How to Shoot an *Aulos*
Taking Measurements from Photographs

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Zusammenfassung

Eine Anleitung, wie man fotografische Aufnahmen von Blasinstrumenten anfertigt, die sicherstellen, dass wichtige Messdaten nachträglich überprüft werden können.

1 Taking Measurements

You are granted permission to investigate an instrument at a distant museum. You travel there. Eventually, you actually get access to the item. Necessarily, you have a limited amount of time to complete your investigation. Perhaps while you are in a hurry to take all the relevant measurements and photographs, you experience the problem of keeping your mind from shifting to questions of interpretation (on the other hand, you might miss some important details if you don't think about interpretation). Very likely you will get home having made one or more mistakes. Thorough preparation may have saved you from forgetting to take along relevant data (assuming the nature of all relevant data could be anticipated). But there is hardly any way of making sure your measurements are taken accurately and noted down no less accurately – except by going through all the work twice and comparing the results. Usually I do not have the time for two complete measuring cycles. So the danger of errors lingers at every step, in handling and reading the tools no less than in writing down the figures or in later reading and copying them to the computer. Apart from my experience with my own work, a surprising amount of flawed data, printed in articles or underlying published calculations, testifies to the problem.

As a consequence, it is desirable, perhaps even indispensable, to have all the data collected in a less error-prone form as well, so that the figures obtained from the object can be checked later. Optimally, this amounts to preparing a three-dimensional digital image. Computer tomography serves this purpose extremely well, because it also exhibits internal structures. In practice, however, it is very often impossible to get a CT done, if only because it is an expensive technique, or simply because you cannot take the object out of the building where it is stored. As an alternative, it is possible to obtain a three-dimensional representation by photographic techniques; these, in turn, require specialist equipment, specialist software, and specialist skills to deal with both.

Taking simple photographs, on the other hand, does not provide the desired results, not even if the object sits on scale paper, let alone if a small scale is placed beside it. The reason for this is photographic distortion. Firstly, there is geometric distortion: two points of similar distance in reality are mapped onto points of very dissimilar distance in a photograph. This holds true whenever they are located at different distances from the camera, or whenever the respective lines between them point in different directions – so, to all intents and purposes, it holds universally true. Secondly, there is the factor of lens distortion: straight lines become curves in the photograph, an effect that is especially noticeable with wide-angle optics and towards the margins of the image. As a result, it is impossible to read measurements from a photograph unless it includes a ruler that effectively touches all the points one wants to measure. Again, there is software with the help of which, in principle, it is possible to eliminate all sorts of distortions from a set of photographs of the same scene taken from different angles; but it has a steep learning curve and one usually needs to go through a relatively long amount of manual adjustments in order to obtain some results, so I doubt it is worth the effort if satisfying results can be reached in a less laborious way.

In comparison to computer tomography, X-raying provides a relatively cheap means of viewing an object's interior, albeit in two-dimensional projection. Where it is available, it can also be used to take measurements – provided that proper caution is taken. Here as well, it is as tempting as it is misleading to take measurements directly from the image. Since the rays emerge from a sharp point, they

are not parallel, and therefore distances represented on the plate are always larger than they are in reality, with increasing magnification towards the margins (cf. Fig. 1).[1] If the relevant data are known (i.e., the position of the X-ray source, the distance between object and photographic plate, and the orientation of the object), it is comparatively easy to calculate original measurements from those obtained on the image with satisfactory precision.

In this contribution I explain a technique that is simpler than the ones mentioned up to now and which I have employed repeatedly in measuring the remains of ancient pipes (*auloí/tibiae*). Its primary purpose is the determination of longitudinal finger-hole positions, and it is applicable to all woodwind instruments with a straight tube (with slight modification, also to instruments of a conical shape). Its main advantage is that it requires no equipment that is not either readily available or most easily manufactured. If executed properly, it yields results that are precise at least to the millimetre, which is by far sufficient to detect any gross errors, and also precise enough to determine the plausible pitches of individual finger holes (or cross fingerings) by means of computer calculations.

All one needs is a digital camera, two long rulers, and a means of elevating these rulers by any given distance between, say, 10 mm and 25 mm – or in any case by the external diameter of the instrument under investigation. In addition, it is useful to have the camera mounted on a tripod and a sheet of scale paper large enough to place the object on it. In order to position the rulers vertically I use simple wooden wedges, onto the sides of which I have glued some scale paper in order to simplify adjustment. Now the trick is to place both rulers parallel to the instrument on each of its sides (here the scale paper on the table is helpful), so that their upper surface is level with the upper side of the instrument (cf. Fig. 2; slight deviations do not noticeably affect the outcome).[2] Now a set of photographs can be shot, progressively turning the instrument so that each point to be measured comes to lie at the top at least once (Fig. 3).

From such a photograph, measurements along the top of the object are easily retrieved, especially with the help of some computer program in which it is possible to overlay bitmap graphics with vector graphic elements; in less technical words, to draw lines on top of a photo and move them around. One need not use dedicated graphics software for that; *OpenOffice Writer* or *Microsoft Word* do the job perfectly. The photograph must be inserted into a document (for maximal magnification, it is useful to switch the document to landscape format if the image is landscape, and also to clip the margins of the image); then it is necessary to draw lines that run from a point on one ruler to

the respective point on the other ruler[3] and right through the point to be measured on the object. Due to perspective, these lines converge toward the background, and so it takes a little playing around with their endpoints to achieve the desired result; but then the distance of the points on the object can be read from one of the rulers (Fig. 4).

The procedure can be greatly simplified if the image is pre-processed in a way that transforms those converging lines to parallel vertical lines. If done with special care (which is once more not crucial with regard to the final figures), the lines of the scale paper are also transformed to squares in the resulting picture and measurements may be read directly from its pixels, for example with a resolution of 10 dots per millimetre. On the CD that accompanies the present volume I enclose a copy of the software that I have designed and use for this purpose, in the hope that it may also come in useful to others. Here is a short description of how it works:

1. Enter the location of an image file in the address field at the top of the window, or use the "Open" button to the right to select a file. You may use an Internet address as well. The drop-down list connected to the address field holds a record of recently used images.
2. Initially, you will find a couple of red vertical lines at the top left of the image. Adjust these lines so that their respective endpoints are located at corresponding distances on the two rulers on your image; one line should be positioned at about the left end of the object to be measured, and one close to its right end (cf. Fig. 5). If the setup of the shot ensured that the rulers were parallel to the horizontal lines on the scale paper, try to make sure that the red lines are parallel to the vertical lines on the scale paper. Magnify the image as much as necessary to work accurately. The toolbar at the top holds zoom buttons, a drop-down list of zoom values, and a "Fit (in window)" checkbox. You may move both lines at once by clicking in the space between them, or move one line by clicking at it somewhere not too close to the ends,

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[1]   The effect displayed in figure 1 can be studied in Hagel 2010, 84 fig. 17, if the distances of the highest three holes in the two X-rays are compared.

[2]   With a conical instrument, its narrower end must be rested on a support so that the measured line is level (the height of the support is the difference between the external diameters of both ends).

[3]   It is of course most straightforward to use identical numbers on the two rulers as endpoints, but this is by no means necessary, since (thanks to the intercept theorem) it is also not required that the starting points of the rulers be opposite each other. Just make sure that the measured distances between the lines are the same on both rulers.

or move only the endpoint of a line by clicking at it. Note the changing shape of the cursor, which varies depending on what you move when clicking on a given point. If the colour of the lines is difficult to discern against the background, you can change it by right-clicking on them.

3. In the "Width" field (found below), specify the distance between the two lines as read from the rulers, in mm.

4. In the "Depth" field, enter the distance that would correspond to the length of the red lines. If you are not sure that the rulers sit at a specific distance from each other, this step may require some calculations involving figures read from the scale paper on which the rulers rest, and their width. If you cannot come up with exact figures, give a rough estimate – an error here will not affect the results, as long as the measured distances are roughly parallel to the rulers.

5. If the object extends beyond the lines at one or both sides, specify the amount of the spread in the "Horz. Padding" field.

6. Click the "Tort" button. A second image will open on the right side, containing the specified portion of the original, with geometrical distortion removed *at the level of the rulers* (cf. Fig. 6). (You may now move the dividing line between the graphics or uncheck "Source" below to have a better view of the resulting image).

7. Right-click this image to "Copy" it to any graphics software or word processing program, or "Save" it to a file.

8. You may measure off approximate distances on the resulting image directly by holding down the *Ctrl* key, clicking on a start point and moving the mouse to another point; the distances are detailed at the bottom of the image. But always keep in mind (1) that such measurements may still be subject to lens distortion, (2) that you must refer exclusively to the plane at the level of the rulers, not to anything higher or lower than their surface, and (3) that their reliability depends on the values you have specified for the "Width" and "Depth" of the image (if merely the "Width" value were exact, only horizontal measurements would work). Therefore, it is always preferable to use the procedure that I describe below.

With the new image, one can go back to the software where the measuring is done. Once more, it is necessary to draw lines which extend from the points to be measured on the object to one or both of the rulers; but this time these are simple vertical lines, which are set up in no time at all (cf. Fig. 7). Subsequently the distances can be read directly from one of the rulers. Keeping a document with all the drawn lines has the advantage that one can later go back to it and make sure that the lines are perfectly adjusted (e.g., at the exact centres of the finger holes) and that measurements have been read correctly. For a quick survey, my software also gives the option to move a vertical line around (available by right-clicking on the resulting image).

In order to exclude another source of error, one might want to type the figures read from the ruler into a spreadsheet program such as *OpenOffice Calc* or *Microsoft Excel*, and have the distances between them calculated automatically. Thus it is also possible to correct measurements along lines that are not exactly parallel to the rulers, for instance because the instrument is bent at one point or another: in this case, the angle between object and rulers must be determined and the raw measurement must be divided by its cosine.[4] Instead of fiddling around with protractors or set squares on the screen, by the way, it is preferable to calculate the angle in question from its tangent, since this amounts to no more than drawing a rectangle from one end point of the measured line to the other: its height divided by its width gives the tangent of the sought angle. Also in this case, the program I provide may be useful: when measuring a 'distance' as described above (clicking and moving the mouse while holding the *Ctrl* key), the angle between the measured line and the horizontal axis also shows up.

If the same spreadsheet also holds measurements obtained directly from the object, both may be compared automatically and possible mismatches that exceed a given limit (e.g., 1 mm) can be indicated, for instance by displaying the respective figures in a different colour. To all who might profit from such an approach I offer a spreadsheet template that works well for me (together with explanations and an example), which is included on the accompanying CD.[5]

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4   In figure 6, for instance, the instrument's axis deviates from the horizontal by 1°. Consequently, all horizontal measurements are to be multiplied by 1/cos(1°) = 1.00015, or 0.15 millimetres per metre, which is however negligible for most purposes.

5   This is a *Microsoft Excel* document, but it should work equally well with *OpenOffice Calc*. Please note that in its empty state it contains numerous circular references, which may generate a warning message on opening. This is not an error: the tables are built in a way so that unavailable data are calculated or estimated from available data. For instance, on a fragmented pipe one may know the starting point of a finger hole and its transversal diameter; from these values, the end and centre of the hole can be guessed. In another case, the transversal diameter of a hole may be lost and thus must approximately be equated with its longitudinal diameter. The spreadsheet accounts for both cases.

2 Taking Stereographic Images

One main disadvantage of photographs is that they are flat, thus giving only a very incomplete impression of the actual shape of an object. Since our memory is not, of course, a more reliable guide, it can be extremely helpful to preserve three-dimensional images of the objects we have studied. This is most easily and cheaply done by stereographic photography. However, true stereographic cameras or sets of cameras mounted and manipulated together are rare, comparatively expensive and also rather unwieldy for travelling. Nonetheless it is quite easy to obtain three-dimensional pictures for our purposes with very little more than an ordinary digital camera and a tripod, thanks to the fact that objects from the archaeological record generally do not move. This makes it possible to take the two shots needed for stereography not simultaneously, but one after the other.

As additional equipment, we need a sheet of cardboard large enough to fit the tripod on it plus an additional 10 cm or so extending sidewards. Place the tripod as much to the left of the sheet as possible and mark the position of its feet. Take the tripod away and construe a set of matching positions at a distance of about 7 cm (or your personal eye distance) rightwards from the original ones (cf. Fig. 2). When taking a stereographic picture, place the tripod first on one, then on the other of the two sets, and make sure that the direction of the camera objective is oriented at a right angle to the line between them. Operate the camera by remote-control release or set the self-timer. Do not use flash – the two pictures would have different highlights and shadows. If you really need to use flash, it must be separate from the camera and be kept at the same place for both shots.

Having obtained pairs of photographs, they must be combined for viewing. There are a number of ways to do that. Most simply, the two photographs (or matching clippings) are mounted side by side, for example on a computer screen, placing the shot taken from the right side on the left and the one taken from the left side on the right (cf. Fig. 8). The viewer, head held upright, crosses his or her eyes, so that the pair of images appears redoubled (i.e., four images). Now the angle of the eyes is adjusted until the central pair of the four virtual images overlap: once this is achieved, one obtains a very natural three-dimensional view. The method requires a little practice, but it yields 3D images in natural colours without additional equipment.

Alternatively one can try adjusting a vertical mirror in front of the computer screen (images once more set up side by side, but this time the left one goes left, and one is mirrored). More comfortably, the pairs of images may be processed with appropriate software in order to obtain single anaglyphic pictures which can be viewed with, for instance, 3D red-cyan glasses (cf. Fig. 9).[6] Such colour-anaglyphs always fall short of the original colours, but viewing them needs no training, so they are definitely a good way of sharing 3D images with colleagues.

Finally, sets of images of the same object in a well-defined setting including rulers and scale paper are also a good starting point for real hardcore photogrammetry – the art of obtaining measurements in all three dimensions from photographs. But as I have stated in the beginning, this requires expertise way beyond the simple procedures detailed above.[7]

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[6] A richly featured free software package for this purpose is *Stereo PhotoMaker* by Masuji Suto and David Sykes, available at <http://www.stereomaker.net> (January 27, 2011).

[7] One of the leading photogrammetric software packages, *PHOTOMOD*, is available in a free 'light' version, obtainable from <http://www.racurs.ru> (January 27, 2011).

Bibliography

HAGEL, S.
2010 Understanding the Aulos Berlin Egyptian Museum 12461/12462, in: R. Eichmann – E. Hickmann – L.-Ch. Koch (eds.), Studien zur Musikarchäologie 7, Orient-Archäologie 25 (Rahden/Westf.), 67–87.

Content of the CD

FotoTorter_setup.exe
Windows software helping in the establishment of longitudinal measurements, such as finger hole positions on pipes, from photographs.
Simply execute the program which will guide you through the setup process.

Fingerholes-Template.xls
Microsoft Excel sheet helping in establishing woodwind finger hole positions and sizes from measurements and photographs. Contains, on separate pages, the template and an example how it can be used.
When opening this file, ignore warnings: circularity is intentional and disappears once sufficient data is entered.
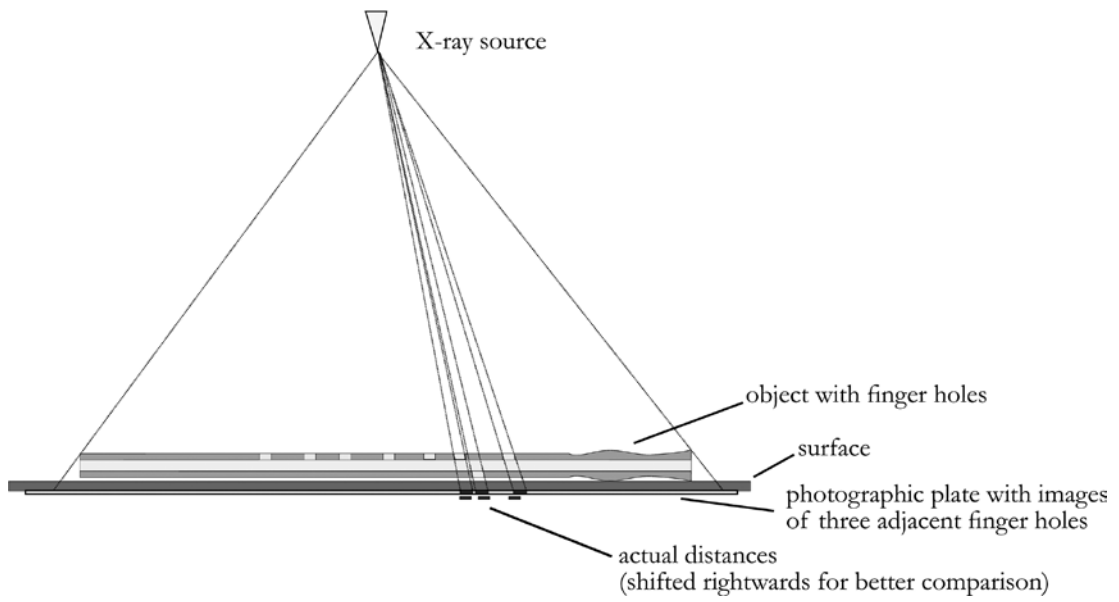
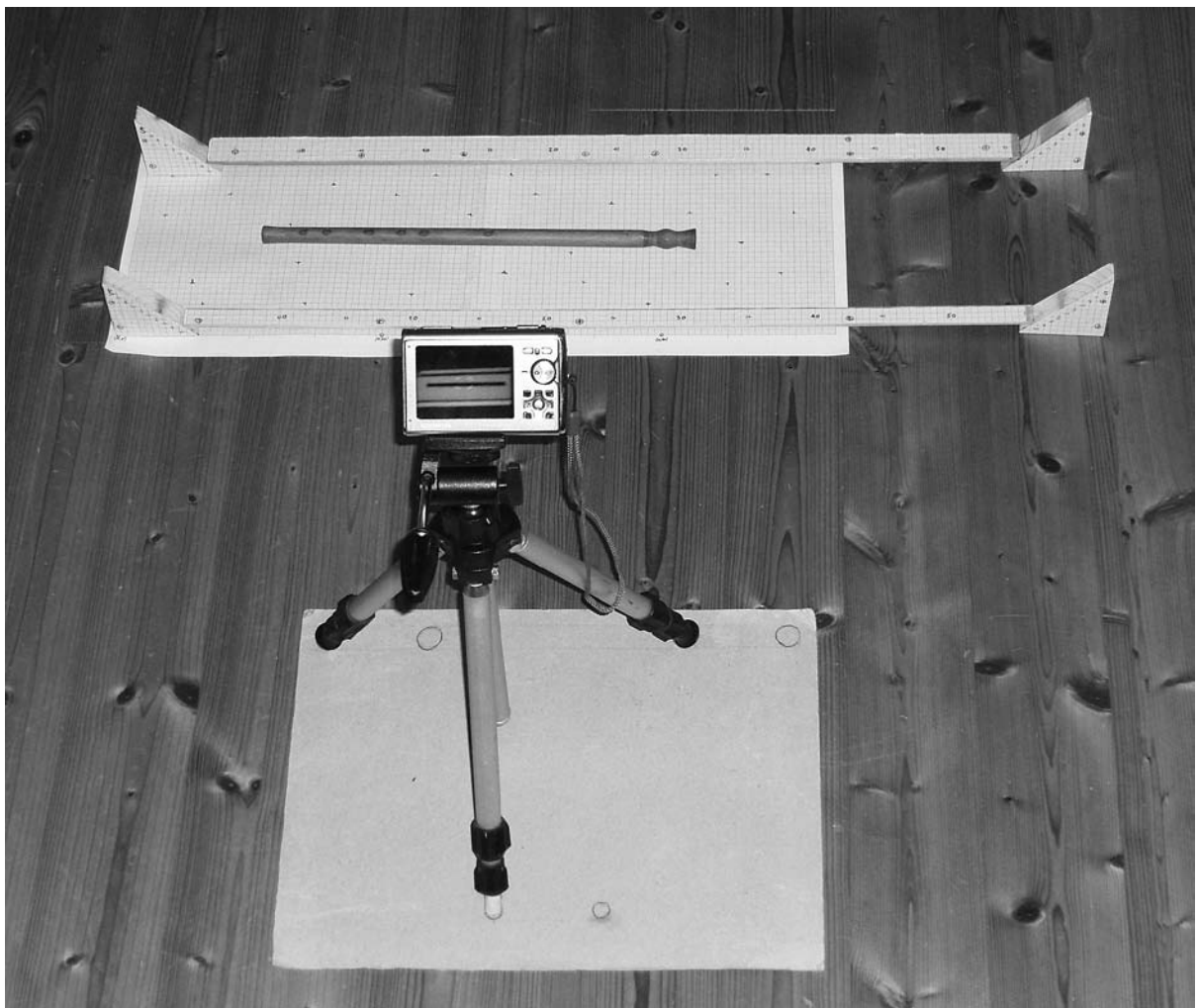Fig. 1 Distortion on X-raying (made by S. Hagel).

Fig. 2 Preparing a photograph from which finger-hole positions can be measured (photograph by S. Hagel).
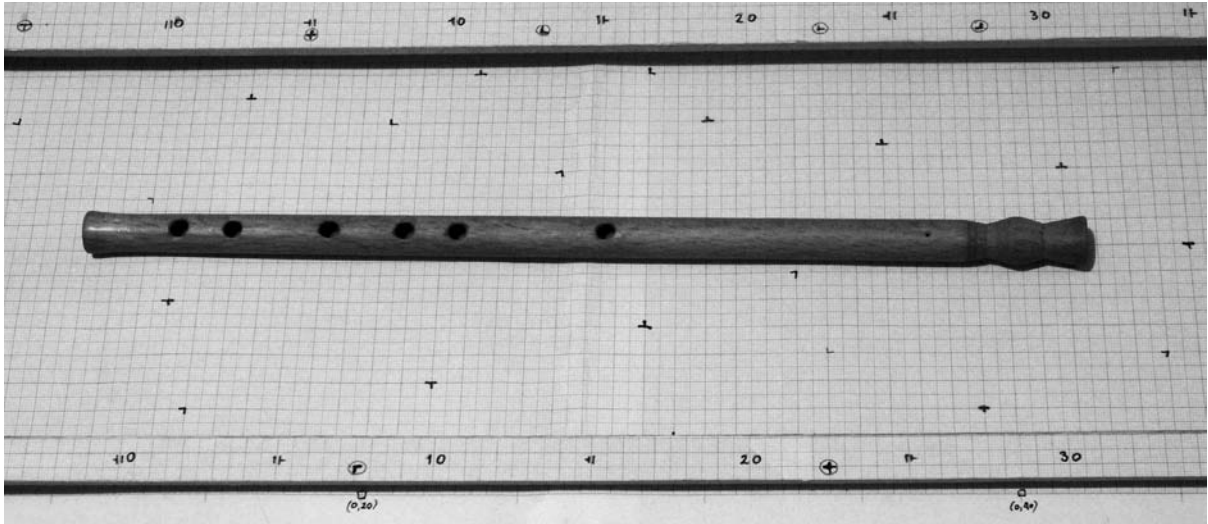
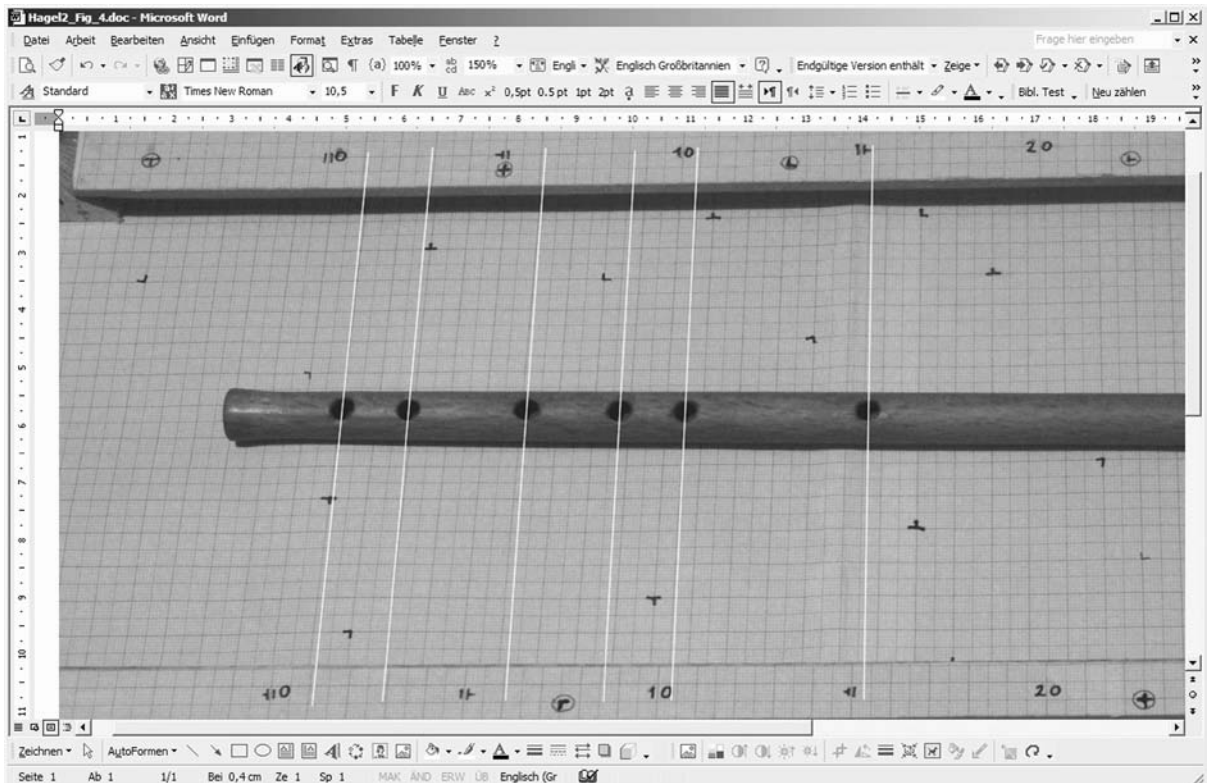Fig. 3 A photograph taken with the setup of figure 2 (image by S. Hagel).

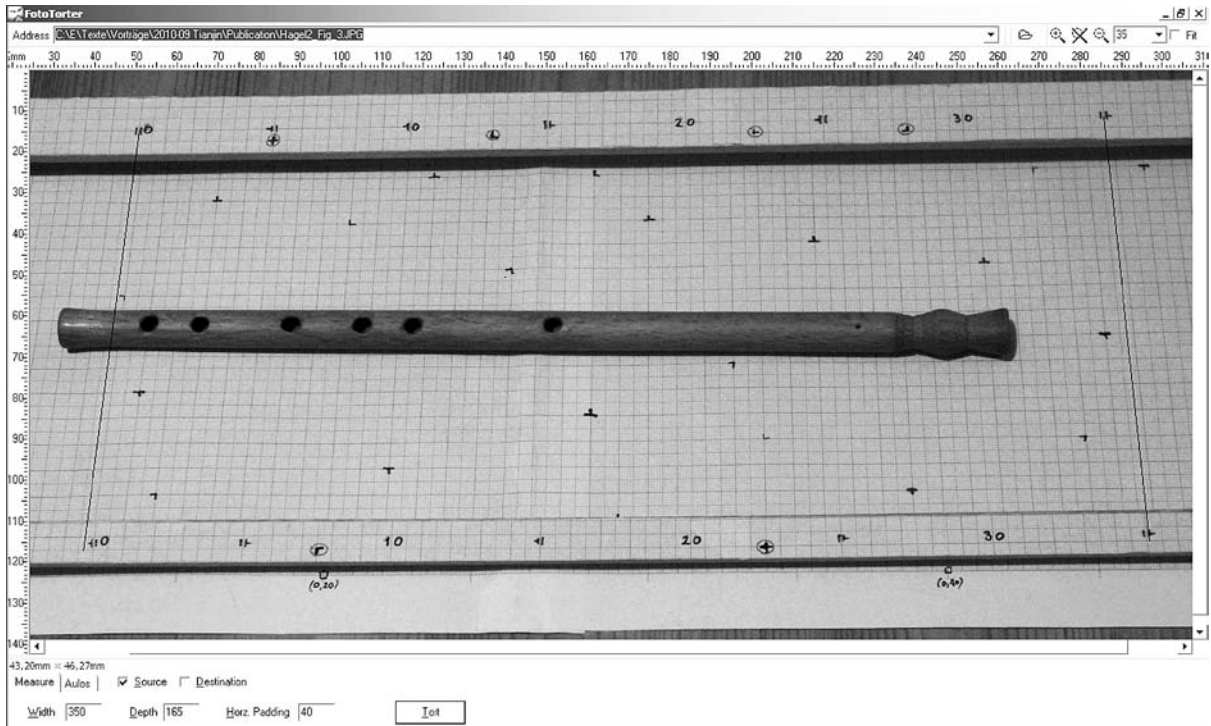Fig. 4 Taking inter-hole distance measurements from figure 3 in Microsoft Word (image by S. Hagel).

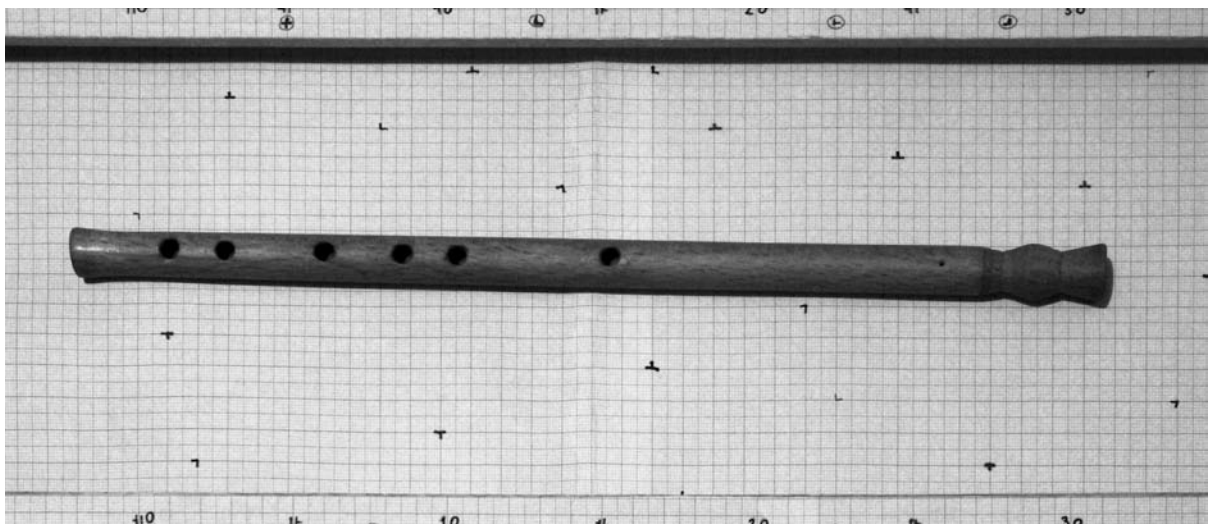Fig. 5 Preparing the photograph of figure 3 for digital processing with dedicated software (image by S. Hagel).

Fig. 6 The photograph of figure 3, digitally processed so that right angles are restored (image by S. Hagel).
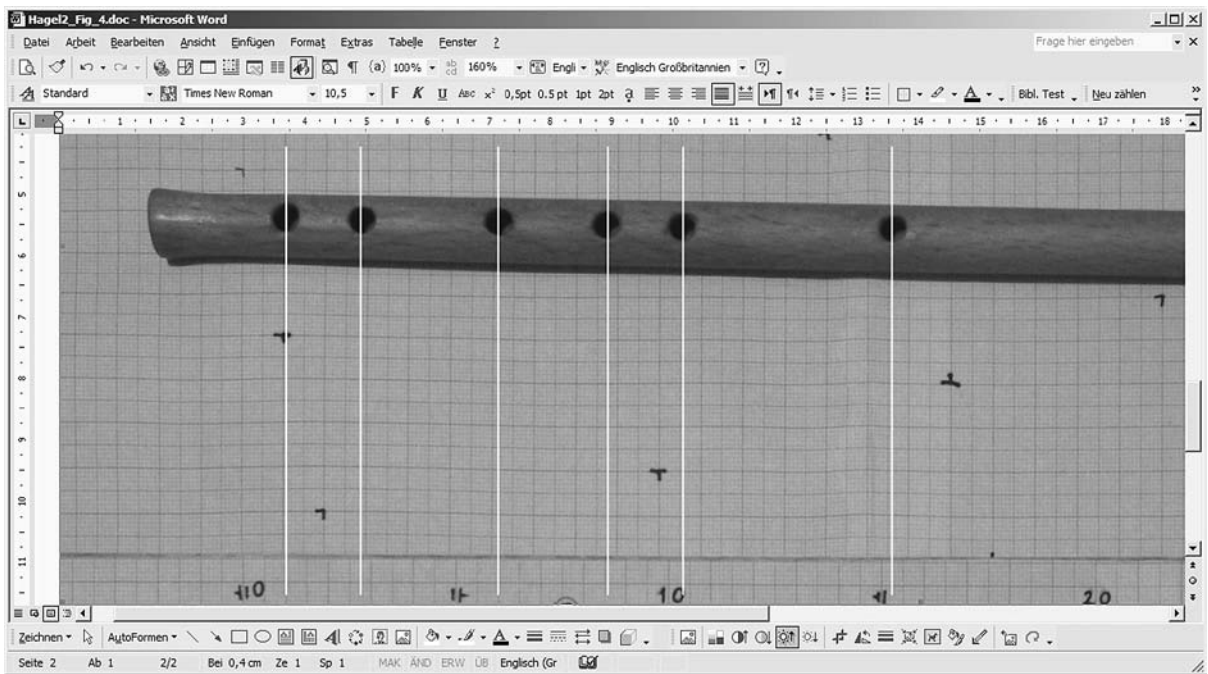
Fig. 7 Taking inter-hole distance measurements from figure 6 in Microsoft Word (image by S. Hagel).
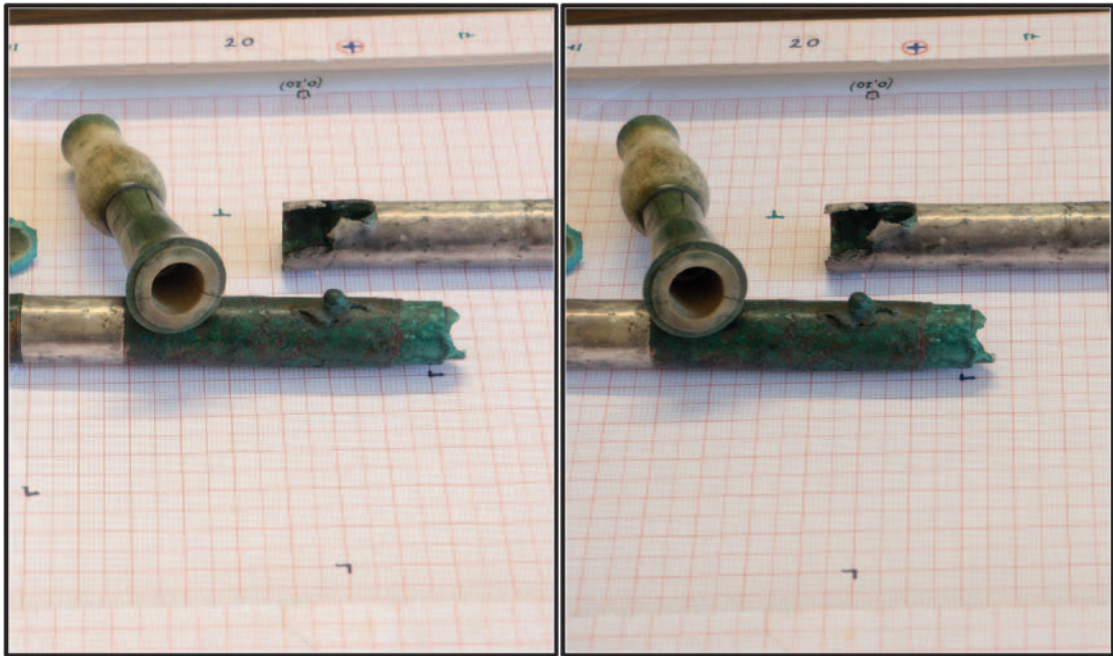
Fig. 8 3D pair of photographs set up for cross-eyed viewing (images by S. Hagel; courtesy of the Naples National Museum).
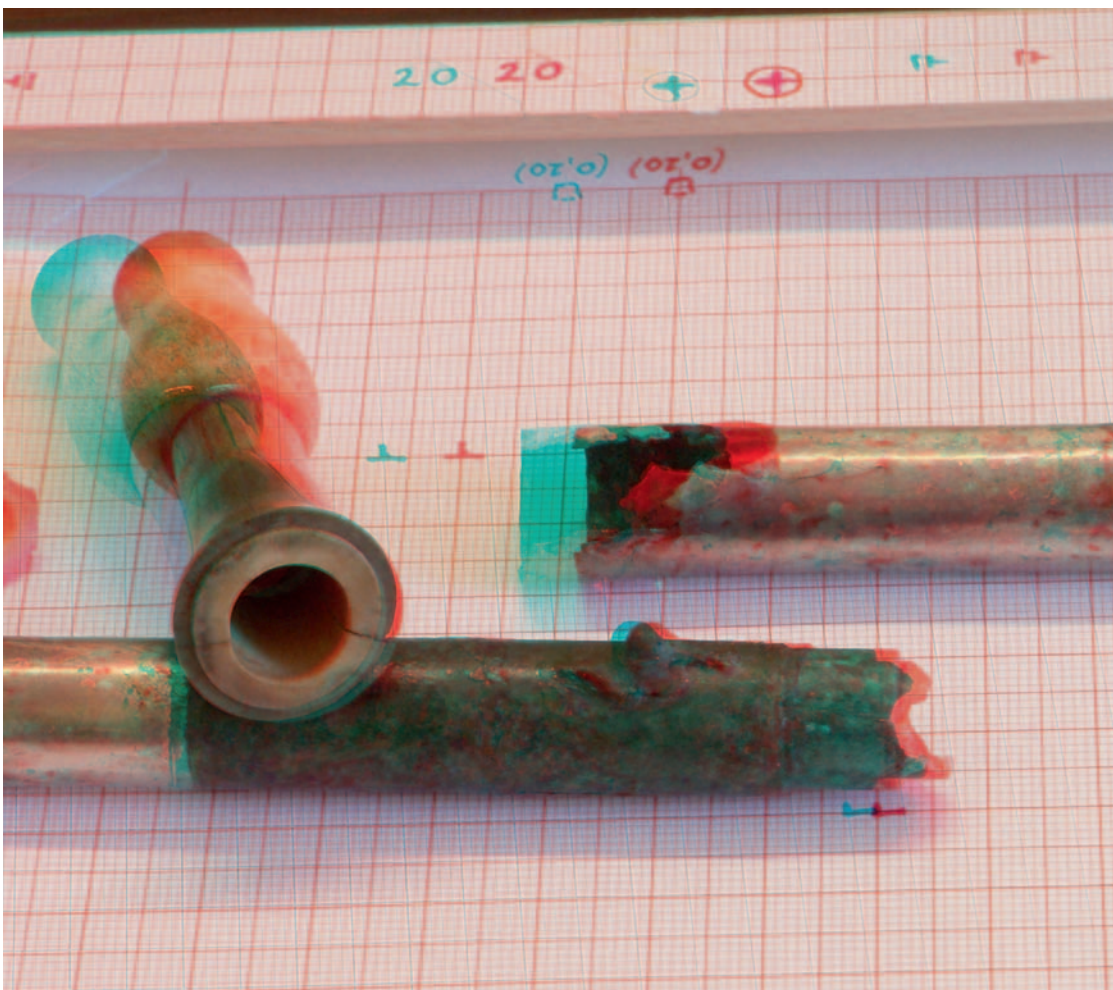

Fig. 9 As figure 8, set up as a red-cyan colour anaglyph (best viewed with red-cyan colour glasses). Produced with *Stereo PhotoMaker* (© M. Suto – D. Sykes/image by S. Hagel).