Digital Photogrammetry

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Digital Photogrammetry

A Practical Course

Springer

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Preface 1st edition

Photogrammetry is a science based technology with more than a century of history and development. During this time, the techniques used to get information about objects represented in photos have changed dramatically from pure optic-mechanical equipment to a fully digital workflow in our days. Parallel to this, the handling became easier, and so its possible also for non-photogrammetrists to use these methods today.

This book is especially written for potential users which have no photogrammetric education but would like to use the powerful capabilities from time to time or in smaller projects: Geographers, Geologists, Cartographers, Forest Engineers who would like to come into the fascinating field of photogrammetry via "learning by doing". For this reason, this book is not a textbook – for more and deeper theory, there exists a lot of literature, and it is suggested to use some of this. A special recommendation should be given to the newest book from KONECNY (2002) for basic theory and the mathematical backgrounds or to the book from SCHENK (1999) for the particular situation in digital photogrammetry. For a quick reference especially to algorithms and technical terms see also the Photogrammetric Guide from ALBERTZ & WIGGENHAGEN (2005).

This book includes a CD-ROM which contains all you need from software and data to learn about the various methods from the beginning (scanning of the photos) to final products like ortho images or mosaics. Starting with some introductory chapters and a little bit of theory, you can go on step by step in several tutorials to get an idea how photogrammetry works. The software is not limited to the example data which we will use here – it offers you a small but powerful Digital Photogrammetric Workstation (DPW), and of course you may use it for your own projects.

Some words about the didactic principle used in this book. In Germany, we have an old and very famous movie, "Die Feuerzangenbowle" with Heinz Rühmann. This actor goes to school, and the teacher of physics explains a steam engine:

"Wat is en Dampfmaschin? Da stelle mer us janz dumm, un dann sage mer so: En Dampfmaschin, dat is ene jroße, schwachze Raum..." (SPOERL, 1933. A language similar to German, spoken in the area of Cologne; in English: What is a steam engine? Suppose we have really no idea, and then let's say: A steam engine, that is a big black hole...). This “suppose we have no idea” will lead us through the book – therefore let’s enter the big black hole called photogrammetry, let’s look around and see what happens, just learning by doing. Theoretical background will only be given if it is indispensable for the understanding, but don’t worry, it will be more than enough of theory for the beginning!

Concerning the object(s) of interest and the camera position(s), we distinguish between terrestrial (close-range) and aerial photogrammetry. This book mostly deals with the aerial case. Nevertheless, the mathematical and technical principles are similar in both cases, and we will see an example of close-range photogrammetry in the last tutorial.

A briefly description of the software is included in the last part of this book (chapter 7).

This is the right place to give thanks to all people who helped me:

To my chief, Prof. Dr. Ekkehard Jordan, for all the time he gave me to write this book, and for his interest in this science – he was one of the first Geographers using analytical photogrammetric methods in glacier investigation – and to all my friends and colleagues from the Geographic Institute, University of Düsseldorf, for many discussions and tests. To Mrs. Angela Rennwanz from the same institute – she made the final layout, therefore my special thanks to her!

To Prof. Dr. mult. Gottfried Konecny, who encouraged, helped and forced me many times and gave me a lot of ideas, and to all my friends and colleagues from the Institute of Photogrammetry and GeoInformation (IPI), University of Hannover, for their scientific help and patience – especially to my friend Dr.-Ing. Karsten Jacobsen. To Prof. Dr.-Ing. Christian Heipke, now chief of the IPI, who agreed that I could use all of the infrastructure in this institute, and for several very interesting discussions especially concerning image matching techniques.

For proof-reading of this book thanks (in alphabetical order) to Dr. Jörg Elbers, Glenn West and Prof. Dr. mult. Gottfried Konecny.

Un agradecimiento de corazón a mis amigos del America del Sur, especialmente en Bolivia y Colombia!

It may be of interest for you: All figures in this book are also stored on the CD-ROM (directory …\figures) as MS PowerPoint™ files. Whenever you would like to use some of them, may be for education or scientific texts, please refer to this book! Thanks to the publishers for this agreement.

Bad Pyrmont, March 2003 *Wilfried Linder*

Preface 2nd edition

During the short time between the first edition and now many things happen giving the editors and me the idea not only to actualise this book but also to include further chapters. The changes are (among others):

The subtitle. It was the goal to give readers a compact and practical course with theoretical background only as far as necessary. Therefore we changed the subtitle from “Theory and Applications” to “A practical course”. Nevertheless, and this was a remark of several reviewers, some more theory than before is included.

More about close-range photogrammetry. The first edition dealt mainly with aerial photogrammetry, now the field of terrestrial or close-range applications is expanded. For instance, an automatic handling of image sequences (time series) was developed and will be presented.

In this context we also take a special look to digital consumer cameras which now are available for low prices and which the reader may use for own projects in close-range applications. Regarding the lens distortion of such cameras, a chapter dealing with lens calibration was added.

A glossary now gives the reader a quick reference to the most important terms of photogrammetry. All words or technical terms included there are written in *italics* in this book.

Last but not least: The software which you find on the CD-ROM was improved and expanded, and the installation of software and data is now easier than before.

Bad Pyrmont, July 2005 *Wilfried Linder*

Preface 3rd edition

Also the second edition was sold successful. It seems that the hope I wrote about in chapter 6.8 ("A view into the future: Photogrammetry in 2020") will be fulfilled – photogrammetric techniques are not only in use until today but even new fields of applications came up. One of them is stereo photogrammetry with high resolution satellite images about which we will talk and learn in a new tutorial, see chapter 6.6. Another interesting new chapter (6.7) deals with simple flatbed scanners which you can use to create anaglyph images from small objects.

Again the software (included on the CD-ROM) was improved, a new programme (LISA FFSAT) was added, and the text in this book was actualised to the new possibilities of the software.

This is the place to thank the publisher and in particular Dr. Christian Witschel for the pleasant and straightforward collaboration since nearly 10 years!

Düsseldorf, January 2009 *Wilfried Linder*

Contents

1 Introduction

1.1
Basic idea and main task of photogrammetry

If you want to measure the size of an object, let's say the length, width and height of a house, then normally you will carry this out directly at the object. Now imagine that the house didn't exist anymore – it was destroyed, but some historic photos exist. Then, if you can determine the scale of the photos, it must be possible to get the desired data.

Of course you can use photos to get information about objects. This kind of information is different: So, for example, you may receive *qualitative data* (the house seems to be old, the walls are coloured light yellow) from photo interpretation, or *quantitative data* like mentioned before (the house has a base size of 8 by 6 meters) from photo measurement, or information in addition to your background knowledge (the house has elements of the "art nouveau" style, so may be constructed at the beginning of the 20th century), and so on.

Photogrammetry provides methods to give you information of the second type, quantitative data. As the term already indicates, photogrammetry can be defined as the "science of measuring in photos", and is traditional a part of geodesy, belonging to the field of remote sensing (RS). If you would like to determine distances, areas or anything else, the basic task is to get object (terrain) co-ordinates of any point in the photo from which you can then calculate geometric data or create maps.

Obviously, from a single photo (two-dimensional plane) you can only get two-dimensional co-ordinates. Therefore, if we need three-dimensional co-ordinates, we have to find a way how to get the third dimension. This is a good moment to remember the properties of human vision (see also chapter 4.4). We are able to see objects in a spatial manner, and with this we are able to estimate the distance between an object and us. But how does it work? As you know, our brain at all times gets two slightly different images resulting from the different positions of the left respectively the right eye and according to the fact of the eye's central perspective.

Exactly this principle, the so-called *stereoscopic viewing*, is used to get three-dimensional information in photogrammetry: If we have two (or more) photos from the same object but taken from different positions, we may easily calculate the three-dimensional co-ordinates of any point which is represented in both photos. Therefore we can define the main task of photogrammetry in the following way: For any object point represented in at least two photos we have to calculate the three-dimensional object (terrain) co-ordinates. This seems to be easy, but as you will see in the chapters of this book, it needs some work to reach this goal...

For the first figure, let's use the situation of aerial photogrammetry. To illustrate what we have said before, please take a look at figure 1:

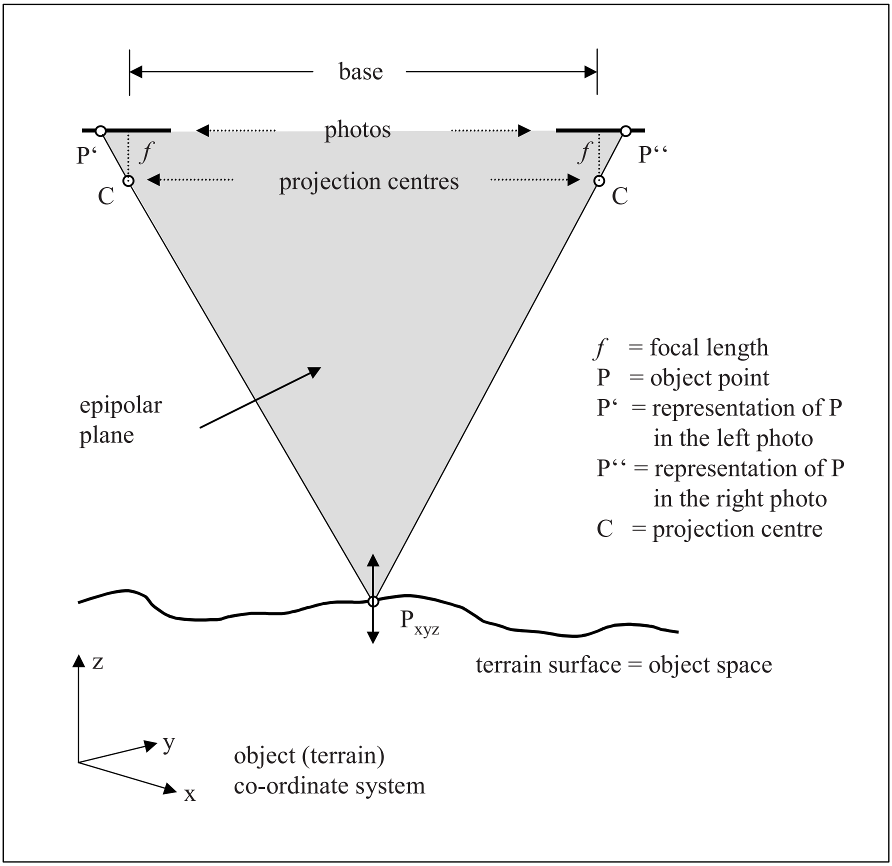

Fig. 1: Geometry in an oriented stereo model. Changing the height in point P (on the surface) leads to a linear motion (left – right) of the points P' and P'' within the photos along *epipolar lines*.

Each point on the terrain surface (object point) is represented in at least two photos. If we know or if we are able to reconstruct all geometric parameters of the situation when taking the photos, then we can calculate the three-dimensional co-ordinates (x, y, z) of the point P by setting up the equations of the rays [P' → P] and [P" → P] and after that calculating their intersection. This is the main task of photogrammetry as you remember, and you can easily imagine that, *if* we have reached this, we are able to digitise points, lines and areas for map production or calculate distances, areas, volumes, slopes and much more.

1.2

Why photogrammetry ?

There are many situations in life or science in which we must measure co-ordinates, distances, areas or volumes. Normally we will use tools like a ruler or a foot rule. This is the place to discuss situations in which photogrammetric techniques may be used as an alternative or in which photogrammetry is the only possible way to measure:

In many cases the methods of measurement depend on the kind of the objects. As already mentioned in chapter 1.1 it may happen that the object itself doesn't exist any more but only photos from the object. Similar to this are situations in which the object cannot be reached. For instance, imagine areas far away or in countries without adequate infrastructure, which then can be photographed to create maps.

Measure in photos means also measure without a physical contact to the object. Therefore, if you have very smooth objects like liquids, sand or clouds, photogrammetry will be the tool of choice.

Further, all kind of fast moving objects will be measured with photogrammetry. For instance these may be running or flying animals or waves. In industry, high-speed cameras with simultaneous activation are used to get data about deformation processes (like crash tests with cars).

In some examples, nowadays laser scanner equipment is an alternative to photogrammetry. In the aerial case laser scanning is used to get information about the relief (terrain models), but also in the close-range case these techniques are widely spread especially if it is necessary to get large amounts of three-dimensional point data (point clouds). The advantage here is that the object can be low textured – a situation where photogrammetric matching techniques (chapter 4.6) often fail. On the other hand, laser scanning is time consuming and up to now very expensive, comparing with photogrammetric methods, and laser scanning cannot be used for fast moving objects. Therefore, these methods may be seen as a supplement to photogrammetry.

1.3
Image sources: Analogue and digital cameras

The development of photogrammetry is closely connected with that of aviation and photography. During more than 100 years, photos have been taken on glass plates or film material (negative or positive). In principle, specific photogrammetric cameras (also simply called *metric cameras*) work the same way as the amateur camera you might own. The differences result from the high quality demands which the first ones must fulfil.

Beside high precision optics and mechanics, aerial cameras use a large film format. You may know the size of 24 by 36 mm from your own camera – aerial cameras normally use a size of 230 by 230 mm (9 by 9 inch)! This is necessary to receive a good ground resolution in the photos. As a result, the values of "wide angle", "normal" and "telephoto" focal lengths differ from those you may know – for example, the often used wide angle aerial camera has a focal length of about 153 mm, the normal one a focal length of about 305 mm.

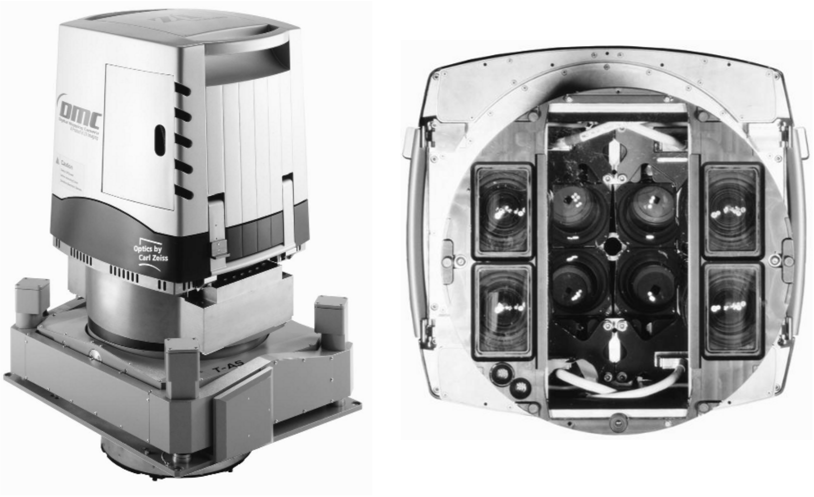

Fig 2: The DMC (Digital Mapping Camera) – an example of a digital aerial camera. Left: Camera mounted on carrier. Right: View from below – you can see the lenses belonging to the four area sensors. Courtesy of Intergraph Corp., USA.

Furthermore, the lens system of aerial cameras is constructed as a unit with the camera body. No lens change or "zoom" is possible to provide high stability and a good lens correction. The focal length is fixed, and the cameras have a central shutter.

Similar to this, also for close-range applications special cameras were developed with a medium or large film format and fixed lenses.

Since long times, manufacturers like Z/I imaging (now Intergraph Corp.), Leica or Vexcel have been developing digital aerial cameras. As we can see today, there are two construction strategies. One is to keep the central perspective principle well-known from existing film cameras with the advantage that you can use existing software to handle the data. For this solution (called *frame camera*), an area sensor is required. Considering the fact that a high-resolution area sensor giving the same information like 230 by 230 mm photos taken on film would be extremely expensive, efforts are made to use four overlapping smaller sensors of industrial standard and then match the four image parts together (DMC from Intergraph, see figure 2). The other strategy is to use a *line sensor* across the flight direction and collect data continually during the flight. This is a bit similar to the techniques known from sensors on satellites or from hyper-spectral scanners (ADS 40 from Leica).

Fig. 3: Example of metric digital cameras: The medium-format AIC (left) and the small-scale d7 metric (right) from Rollei. Courtesy of Rollei Fototechnic, Germany.

For the close-range case the transition from film to digital cameras can be described in the way that existing film cameras are still in use, but if a new camera shall be purchased it will be a digital one in any case. On the market are small-format and medium-format cameras like those from Rollei (d7 metric, d30 metric or the AIC, also well suitable for the aerial case, see figure 3).

Nowadays digital consumer cameras have reached a high technical standard and good geometric resolution and are available for low prices. Due to the fact that these cameras can be used for close-range photogrammetry without any problem if the accuracy to be reached is not too high, a separate chapter will deal with this kind of equipment.

1.4
Digital consumer cameras

As mentioned just before, various types of digital consumer cameras are on the market which may also be used for photogrammetric applications. The differences of the construction principles between metric and consumer cameras can be seen in general in quality and stability of the camera body and the lens. Further, consumer cameras usually have a zoom (“vario”) lens with larger distortions which are not constant but vary for instance with the focal length, so it is difficult to correct them with the help of a calibration.

If you want to purchase a digital camera to use it for photogrammetry please take the following remarks into account:

General: It should be possible to set the parameters focal length, focus, exposure time and f-number manually, at least as an option.

Resolution (Number of pixels): Decisive is the real (physical), not an interpolated resolution! The higher the number of pixels, the better – but not at any price: Small chips with a large number of pixels of course have a very small pixel size and are not very light sensitive, furthermore the signal-noise ratio is less good. This you will find especially with higher ISO values (200 and more) and in dark parts of the image.

Focal length range (zoom): Decisive is the optical, not the digital (interpolated) range!

Distance setting (focus): It should be possible to de-activate the auto focus. If the camera has a macro option you can use it also for small objects.

Exposure time, f-number: The maximum f-number (lens opening) should not be less than 1:2.8, the exposure time should have a range of at least 1 ... 1/1000 seconds.

Image formats: The digital images are stored in a customary format like JPEG or TIFF. Important: The image compression rate must be selectable or, even better, the compression can be switched off to minimise the loss of quality.

Storage: Usual are SD memory cards with capacities up to 4 GB. Modern PCs / Laptops are supplied with SD card readers – this will save accumulator energy when transferring data from the camera to the computer.

Energy supply: Make sure that you can use customary batteries or accumulators. They are much cheaper than special ones and available everywhere.

Others: Sometimes useful are a tripod thread, a remote release and an adaptor for an external flash. Two sets of accumulators, a battery charger, additional memory cards, if need be a card reader and a good tripod complete the equipment. A final remark: As everywhere in life, “cheap” is not always equal to “good”! Therefore you should better proof the quality than the price…

To work with image data from a digital camera you need some information like the focal length or the size of the pixels on the CCD chip. In the appendix you find a table with technical data of several CCD chips, and in the tutorials 3 and 4 you will see how to handle the images.

1.5

Short history of photogrammetric evaluation methods

In general, three main phases of photogrammetry can be distinguished concerning the techniques of the equipment used for evaluation and the resulting workflow. The transition from one phase to the following took a time of about 20 years or even more.

In the chapter 1.1 you saw that, if we want to get three-dimensional co-ordinates of an object point, we must reconstruct the rays belonging to this point from the terrain through the projection centres into the central perspective photos, a procedure which we call *reconstruction of the orientation* or briefly *orientation*. In the first decades of photogrammetry this was done in a pure optical-mechanical way. The large, complicated and expensive instruments for this could only be handled with a lot of experience which led to the profession of a photogrammetric operator. Not only the orientation of the photos but also any kind of the following work like measuring, mapping and so on was carried out mechanically. In later times, this phase was named the *Analogue Photogrammetry*.

With the upcoming of computers, the idea was to reconstruct the orientation no more analogue but algorithmic – via formulas with their parameters (coefficients) being calculated and stored in the computer. The equipment became significantly smaller, cheaper and easier to handle, and was supplied with linear and rotation impulse counters to register hardware co-ordinates, and with servo motors to provide the ability to position the photos directly by the computer. Nevertheless, the work still was done with real (analogue) photos and still needed a high precision mechanical and optical piece of equipment, the so-called *analytical plotter*. According to that, this phase was called *Analytical Photogrammetry*.

As everybody knows, in the last decades the power of computers rose at breathtaking speed. So, why not use digital photos and do the work directly with the computer? Even a simple PC nowadays has power and storage capacity enough to handle high-resolution digital photos. That is the phase now: *Digital Photogrammetry*, and that’s what we want to explain with the help of this book, the included software and some examples. The only remaining analogue part in the chain of a total digital workflow often are the photos themselves when taken with traditional cameras on film, but also this will end soon.

For existing photos on film or paper, we will need a high-precision scanner as the only special hardware periphery. And due to the fact that around the world hundreds of “classical” aerial cameras are in use – instruments with a lifetime of decades – and digital cameras are much more expensive up to now, photo production on film with subsequent scanning may be the standard for many years (MAYR 2002). On the other hand we must recognise that a totally digital workflow has much advantages and is much faster, and no film development is necessary, a fact which significantly decreases the costs.

1.6

Geometric principles 1: Camera position, focal length

To explain the relation between the distance camera position – object (aerial case: flying height) and the focal length, we use a terrestrial example. First, take a look at figure 4:

Our goal is to take a photo of the house, filling the complete image area. We have several possibilities to do that: We can take the photo from a short distance with a wide-angle lens (like camera position 1 in the figure), or from a far distance with a small-angle lens (telephoto, like camera position 2), or from any position in between or outside. Obviously, each time we will get the same result. Really?

Figure 5 shows the differences. Let’s summarise them:

- The smaller the distance camera – object and the wider the lens angle, the greater are the displacements due to the central perspective, or, vice versa:

- The greater the distance camera – object and the smaller the lens angle, the smaller are the displacements.

In a (theoretical) extreme case, if the camera could be as far as possible away from the object and if the angle would be as small as possible (“super telephoto”), the projection rays would be nearly parallel, and the displacements near to zero. This is similar to the situation of images taken by a satellite orbiting some hundreds of kilometres above ground, were we have nearly parallel projection rays but also influences coming from the earth curvature. The opposite extreme case are photos taken with a *fisheye* lens which have an opening angle of up to 180 degrees, sometimes called whole-sky-systems.

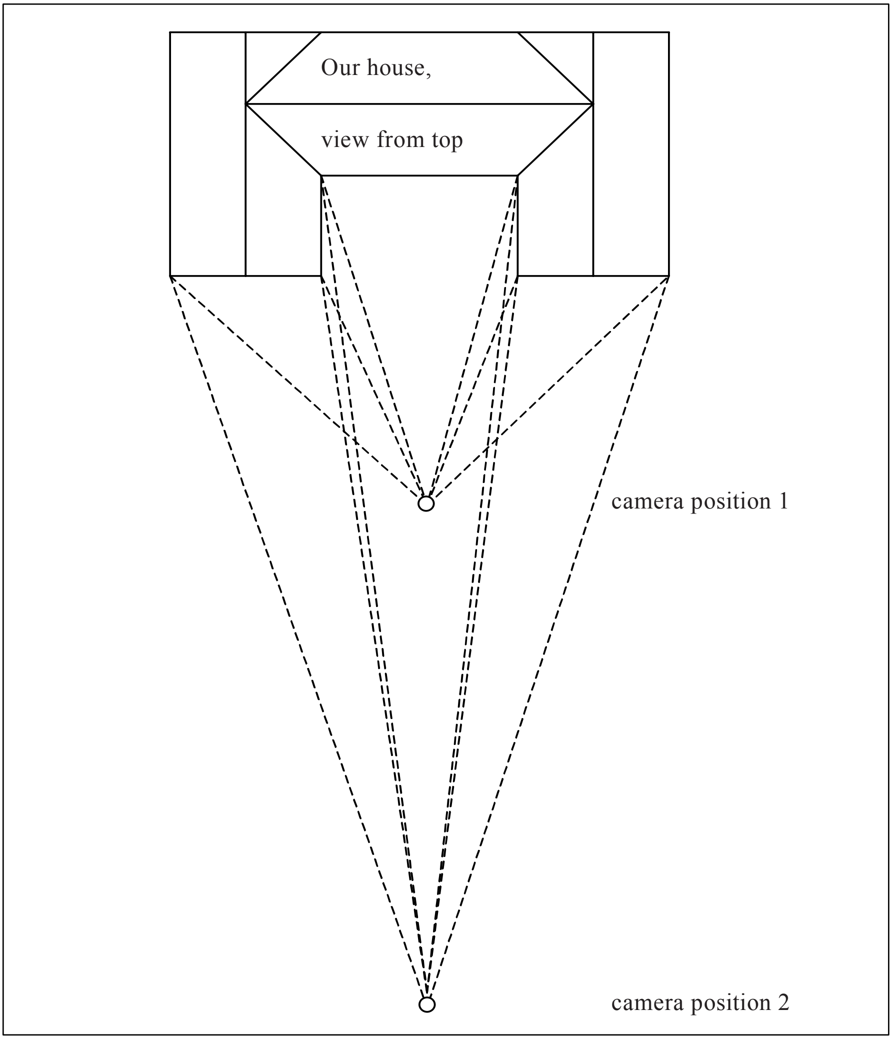

Fig. 4: Different positions and lens angles. The situation, view from above.

What are the consequences? If we would like to transform a single aerial image to a given map projection, it would be the best to take the image from as high as possible to have the lowest displacements – a situation similar to satellite images (see above). On the other hand, the *radial-symmetric displacements* are a prerequisite to view and measure image pairs stereoscopically as you will see in the following chapters, and therefore most of the aerial as well as terrestrial photos you will use in practise are taken with a wide-angle camera, showing relatively high relief-depending displacements.

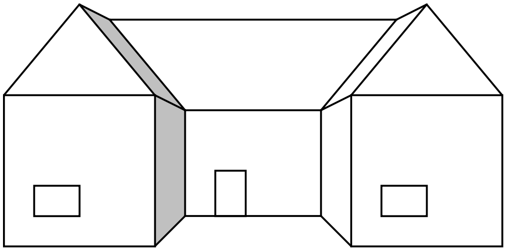

Photo taken from camera position 1

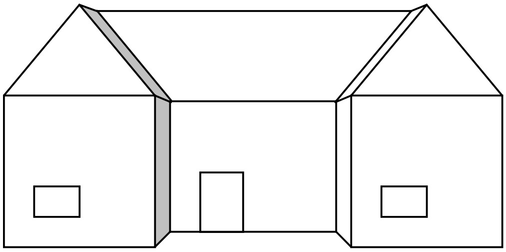

Photo taken from camera position 2

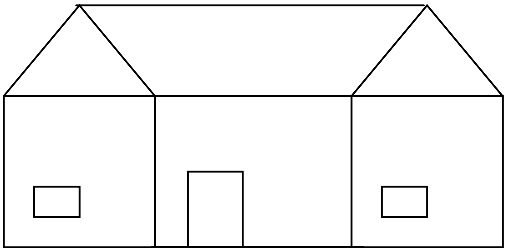

Photo taken from a position infinitely far away

Fig. 5: The results: Photos showing the house in same size but in different representations due to the central perspective.

1.7

Geometric principles 2: Image orientation

As already mentioned before, the first step of our work will be the reconstruction of the orientation of each photo, which means that we have to define the exact position of all photos which we want to use within the object (terrain) co-ordinate system. Now please imagine the following: If we know the co-ordinates of the projection centre, the three rotation angles (against the x-, y- and z-axis) as well as the focal length of the camera (part of the interior orientation, see chapter 4.2.2), then the position of the photo is unequivocally defined (see figure 6). Therefore our first goal will be to get the six *parameters of the exterior orientation* (x_0, y_0, z_0, φ, ω, κ; see chapter 4.2.5).

In the case of aerial photos, the values of φ (phi) and ω (omega) will normally be near to zero. If they are exactly zero, we have a so-called *nadir photo*. But in practice, this will never happen due to wind drift and small movements of the aircraft. Always remember the rule “nothing is exact in real life”! The value of κ (kappa) is defined as “east = zero” according to the x-axis of the terrain co-ordinate system, then counting anti-clockwise in grads, defining north = 100, west = 200, south = 300 grads (see chapter 1.10 for the units).

Please note that only exact nadir photos of a true horizontal plane would have a unique scale or, in other words, non-zero values of φ and/or ω as well as the form of the object (for instance the relief) lead to scale variations within the photo.

If M_b is the mean photo scale or m_b the mean photo scale number, h_g the height of the projection centre above ground and f the focal length, we can use the following formulas (see figure 7):

$$m_b = h_g/f \qquad \text{or} \qquad M_b = 1/m_b = f/h_g \qquad \textit{1.7.1}$$

Now take a look at the different co-ordinate systems (CS) which we have to deal with. First, the camera itself has a two-dimensional CS; this may be a traditional or a digital one (*image CS*). Second, in case of film or paper material we must use a scanner which has a two-dimensional pixel matrix (*pixel CS*) – the equivalent to the photo carrier co-ordinates of an analytical plotter (see chapter 1.5). And finally our results should be in a three-dimensional *object (terrain) CS* – normally a rectangle system like used for the Gauss-Krueger or the related UTM projection, connected with an ellipsoid to define the elevation (for instance, in Germany the Gauss-Krueger system is related with the Bessel ellipsoid, the UTM system with the ellipsoid defined from Hayford).