order to create a continuously updated, living archive. The recording of our monuments, sites and works of history & art and engineering achievements enables individuals to appreciate them without actually visiting them.

Ad.2. The paper provides an approach which enables the preparation of building documentation on the basis of a single amateur photograph and the project assumptions i.e. the facade is a vertical plane and it can be bisected with the derived rays of bundle. Such an approach is similar to the mono-plotting technique with one exception: the plane is vertical (not horizontal). In order to illustrate these statements the practical task is also presented.

Keywords: cultural heritage, amateur photographs, photographic recording, object shape reconstruction, visualisation, monoplotting

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Wykorzysując Amatorską Dokumentację Fotograficzną

Streszczenie

W obecnych czasach katastrofy naturalne, zanieczyszczenia (szczególnie powietrza), konflikty zbrojne i polityczne,andalizm itp. stanowią zagrożenie dla obiektów tworzących nasze dziedzictwo kulturowe. Nie powinienśmy obojętnie omijać dogorywających na naszych oczach świadków historii. Warto prowadzić ich inwentaryzację, aby ocalić je od zapomnienia. Myślę o tak obszarnej bazie danych autorzy opracowali sposób na szybką i sprawną dokumentację obiektów

Słowa kluczowe: dziedzictwo kulturowe, zdjęcia amatorskie, dokumentacja fotograficzna, odtworzenie kształtu obiektu, monoploting