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The use of geographical information system at local airport management

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Abstract

In this article the process of building three-dimensional airport model in Geographic Information System with the use of different GNSS techniques and classical geodetic measurements carried out at the Olsztyn-Dajtki airport was described. The main goal of this study was primarily to open new possibilities in the management of the airport with use of GIS, improving the safety of takeoffs and landings of the aircrafts and providing information for planning and possible expansion of the airport. Apart from the procedures for data acquisition in the direct field measurements, model construction process also covered the procedures associated with the system planning, procedures of secondary data collection (digitalisation), the processing of these data, characteristics of their sources and methods of presentation. A way to perform spatial data analysis was also presented, and the activities related to the preparation of the mapping were described.

Keywords: Geographic Information System (GIS); Digital Terrain Model (DTM); GNSS; Real Time Kinematic (RTK); Differential GPS.

1. Introduction

The three-dimensional model of the airport made in the form of a geographical information system aims to open the new possibilities in the management process for the administration of the object, contribute to improving the safety of aircraft takeoffs and landings, as well as provide the information for administration, management and the possible expansion of the airport. The whole is designed to serve for the better management of the object through systematization of information and ensuring data integrity. Wenlai Chen [1] developed interesting applications and utilized the power of GIS and GPS for data collection, data storage, geospatial analysis of the airport. It will give an opportunity to learn every detail, which together form a whole, and additionally can provide promotional material in the process of raising the funds for expansion or improvement of existing infrastructure. Basing of the investment procedures on computer system allows for speeding up the design work and, more importantly, capturing new data which may prove essential to overcoming the resistance of public opinion or potential investors. One should bear in mind, that in case of airports near urban areas, the noise accompanying the takeoffs and landings of planes reduces the value of neighbouring properties and negatively affects the quality of life. This could translate into protests of the residents, which often are based on erroneous data, designed to highlight the negative effects. Furthermore, there are strict regulations on environmental protection and public health, and if airports' Geographic Information System (GIS) is to speed up and facilitate obtaining appropriate decisions and approvals, the results of spatial analysis must reflect the facts, so that based on them one would be able to assess conformity with applicable law. In order to achieve a high level of safety of flight operations, InternationaI Civil Aviation Organisation in ICAO Annex 14 [2] imposed on the appropriate authorities a duty to take action to minimise the hazards resulting from the presence of birds at the airport or in its vicinity by using appropriate repellents, as well as to eliminate the places which may cause the birds staying in these places or in their vicinity. Geographical Information System, with the use of appropriate tools for spatial analysis, allows for easy identification and localization of potential threats and defining the border of the area covered by, for example, the prohibition of breeding birds. Another factor responsible for ensuring the safety of aircraft is adequate distribution of radio navigation stations [3], and such management of the space surrounding them to ensure their proper operation. Radio-navigation stations are often prone to errors caused by the influence of the terrain and the neighbourhood of larger objects on the propagation of radio waves [4]. Depending on the type of radio-navigation system [5], surroundings of the station must meet certain conditions. For example, for the VHF Omnidirectional Station (VOR system station), within

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300 meters the area should be leveled, while within 1000 meters there should not be any objects with the angular height of more than 2°. GIS system for the airport makes it possible to identify such places in space, which will meet the specified criteria. This will allow for such positioning and maintenance of radio-navigation system components so that it can operate in possibly optimal manner.

2. Construction of the local airport's Olsztyn-Dajtki (EPOD) GIS database

Construction of GIS for the airport begins with the process of gathering all available data about this area and its component elements, which may be relevant from the viewpoint of the object administrator, and also guarantee building a coherent and comprehensive system. Geoinformation systems may use different types of spatial data from various sources. In the process of database creation the spatial raster and vector data should be divided into primary and secondary data. Primary data is the data which is obtained with the use of direct field measurements. An example of such data are raster images from SPOT or IKONOS satellites and the results of geodetic measurements recorded in digital form. Secondary data is created based on already existing geoinformation systems, mappings and field measurements performed earlier. The data may also exist in the digital or analog (raster) form, but due to the fact that it was originally acquired for other purposes it must be transferred to such a digital format that is understandable by the GIS. Examples of secondary data sources are paper maps and aerial photos. Longley [6] suggested that to be able to use them to build a Geographic Information System, they must be scanned and vectorised.

As the best source of data can be considered the direct field measurements made at the airport. One can then freely choose the measurement technique that guarantees the specified accuracy of the results, the highest level of timeliness of data and complete freedom in choosing the objects for the measurement. Now for measurements the modern electronic total stations are used, which are recording the data automatically, calculating the XYH coordinates of the terrain details based on the position of the instrument, slant distance and vertical and horizontal angle. For even more convenience can allow the GPS measurements, which completely automate geodetic measurements [7] limiting to the minimum the actions that must be done by a surveyor. Chen and Hill conducted sensitivity analysis of the uncertainties in source data of the GIS-based model [8] and concluded that the best possible data source should be used. However, the measurement activities significantly lengthen the data acquisition, require the involvement of more people and increase financial expenses (salaries, accommodation, fuel etc.). Moreover, one can consider unfounded the re-measurement of objects measured before, if it doesn't aim to improve significantly the accuracy of obtained results or a comprehensive update. Therefore, in the first place you use the already existing GIS database, run by different state institutions cooperating with the town halls and providing their resources for the purpose of urban projects. Data collected by them is practically ready for use in a built GIS system. In practice, however, few cities have such systems, especially in countries where GIS is in development stage. In most cases, cities are only in possession of digital or analogue maps, and these maps are the primary source of data. Obtaining them, however, often involves incurring additional costs. In addition to the city-owned maps, maps for design purposes can be used, in possession of which is every building object, whether it is an airport or an industrial plant. They usually occur in digital form, but in many cases they may need extra processing due to the lack of compatibility between different data storage formats.

Data encoding is one of the most common problems with which the developer of GIS systems faces. There is no one universal standard for data storage, which would meet the requirements of all applications, and its creation is not possible. Often you have to use the tools that allow to convert the data from source file to an intermediate file, which can be visualised in the GIS application. A good example can be the map made in the DXF or DWG format (AutoCAD format), which cannot be imported into the GIS system in such a way so that it would be fully useful and give the ability to carry out the analytical operations with the use of geoprocessing tools. After loading the CAD data into the GIS system, a new group layer "mapa.dwg", which includes 5 individual layers: annotation, point, polyline, polygon and multipatch as shown in Figure 1.

An alternative solution is to use raster images (aerial photographs, satellite scenes, scans of maps) saved as the image files. Calibrated raster images or maps downloaded from the WMS allow to supplement the project with missing data, that is the course of roads, location of trees and water bodies or housing estates. It is important to bear in mind that satellite scenes and aerial photographs obtained from map services often have a low degree of relevance, and thus do not always represent the situation in line with the facts, especially when it comes to impermanent items such as dirt road or the forest line. This implies performing additional measurements aimed at updating the data. Popielarczyk *et al.* in [9] concluded that update measurements and complementary measurements are best done using a mobile GPS receivers, which provide quick determination of coordinates of the details of terrain and automated measurement of the relief. Given that the airport areas are open areas and there are no obstacles that would prevent signal reception from the minimum of 4 satellites, the accuracy of position determination depends only on the measurement Real Time Kinematic method of positioning. The most accurate GPS receivers, which are used in geodesy for measurements in real time (we get the coordinates instantly) ensure the determination of coordinates of a point with an accuracy of several centimetres, which enables to use them for the relief measurement.

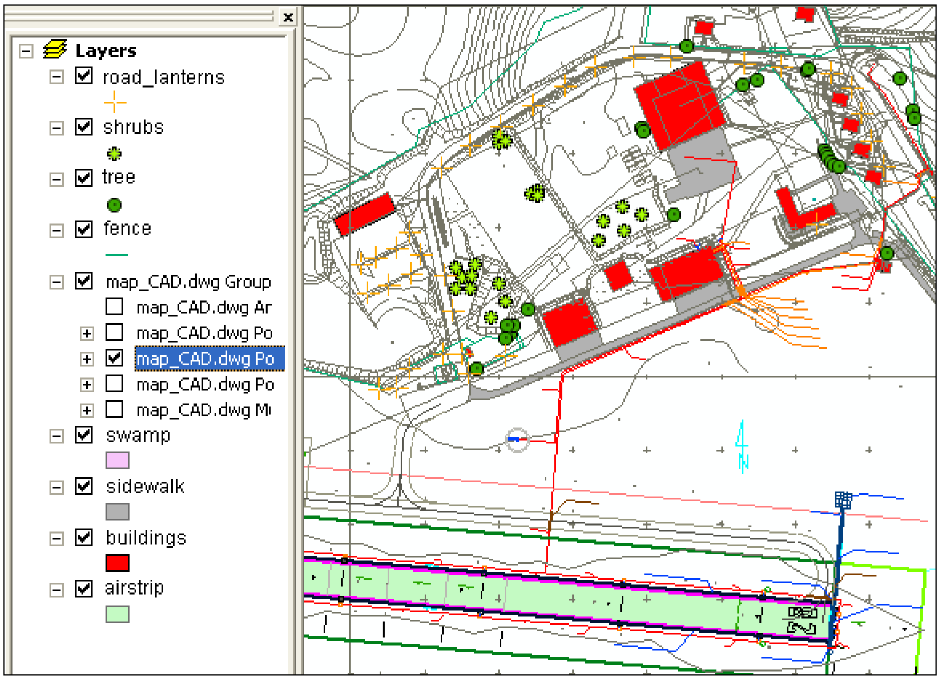

Fig. 1. Fragment of layers with vectorised linear and point objects on the background of the airport (EPOD) map

3. The relief measurements

The relief measurements using GPS can be carried out in two ways. The first one consists in designing a layout of profile points on which the receiver, set for a few seconds, will perform the measurement of coordinates and altitude. The advantage of this method is the increased accuracy due to the redundant observations on individual points.

Ciecko *et al*., use another method [10] – the mounting of the receiver on a mobile vehicle system, which will drive along designed profile lines. Mounted receiver is recording data continuously [11], every second. This allows for significant acceleration of the measurements and results in obtaining a much larger data sets due to the time interval between the observations (Fig. 2). It is important, however, that the height of the antenna mounted on the All Terrain Vehicle was accurately determined.

Fig. 2. ATV vehicle equipped with GNSS receivers and data teletransmission system.
Self study based on GNSS tools

Basing on the DGPS/RTK measurement methods, the GIS software was used to create the digital terrain model of the airport. For this purpose, you use one of the tools provided by the 3D Analyst software–ArcScene. In case of obstructed conditions in the airport area, the post-processing mode was used [12, 13] for DTM modelling. After loading the measured height pickets into the application it is possible to model the digital presentation of the relief on their basis [14].

Digital terrain model created using a triangular irregular network (TIN) shows the surface model as a set of continuous, not overlapping triangles, which vertices form the points of known height. Due to the fact that this model is based on the measured height values, it is very important to provide it with sufficient number of points located in the appropriate distances from each other, so that the created triangles were as small as possible. In order to smooth the edges in the digital terrain model the interpolation of the data to raster is used. It is used to predict the unknown values of certain parameters for each point located between sampling points (points for which are known the actual measurement values of these parameters). GIS software allows to perform the interpolation using a number of methods, which results are shown in the Figure 3.

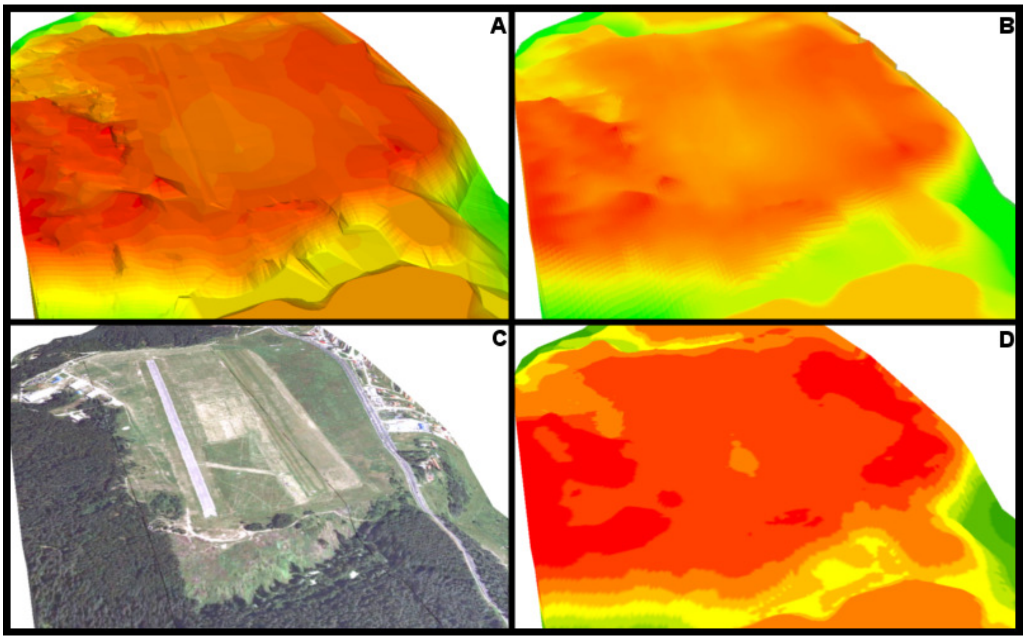

Fig. 3. Digital model of the airport area with superimposed rasters. (A – the TIN model without raster; B – raster interpolated using the 'natural neighbour' method; C – satellite photo imposed on the TIN model; D – raster interpolated using the 'inverse distance' method)

4. Digital model of runway

Digital model of the runway made using the GIS application, also illustrates the surface of the visualised object very well (Fig. 4). To accomplish this task the Trimble SPS882 GPS receiver was used. Using the Trimble Survey Controller software installed on the receiver controller, 5 profile lines were designed along the runway, on which every 20.00 m the height of the point and its coordinates were measured. Measurement of the surface of the runway was done in the RTK mode, and on each point of the profile lines the receiver antenna was set for at least 3 seconds. In total, nearly 230 profile points were measured. In addition, due to the depression that formed on the runway at about six hundredth metre, the measurement was concentrated there with additional 150 points so that the defect of the runway was clearly visible in the finished product. For the detailed measurement the STOP & Go method was used due to the high speed and simplicity of the measurement.

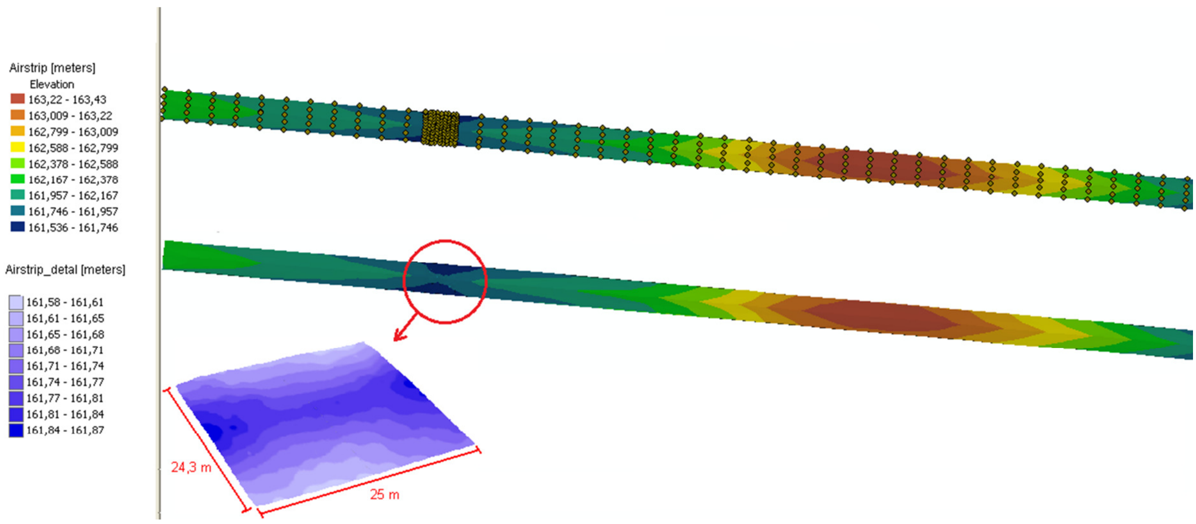

Fig. 4. Digital models of the runway together with the profile points and without the profile points, along with a separate model of depression of the runway

On the model of runway it is clearly seen that along the longitudinal central axis of the runway the surface is raised higher than the outer edges to ensure drainage of water from a rainfall, while the longitudinal section of the runway forms the shape of stretched sinusoid. For the first three hundred meters the runway surface rises and then drops down so that near the six hundredth metre reach the minimum values, and then again slightly rise up. Height differences are shown by colours, which the user can freely modify by setting the colour palette size and height intervals for each of them. In the figure the red colour illustrates the highest area of the runway reaching 163.43 m. The dark blue colour shows the area of the runway, which has decreased. Its lowest point lies at an altitude of 161.54 m. You can calculate that the difference between the highest and the lowest point of the measured surface of runway area was nearly 2 metres.

5. Creation of 3D digital terrain model

Modelling of the airport is not limited to creating two-dimensional maps and three-dimensional terrain models, but also covers the measurement of sleek, tall objects that could threaten flight safety. An example of such objects may be high chimneys, telecommunication towers or single trees located in the vicinity of the takeoff or approach areas. Knowledge about their location and height is of great importance to maintain the aircraft flight safety.

Geodetic height measurements can be carried out using photogrammetric methods, basing on the analysis of satellite images or aerial photos or using the geodetic spatial intersection. To accomplish this task the second method was used, which is a combination of the angular forward intersection and the trigonometric determination of the height of intersected point.

Coordinates and heights are imported into GIS application and loaded into created model. To facilitate the interpretation of the measured points, they must be further described by attributes and assigned a unique map symbols. Another, although rarely used method, is replacing the symbols with three-dimensional visualizations of the measured objects (buildings, structures, trees). Thanks to one of the many plug-ins for GIS application it is possible to load models of buildings and other objects made using Google SketchUp Pro into the GIS system (Fig. 5). With this method it is possible to obtain the three-dimensional, complete map dedicated for the management of the airport.

The process of creating three-dimensional visualisation of a building or structure may be based on geodetic measurements, laser scanning or technical documentation. Whichever method is used, it should lead to the most faithful reflection of visualised object to allow its immediate identification. For this purpose, mostly photographic images are used, from which a realistic textures are created and then applied on the blocks. Moreover, in such a way one can present not only buildings but also other facilities such as street lamps, trees, hydrants, etc. There is no need to model them separately, however, because there are many libraries with already finished models that can be used to suit your needs.

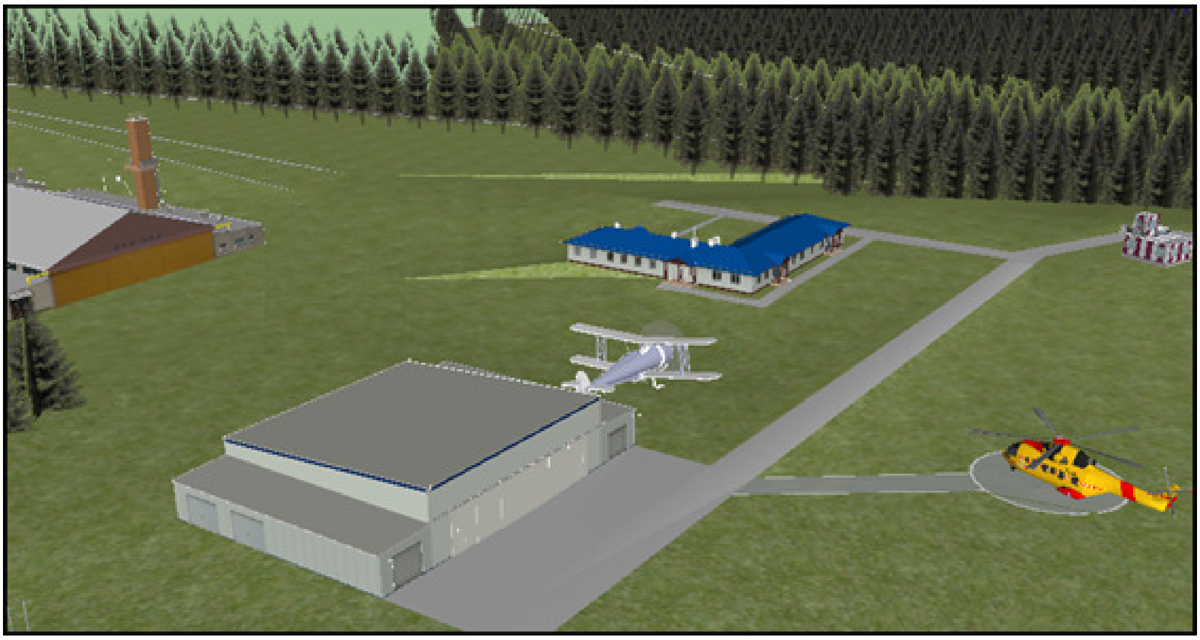

Fig. 5. Three-dimensional visualization of the Olsztyn-Dajtki Airport. Self study based on GIS and GNSS tools

The three-dimensional model of the Olsztyn-Dajtki was largely based on direct measurement of buildings, located throughout the airport. For the measurements laser rangefinder Leica Disto D5 was used. Its advantage over traditional measuring tape was that it allowed to measure the height of objects based on the angle at which the device is inclined to the horizontal plane. As a result information about the shape and size of hangars, control tower was obtained. Information about the administrative building were taken from construction documents, made available by the Aero Club of Warmia and Mazury. Each of the buildings was photographed at the same time during the work to as accurately as possible recreate its appearance. The pictures were also subjected to appropriate graphic processing and served as textures for created three-dimensional models.

After completing the data collection process, remains preparing them to perform spatial analysis. Ensuring the geographical data suitability for spatial analysis includes many different activities such as creating a personal geodatabase to store, share and manage the data set, defining the coordinate system in which the project data will be expressed and appropriate selection of the parameters for their presentation in the Geographic Information System in such a way that it was readable and understandable for users. In addition, at this stage it is also important to set relative paths for added layers. This involves determining the path to the individual layers in relation to the current map document location on computer's hard disk. Assuming that all data and the map file will be in one folder, then the transfer of this folder to any location will not cause errors in reading the map. Thanks to this the designed GIS system can be viewed on any computer with appropriate software to support it.

The most important advantage of Geographical Information Systems is the ability to perform spatial analysis and present their results in the form of maps. The GIS systems are built from spatial databases, supported by a number of tools used for data processing. Operations performed on existing geographic data, aiming to produce new information we call geoprocessing. The results we get from this process may prove extremely useful in supporting decisions in the real world.

GIS software platform allows to perform spatial analysis in several ways, ie: launching the tools from within their own dialog boxes, launching the tools from the command line, creating and initialising the model, which runs the sequences composed from spatial analysis tools, creating and initialising a script that runs geoprocessing tools. For the same input data and geoprocessing parametres, each of them will give the same result. In the figure 6, using two simple tools, was calculated the area of the forest, which should be cut out if there was a need to extend the runway by 400 meters, as well as the course of the border of this surface.

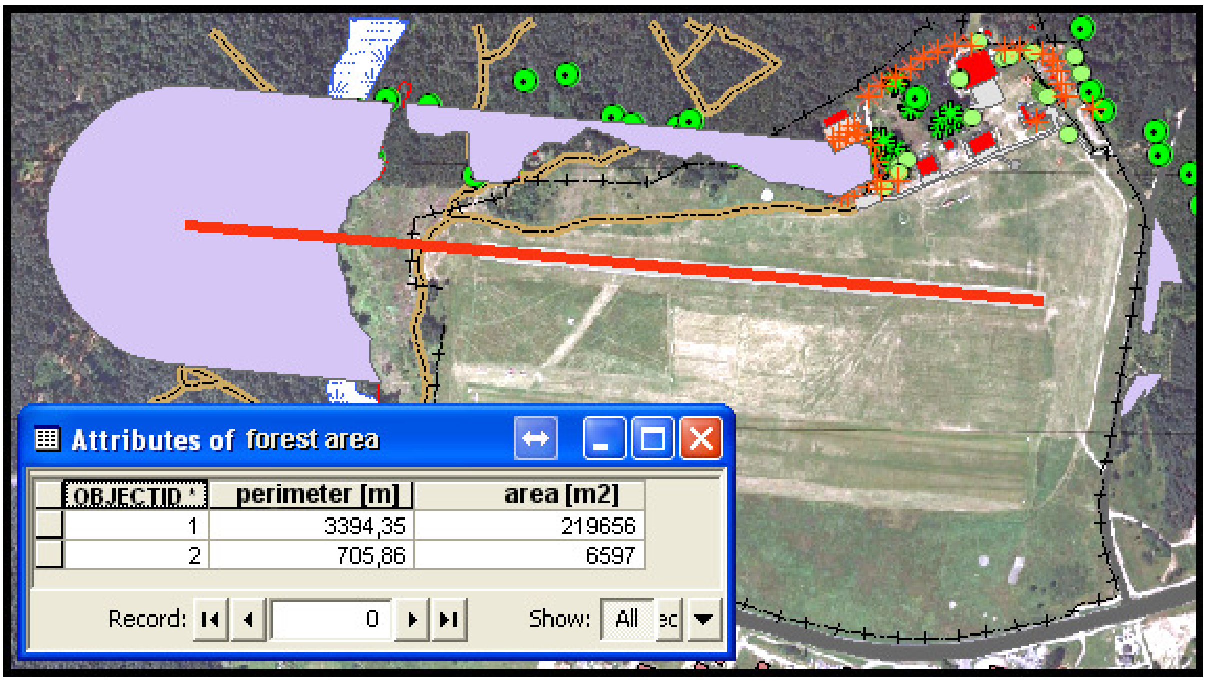

Fig. 6. Area of the forest intended to clearance and its table of attributes.
Self study based on GIS tools

Spatial analysis aimed to determine an area of the forest intended to clearance covered the buffering and object intersecting procedures. First, the buffer was created with a width of 210 meters (10 meters is half the width of the runway), then the intersection of the buffer with a layer of the forest area was created. Area and perimeter are calculated automatically.

6. Summary and conclusions

The culmination of the work related to the creation of Spatial Information System is the presentation of its results in the form of the 3D digital terrain model. In conclusion, the potential that GNSS and GIS systems pose should be appreciated. They allow to understand the surrounding area and provide a range of new information, which cannot be stored in the tables and provided as descriptions, they allow to look at the world from many different perspectives and see the details that are often invisible. With considerable effort and funding the Geographic Information Systems can appear really sensational.

Undoubtedly, three-dimensional maps are the future that awaits us soon. At the moment, however, they are not the standard and there are many problems associated with their creation First of all, the worst looks the process of creating relationships between three-dimensional objects, as well as the need to use several programming environments in the process of building 3D GIS. If, however, the GIS software developers will meet these problems halfway, it can be assumed that the barriers posed by software limitations will be overcome and the quality of the products presented in three dimensions will be much better.

One cannot forget about the second component of the system which is the computer hardware. In the future, into the hands of users will hit a highly efficient computer equipment, for which computational processes for hundreds of thousands of line objects will not pose a problem, and thus it will open the door before the programmers, to more complex computational algorithms [15, 16], guaranteeing even more interesting possibilities. Technological development will therefore allow to improve both the processes of creating GIS, as well as its operation.

Developed model may include a two-dimensional map of the airport, the digital terrain model, the digital model of the runway, and three-dimensional presentation of the project area. It all depends on to whom it would be addressed. Besides the above mentioned elements in the cartographic study should also be included: title of the map, linear scale and legend for each data frame, the north direction arrow, the logo of the airport, the city logo and other graphics of the map composition. With the ability to switch the workspace between the data view and the map composition view, ArcMap is ideal for the preparation of map printing. The prepared DTM can be printed or exported to a graphic file in many different formats with the specified parameters of compression. To sum up all the work that must be done one should address the identified objectives of the project.

The main goal of this study was primarily to open new possibilities in the management of the airport, improving the safety of takeoffs and landings of the aircrafts and providing information for planning and possible expansion of the airport. No doubt all of the above mentioned functions can be carried out based on the built GIS system. Through the support of the management process, which combines with the management and expansion process, one must understand a range of information about the object, that allows to obtain the system without having to go into the detailed tabular and descriptive data. Based on the spatial analysis a number of design information can be obtained, and then a new space can be designed. Items that until now remained in the sphere of imagination, thanks to three-dimensional GIS system may gain the physical shapes. The trees and the highest elements of the buildings measured with geodesic diligence allow implementation of RNAV (area navigation procedures) for improving the safety of performed flights. With this information the designing of an aircraft glideslopes, the identification of risks and optimal management of tree logging is possible, which is an important element of environmental protection. One cannot forget about such factor as aesthetic value, serving to promote the airport, aimed to encourage investors and tourists.

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