

## 2W: NEW TECHNOLOGIES FOR THE GEOREFERENCED VISUALISATION OF HISTORIC CARTOGRAPHY

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**KEY WORDS:** geometrical transformation, geo-referencing procedure, warping algorithms, cartography, software

### ABSTRACT

The procedure of referencing-transformation, set up and used by the Photogrammetry Laboratory of the IUAV, is based on the application of two types of sequential transformation; first, a global transformation and then local transformations.

These two types of transformations are each carried out on the basis of two sets of corresponding points, the first control points, which could originate from a survey, a map or an image, the second set identified on the image to modify.

While the same points could very well be used, the characteristics of the transformations are rather different since the global transformation is controllable in its effects through parameters which model the transformation expressed in analytical form, while the local transformations are controlled only through the use of the features which define them.

The global transformation can be chosen on the basis of its properties and the result is therefore predictable and controllable. In the case of the example where one wishes to transform one map onto another, while maintaining the original shape of the objects (for example, the buildings) it is important to choose a similar transformation.

The local transformations, either using the finished element technique or the technique using force fields (warping), do not offer the opportunity of imposing geometric characteristics as a priority, but are based only on elements placed in correspondence on the source image and the destination image.

The result obtained after the local transformations is the transformation of the original image according to a certain set of features, defined by pairs of homologous points. The main characteristic of this image is to be adapted as much as possible to its reference since between the local transformation algorithms, those leading to a superimposition of the control features were the ones chosen. In this way, the attributes of the initial image are maintained but its geometry has been changed.

If the initial image is a map and the reference is another map, what is obtained is the transfer of the semantic content of the source map on the reference map. This is the same as saying that the source map has changed its metric content, or that it has changed its geometry.

Essentially, with the procedure of referencing-restoration-transformation, the metric nature of the initial map is lost: the map has been mapped on the reference map. The term “mapping” is exactly in the meaning given to it in computer graphics: the adaptation of a texture to a form.

In practice, one can imagine that a map (or image) is dressed with a metric-geometric support which can be changed.

### 1 PROBLEMS WITH TRANSFORMATION

The main problem with this type of procedure is that giving a new geometric support to a map in order to assign it a new metric nature (the mapping of one map onto another), often radically modifies the original map.

This is more evident when the images are different from each other, while still representing the same objects. In the case of the photoplane of Venice, taken in 1911 (see the illustration), the problem did not arise since the images (the maps) were very similar to each other and therefore, the deformations, introduced with the local transformations, compared with the original cannot be determined.

Having identified foundation and fundamental points of the cartography, which are:

- the measurement of the sign,
- the position of the sign,

- the meaning of the sign, and having proven that the signs are contained in the texture, in other words, in the attributes of the image, it is necessary to ask if it is correct to distort the aspect of a map to the point of making it unrecognisable. If it is true that the semantic content is drawn from the change of the geometric support, it would be necessary to investigate if the metamorphosis of the signs implicates a change in their meaning. It is necessary to understand if the presumed indifference of the texture is true with respect to the geometry that would assume a sort of invariance. It can be proven, in a pragmatic way, that the question does not lead to an absolute definition, but is relative to the “amount of change”.

Commonly, if the image of the map has changed little with respect to the initial condition and the new image is acceptable, the operation is correct (as in the case of the photoplane); if on the other hand, the image is unrecognisable, or in any case unacceptable from an “aesthetic” point of view, the operation would be considered incorrect (see the examples of the figures illustrated in this chapter).

Obviously, the distinctions regard the typology of the map as well: for the modern cadastral maps, the questions will be different from an Atlas of the 1500’s and different still from those that concern historic photoplanes.

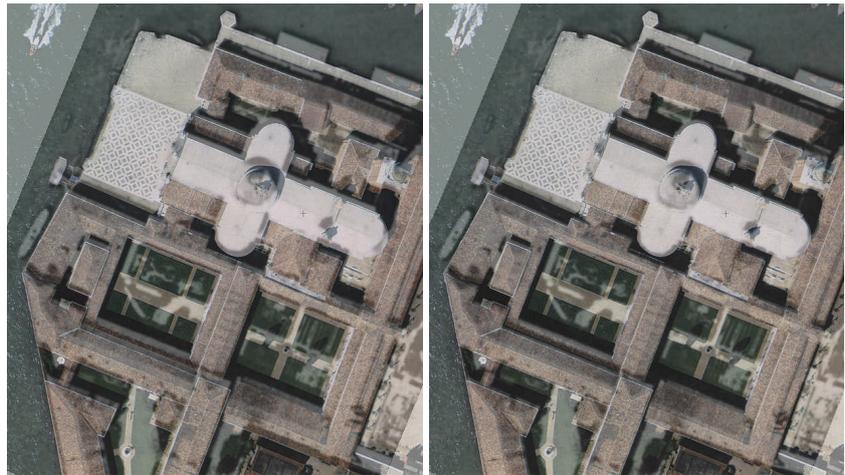


figure1. Superimposition of the geo-referenced images before and after local transformations. The best superimposition of the two images can be seen in the figure at right with respect to the left one.

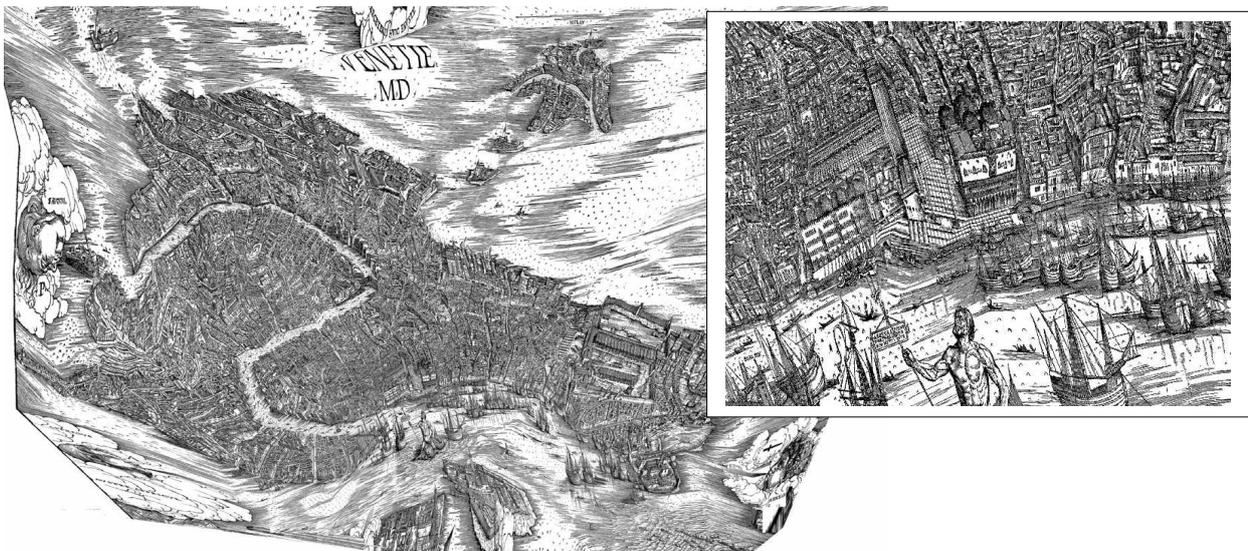


figure2. An example of deformation introduced after a geo-referencing transformation

## 2 HISTORIC CARTOGRAPHY

Historic cartography is surely an area where the questions made in relation to the referencing-transformation assume a great deal of importance.

Although it is always difficult and perhaps even incorrect to generalise, historic cartography does present some common characteristics, such as:

- an undefined reference system,
- an approximate projective system,
- an uncertain metric content,
- a semantic content which is difficult to interpret.

These characteristics in the maps from different time periods are encountered in greater or lesser measure, and as has been proven time and time again that it is imperative to make specific considerations when faced with each different map.

The fact remains that, in general, the assignation of a correct metric support is highly important for the use of this cartography, not only as an archive document, having a qualitative nature but rather as real cartography from where quantitative information can be taken.

An idea that must guide in this direction is that of keeping in mind that these maps have been drawn up as maps, that is, with an practical operational purpose, and were used for this. Perhaps the concept of metrics has changed, or more simply, the threshold for acceptable levels of uncertainty has changed over time.

### 3 TRANSFORMATION-CORRESPONDENCE

*Can the geometric transformation of a map be avoided and can other alternative ways for its quantitative reading be found?*

To respond positively to this question, it is necessary to introduce a radical change in the way to use cartography which must change from a paper map to a digital map.

The warping techniques can be used, not in order to transform the maps but in order to create correspondence, realising special software which manage and visualise these correspondences between the maps.

The procedure of referencing-transformation, previously cited, remains valid but is combined with and in some cases replaced by the procedure of **referencing-correspondence**.

The analytical and algorithmic part of the two procedures is the same:

global transformations + local transformations (warping).

The ways to apply the transformations changes as well as the support for the cartographic image which in the correspondence becomes numeric and no longer paper.

It is possible to image that the relations between pixels in the source image and the destination image are resolved in a definitive way at the time of sampling in the final image for the transformation procedure, while in correspondence, it is resolved quickly and visualised in real time.

The procedure of referencing-transformation, which has for an output a new image with geometric characteristics controlled and assigned through the use of features, is replaced by the procedure of referencing-correspondence, where the features are used for the on-flight calculation of homologous points.

### 4 2WIN SOFTWARE

What has just been described must be realised with special software that allows for the loading of digital maps and the identification of homologous points.

The software implemented by the author for this purpose has the name 2WIN, inspired by the fact that the screen is organised into two windows. In these, on the left window, the reference cartography is visualised and on the right, the map to transform. The methods of functioning are quite commonplace: by identifying a point on one of the two maps, the program calculates the position on the other and highlights this by centring the two windows on homologous points. The centre of the two windows is always on two corresponding points.

The method of calculation to use can be that of the WPP or WPF programs, developed by the author for his PhD thesis. This involves a software which implements the algorithms of local transformation, based on points or lines, borrowed from the morphing techniques of computer graphics and properly adapted to cartography.

The definition of the features for this correspondence and their memorisation is done by two WPP and WDF software which therefore complement 2WIN. 2WIN is in fact a “visualiser” of numeric cartography which also implements the algorithm for the interactive identification of the homologous points.

The fact that this program is interactive, meaning that it must respond in real time to the questions placed by the user, has made it necessary to optimise the code for a greater speed of execution. In the transformation programs such as WPP and WPF, the problem did not arise since the execution of the transformations occurs only once and therefore the problem of an extended wait is limited.

Even though today enormously powerful calculators are used, the warping algorithms are so burdensome from a computer calculation standpoint that without optimisation, it was not possible to obtain acceptable response times. Therefore, it was decided to calculate the local transformations, not by using the complete set of the features, but only those closer to the point to calculate. The decision is justified from a numeric point of view if one thinks that the weight, in the definitions given, is always inversely proportionate to a power of the distance. Therefore a feature’s influence diminishes in proportion to the farther away it is.

The problem of the research into the nearby features has been resolved by implementing a “quadtree” structure for the memorisation of the features themselves. In this way, the research into the nearby features and the calculation of the homologous point have given acceptable response times.

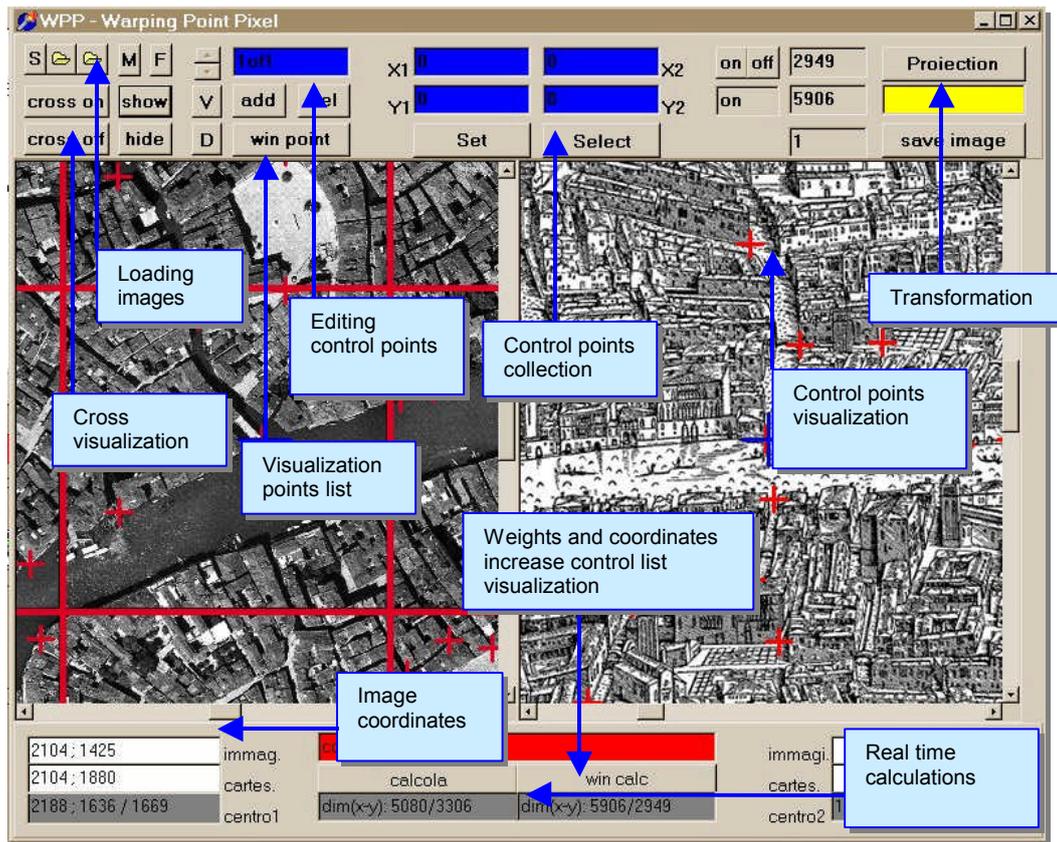


figure3. 2W operator's interface: it allows to collect control points, to calculate coordinates in the new reference system and therefore to obtain the correspondence

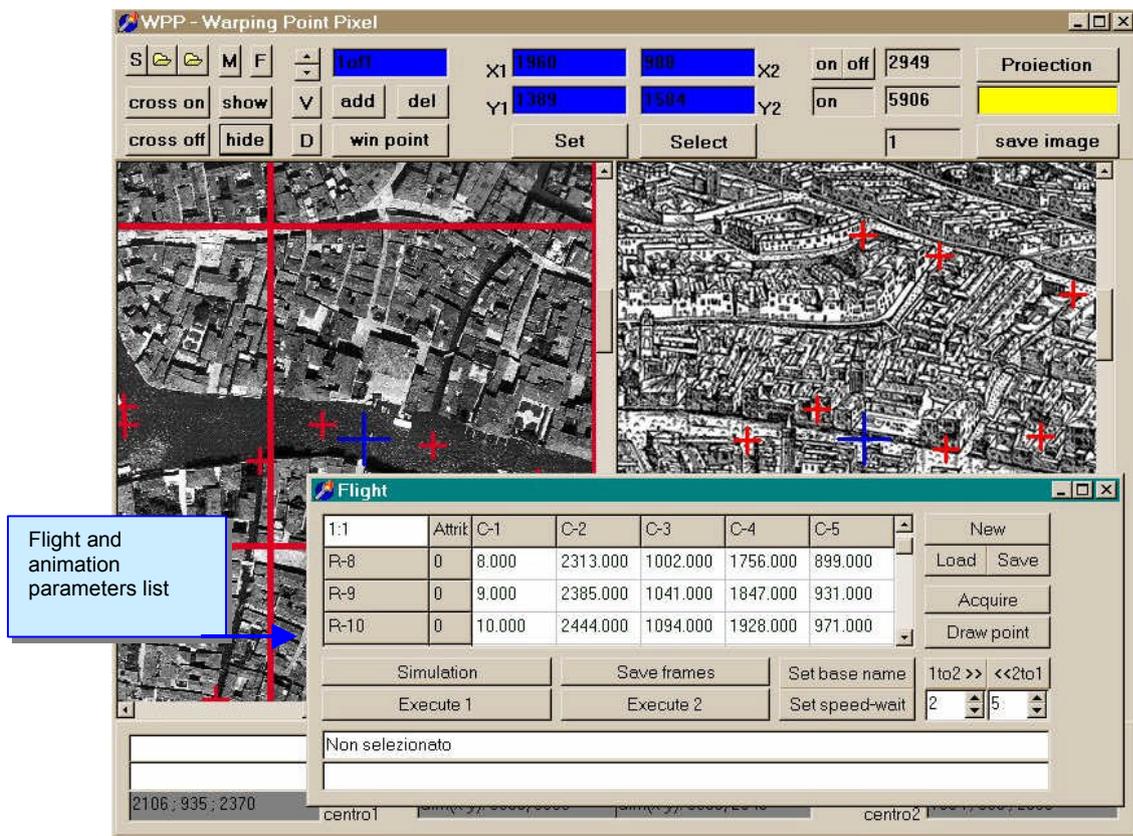


figure4. 2W operator's interface (flight planning)

## 5 THE REFERENCING – CORRESPONDENCE PROCEDURE

This procedure is from an algorithm point of view practically identical to the referencing-transformation, which it differs from only in two points:

- the interactive management of the correspondences,
- the type of global transformation used.

The procedure of referencing-correspondence is based on the application of a global transformation to which a local transformation follows; the introduction of this procedure is motivated by the desire to not destroy the image of the paper in the cases where the transformations to introduce are of an elevated quantity. If, therefore, the purpose that has motivated the definition of the procedure is the preservation of the form, it is opportune to apply this principle not only in the local phase, but also in the global phase. Only some types of global transformations are compatible however, the conform ones. Among these, it was decided to admit the translations, the rotation and the variation of the isotropic scale.

## 6 HISTORIC CARTOGRAPHY AND NEW TECHNOLOGIES

The 2WIN software aids in identifying corresponding points and therefore also the calculation of the co-ordinates in the system of the reference map.

These two actions:

- identify points,
- find the co-ordinates of these points,

the fundamental operations which are carried out on the cartography are:

- localisation,
- measurement.

The software designed and implemented in this way realises in a conclusive way the idea of returning to the historic cartography a strict metric support without however modifying the original aspect. This would suggest reflecting on the possibilities offered by the use of informational instruments in the field of cartography, and not only of historic nature.

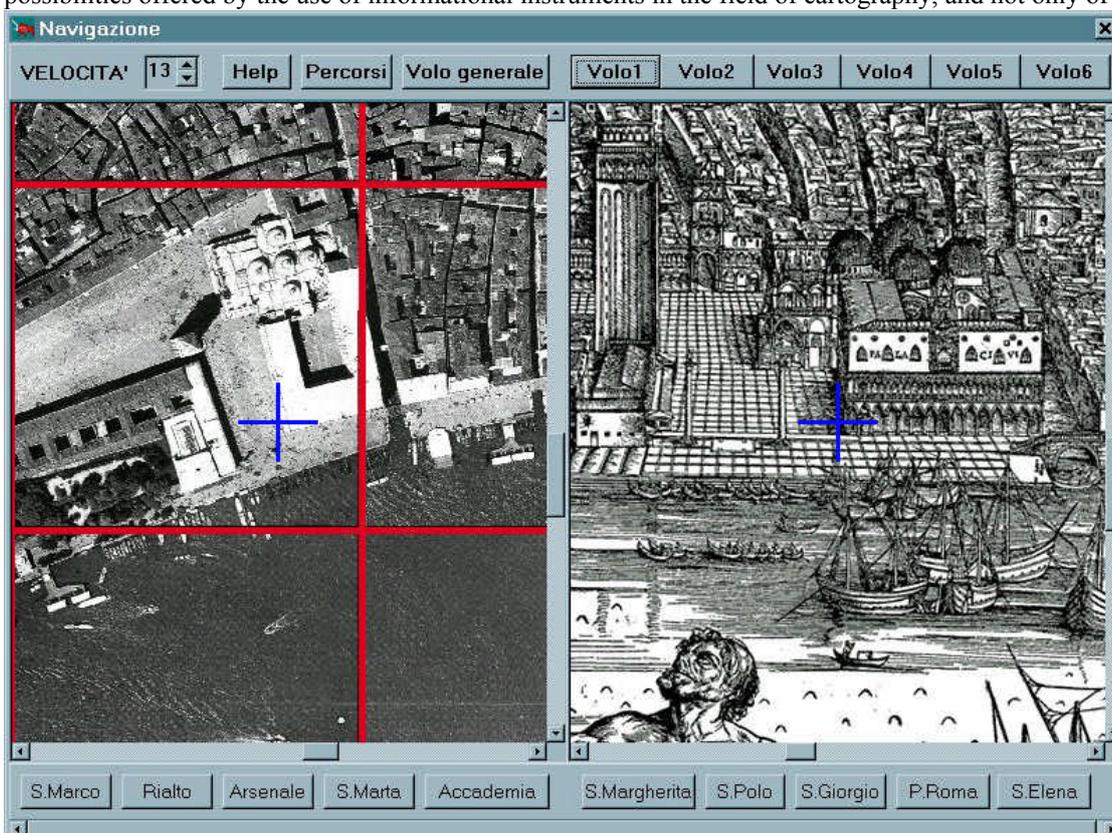


figure5. 2W user's interface. The crosses in the middle of the windows show the homologous points

## APPENDIX

## 6.1 The warping algorithms

### 6.1.1 Points of force

The algorithm for points of force is simpler. Once vector movement for each pair of homologous points is calculated, each other point (pixel or node) will be displaced in ratio to the vector obtained as a weighted average of the reference vectors.

The fundamental problems to resolve are the identification of a criteria for the selection of the weighted values of the reference vectors and the elevated number of these vectors.

In the software implemented, the weight  $w_i$  to give to each vector movement  $\overline{A_i B_i}$  was calculated as

$$w_i = \frac{1}{d_i^2}$$

where  $d$  is the distance between the point in discussion and the control point.

A linear factor of reduction of the weight,  $s$ , has been introduced within the range of influence of each control point. The range defines a circular region beyond which the control point has no effect. The factor of reduction has the value

$$s = 0 \quad \text{per } d > r$$

$$s = 1 - \frac{d}{r} \quad \text{per } 0 \leq d \leq r$$

The functions of weight and reduction can be changed in ratio to the characteristics of the elements presented on the images. Even being able to calibrate the system in this way, the fact remains that the method based on points of force is very sensitive to the distribution of the points themselves. It is difficult to utilise with raster images since it is practically inevitable that the straight lines in the initial image result curved after the transformation. At times this, in the case of tract cartography or architectural designs, leads to the production of unacceptable formulation: it is not possible, in fact, that corners of buildings, roads, technological lines, etc. assume curved courses. In the case of photographic images which contain landscapes or people the phenomenon is much less noticeable. With vector images the application turns out to be facilitated insofar as working only on the nodes and leaving the arches unaltered it is possible to avoid the problem. The reconstruction of the survey of the parchment of Siena presented in point 4 was realised in this way.

In some specific cases, like for example in the antique maps where it is possible to recognise only the position of some objects, this algorithm is the only one that applies. In general, however, feature-based warping tends to be used.

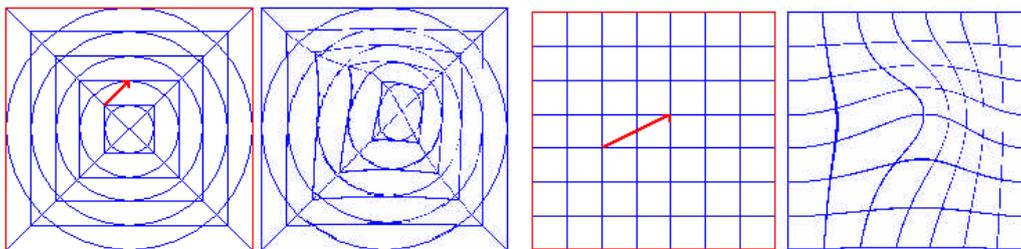


figure 6. Distortions induced by a point of force.

### 6.1.2 Feature-based warping

This technique requires that the relationships between the source image and the resultant image are no longer defined by pairs of points but rather by pairs of applied vectors. The advantage is that not only the position between the parts of the image is indicated but also their direction. As far as of definition of the relationships goes, the technique for lines of force generally requires a lesser definition (that is, fewer control points). The points outside of the lines undergo a displacement which is calculated according to the distance and the projection of the point on the line. This leads to, in the case of cartography, the possibility of maintaining the linearity some elements during the transformation.

The algorithm acts in the following way. Consider initially a

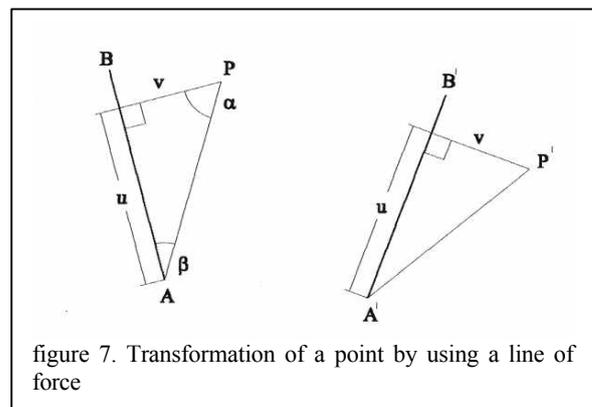


figure 7. Transformation of a point by using a line of force

single pair of vectors:  $\overline{AB}$  in the first image and  $\overline{A'B'}$  in the final image. A point  $P$  (pixel) will be tied to the initial vector and will be displaced by the movement of this vector. The relative position of  $P$  is determined with respect to  $\overline{AB}$  and the co-ordinates are calculated for  $P'$  which, with respect to  $\overline{A'B'}$ , is in a position homologous with  $P$ . The projection of the point onto itself is considered the position with respect to a vector. Two values are therefore calculated, the distance  $v$  from the point to  $\overline{AB}$  and the length of the projection (normalised)  $u$  of  $\overline{AP}$  onto  $\overline{AB}$ . The difference between the positions and the directions of  $\overline{AB}$  and  $\overline{A'B'}$  defines a rototranslation with variations in scale.

Expressing the vector  $\overline{AB}$  in these terms:

$x_1, y_1$  point of application  
 $\square_1$  corner with the X axis  
 $l_1$  module;

The vector  $\overline{A'B'}$  in the terms:

$x_2, y_2$  point of application  
 $\square_2$  corner with the X axis  
 $l_2$  module

And the points  $P$  and  $P'$  respectively  $x, y$  and  $x', y'$  the following is obtained:

$$u = \frac{(x - x_1) * \cos(\alpha_1) + (y - y_1) * \sin(\alpha_1)}{l_1}$$

$$v = (x - x_1) * \sin(\alpha_1) - (y - y_1) * \cos(\alpha_1)$$

$$x' = x_2 + u * l_2 * \cos(\alpha_2) + v * \sin(\alpha_2)$$

$$y' = y_2 + u * l_2 * \sin(\alpha_2) - v * \cos(\alpha_2)$$

It can be assumed that if  $\overline{AB}$  and  $\overline{A'B'}$  maintain the same direction but have different position, then even the final image will be translated with respect to the original. Changing the direction will produce a rotation and varying the length of one of the two vectors will produce a stepped image.

The rototranslations necessary for the transformation of the image are difficult operations from a computing point of view: for each point 8 products and 6 sums are necessary. Since the rototranslations however are linear operations and use finite differences, it is possible to reduce the calculations to two sums.

To effect the complex transformations it is necessary to introduce more vectors. In the transformations with various pairs of vectors, an elaboration is carried out which considers all the contributions, opportunely weighing the transformation induced by each pair. For each pair of vectors  $\overline{AB}_i$  and  $\overline{A'B'}_i$  there will be rototranslation of the point  $P$ .

## 6.2 Transformation of a point utilising two lines of force

The final co-ordinates of the point  $P$  will be given by the pondered average of the co-ordinates of all the points  $P_i$ . The weight is calculated in the following way:

where

$$w_i = \left( \frac{l_i^p}{a + d_i} \right)^b$$

$w_i$  is the weighted value to assign to the co-ordinates  $x_i'$  and  $y_i'$ ,

$l_i$  is the model of the  $i$  vector

$d_i$  is the distance from the point to the vector

$a, b, p$  are constant parameters used for the control of the transformation, varying more or less incisively the effect of the vectors on the pixel.

If  $a$  tends toward 0 and if the distance  $P$  from the vector is 0, the weighted value tends toward infinity; this means that the pixels that are on the original vector will go exactly onto the destination vector. Values greater than  $a$  give a

warping that is softer but less easily controlled. In cartographic applications it is convenient to place the value of  $a$  as always equal to 0.

The constant  $b$  determines in what way the influence of the vectors diminishes with the distance: if  $b=0$  each pixel is influenced in the same way; the usual values for  $b$  are inclusive between 0.5 and 3.

The value  $p$  is typically included in the interval (0,1): if  $p=0$  all the vectors have the same weight, if  $p=1$  the vectors with a larger model will have a higher relative weight.

In the case in which  $a=0$ ,  $p=0$ ,  $b=1$  the case from the preceding paragraph is reconsidered.

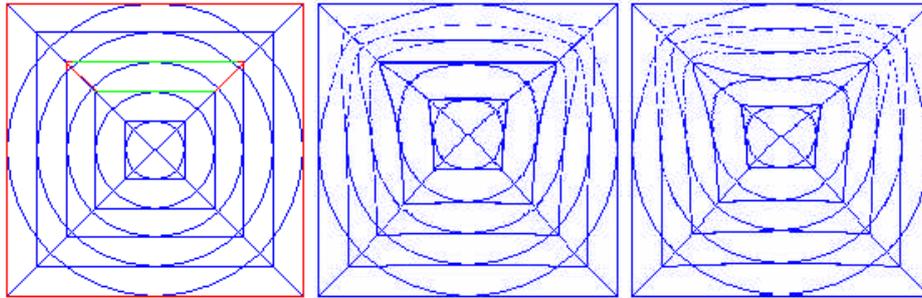


figure8. A comparison between the distortions induced by a line of force and by the points that define it. Notice how the lines are force allow the straight lines to be maintained. The homologous vectors allow for the definition of the rotations as well, where the method using the points of force does not.

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