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Scientific Project »Cartography and GIS«

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Review

Institute for Cartography, Faculty of Geodesy, University of Zagreb, staff and several collaborators from other institutions, did the research on the scientific project »Cartography and GIS« from 1991–96. The project was partially financed by the Ministry of Science and Technology of the Republic of Croatia. Some research findings are presented. The theory of map projections based on analytical geometry, linear algebra and differential geometry has been developed and directed to an immediate computer application. A modification of Gilbert's map projection has been suggested. The determination of parts of Croatia using digitized points from the map at the scale 1:1 000 000 has been presented. For affine transformation of coordinates between the old coordinates systems of Croatian territory and the Gauss-Krüger map projection systems, a STASUH computer program has been written. To eliminate distortions, i.e. transform map contents into its theoretical dimensions, the CARTOMATHICS system has been developed.

Key words: cartography, geoinformation systems, map projections, area determination, cartographic transformations

1. INTRODUCTION

The members of the Institute for Cartography, Faculty of Geodesy, University of Zagreb, together with several collaborators from other institutions, performed research on the scientific project »Cartography and GIS« from 1991–96. The project was partially financed by the Ministry of Science and Technology of the Republic of Croatia. The results of the research have been published in numerous papers. In this paper we present some of the most important results.

2. MAP PROJECTIONS AND GEOINFORMATION SYSTEMS

The geoinformation systems (GIS) made it possible to solve some tasks, which we have been performing up to now by means of geographic maps (different cartometric tasks); now, we do it directly from the databases. Hence, somebody could conclude that the geoinformation systems decrease the importance of geographic maps. From that point of view this could be true, however, the geographic maps are still very important for every GIS. They have a very important role in creating the databases, and also, as a form of data presentation [20].

As every geographic map is made in a certain map projection, we can conclude that the map projections are especially important in designing and creating the geoinformation systems. In creating the national digital bases of topographic and cartographic data, which should be fundamental for any GIS designed for the whole state area, the most important method of collecting the data is the digitizing of existing maps [22, 23]. Therefore the majority of the GIS software contains a module for the digitization. By implementing that module, it is necessary to know the map projection of the source map and the constants of projection (e.g. geographic longitude of the central meridian and the latitude of the standard parallel).

These data are essential in order to make the transformation from the local digitizer coordinate system to the system of the original map projection, and then using the inverse map projection equations into the geographic coordinate system. In that way the GIS software can give us the output in a form of a geographic map obtained in one of the possible map projections. In order to make such a map, it is necessary to compute the coordinates x, y in the selected map projection from the geographic ones.

Thus, in software designing for any GIS it is necessary to know the basic and inverse equations for a large number of map projections. Thus, the use of computers in the map production and especially their application to geoinformation systems, does not decrease, but increases the importance of map projections. The same statement can

be obtained from the fact that there are more than 1 000 of papers on map projections which have been published since 1960. These works have been recorded in the bibliography of J. P. Snyder and H. Steward [21].

That is the reason why we have devoted special attention to the map projections in the frame of our project Cartography and geoinformation systems. The results of research have been published in a large number of papers. Here we present only the most important ones.

2.1. A modern approach to map projections

In the M. Sc. thesis [9] a modern theory of map projections has been developed, based on analytical geometry, linear algebra and differential geometry. On one hand, the proposed approach is sufficiently general to include all statements of the classic theory, while on the other hand it is aimed at the immediate use of computers.

2.2. The modified Gilbert projection

Among many of the map projections being used for world maps, there are only a few of them in which the spherical shape of the earth is preserved to a certain extent. Among them, the Gilbert projection should be especially emphasized. It represents the earth as people usually see it from space, as a globe. With its spherical shape it reminds one of a globe, and at the same time it represents the whole earth's surface. Researching a particular map projection, it is very important to discover and establish the facts about distortions of distances, angles and areas. In a previous paper, a modification of Gilbert projection has been proposed by Lapaine and Frančula [12] with the aim of designing a world map which could be a base to obtain a series of global thematic maps. The modification has been performed by choosing different cartographic pole. In that way the projection of the Republic of Croatia is located in the middle of the projection area. Besides, the represented area of Antarctic is diminished, while in the original Gilbert projection it was obviously too large. Also, instead of the orthographic projection, a general perspective projection has been applied, which enables new possibilities of application [13, 17, 18].

3. AREA DETERMINATION OF THE REPUBLIC OF CROATIA

The area of a polygon can be determined on the basis of the coordinates of its vertices by using different formulas. For the computation in the Gauß-Krüger map projection the following expression is convenient:

$$P = \frac{0{,}5 \cdot \sum [y_{i+1} - y_i][x_i + x_{i+1}]}{p_i}, \quad i = 1, \ldots,$$

where p_i is the local scale of the area.

After Croatia had been recognized as an independent state the area of its land was known, but the area of the sea belonging to Croatia was not known.

The area of a state is usually determined by measurements from maps at a larger scale, e.g. 1 : 25 000. However, because of the large number of map sheets, this is a rather lasting and expensive work. The research we have done [5, 14, 15, 16] show that such measurements can be performed with high accuracy on the smaller scale maps as well.

We have digitized the Croatian borders from the map at the scale of 1 : 1 000 000 made in the Gauß-Krüger map projection, with the central meridian 16°30′. The linear scale at the central meridian is $m = 0{,}9997$. The accuracy obtained in that way ranges from 0,1% to 0,5%, which is a very high accuracy.

4. TRANSFORMATIONS AND GEOINFORMATION SYSTEMS

4.1. Old coordinate systems at the territory of Croatia

The basic data on the old coordinate systems in Croatia can be found in the geodetic literature [1, 2, 3, 6, 19, 24, 25, 26]. Cadastral records of the old land survey contain an immense wealth of information, which can be used as a base in different scientific projects. At the same time, they make distinct historic and topographic representations possible, as well as historic and geographic structure analysis, for the purpose of analysing the spreading of different species in the agricultural land area, for analysing the development of settlements, and so on. Today, in the period of increasing application of computer cartography, the possibilities of transferring the data from old cadastral plans to the plans and maps at different scales and map projections are significantly enlarged.

STASUH is a computer program designed for the affine transformation between the old coordinate systems and the systems of the Gauß-Krüger map projection at the territory of Croatia [4]. The program can be used with personal computers running under MS DOS. No special demands regarding the type of computer, the available memory or the graphical card are requested. Fourteen data sets containing the corresponding points

Fig. 1. Oblique aspect of the Gilbert projection

in the old systems and the systems of the Gauß--Krüger map projection have been formed, as well as the single dataset with the transformation coefficients. The program enables to solve two tasks: the transformation from the old systems into the Gauß-Krüger map projection and vice versa.

4.2. A direct method of the transformation from cartesian to geodetic coordinates

The relationships between the geocentric cartesian coordinates x, y, z and the corresponding geodetic coordinates φ, λ, h are well known. The inverse problem of computing φ, λ and h when x, y and z are given, has been considered by many authors who suggested different methods for its solution.

It is known, that due to the symmetry, the inverse problem can be reduced from the rotational ellipsoid

$$\frac{x^2}{a^2}+\frac{y^2}{a^2}+\frac{z^2}{b^2}=1$$

to the ellipse

$$\frac{\rho^2}{a^2}+\frac{z^2}{b^2}=1$$

where

$$\rho=\sqrt{x^2+y^2}\,.$$

Geodesists have been showing an increasing interest for the problem for last thirty years. Some of the authors have believed that the direct solution does not exist at all. When the direct solutions were found, they were not free from certain difficulties. That is the reason why the others have continued to search approximate procedures or formulas.

In a previous paper Lapaine [7] presented a new direct and numerically reliable solution of the transformation problem. He also proposed an improved version of the first algorithm [8] and compared it with some direct solutions which have been published recently.

4.3. Cartomathics

The basic information that is used in all the types of today's geoinformation systems comes from traditional sources: maps and plans. That information enters into the database by digitizing the maps. Usually, because of the inappropriate way of keeping, use and age, the map contents are

not in the same state as they were at the moment of production, but are distorted. The change of the cartographic drawing holder under the influence of temperature, humidity and aging is the cartographic distortion.

Anybody who ever tried to construct a mosaic from certain neighbouring sheets, encountered the problem of matching the neighbouring vertices and sides. »The best fitting« frequently leaves small cutouts without any data or it comes to the covering of details.

The alternative approach is to treat any map sheet as a single one during the digitization and to arrange the results of digitization by using some mathematics. This approach transfers the problem of visual failures to the domain of transformations and fittings.

A computer system for the elimination of distortions, i.e. the transformation of the map contents into its theoretical dimensions has been developed by M. Lapaine at the Faculty of Geodesy, University of Zagreb. The name of that system is CARTOMATHICS [10, 11].

5. CONCLUSION

The theory of map projections has been developed on the basis of analytical geometry, linear algebra and differential geometry oriented towards the direct computer application. The modifications of the Gilbert's projection have been carried out, and the formulas for calculating distortions, suitable also for computer assisted graphic presentations, have been derived.

The search for the optimal modern algorithms for computations in the Gauß-Krüger projection has braught forward some tasks of a current interest for Croatia: determination of the air cooridor intersections with the state border and the determination of the territorial units area, the area of the Croatian sea and the area of the epicontinental belt. The algorithms have been worked out for the purpose of determining the area of territorial units on the basis of digitized borders from the maps in Gauß-Krüger projection with accuracy estimation included. It has been proved that by means of this method the area can be determined with very high accuracy even from the map at the scale of 1 : 1 000 000. Thus, the so far unknown areas of the Croatian Sea and of the epicontinental belt have been determined.

The computer program for affine transformation of coordinates between the old coordinates systems at the territory of Croatia and the system of Gauß-Krüger projection has been designed on the basis of 14 datafiles of identical points and one datafile of the transformation coefficients.

After analysing more than one hundred algorithms, the best algorithm today, regarding the distribution of errors, for the calculation of ellipsoidal coordinates from the spatial rectangular coordinates has been worked out.

A computer system CARTOMATHICS for the transformation of the map contents into its theoretical dimensions has been designed and will be further developed.

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Ključne riječi: kartografija, geoinformacijski sustavi, kartografske projekcije, određivanje površine, transformacije u kartografiji

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