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CLUTTER HEIGHT PRODUCTION TECHNOLOGY WITH ARCGIS FOR THE PURPOSES OF LTE AND 5G RADIO NETWORK PROPAGATION AND OPTIMIZATION

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Abstract. The geospatial data accuracy and specification requirements for LTE and 5G radio propagation and optimization are much higher than those used in planning 2G and 3G networks. The recommended geospatial data resolution of 1–2 meters allows the display of the smallest parts of geospatial objects. In the article, we describe the technology and its practical implementation to produce an accurate clutter height (raster canopy height model) for the purposes of LTE and 5G radio network propagation and optimization. This technology, which is based on aerial images, may be adapted to use LiDAR data. The technology includes the data integration between the different software. The processing of digital terrain models, obstacles (buildings and vegetation) and DSM cloud points is performed in geographic information systems, such as ArcGIS. The technology was proven by the practical implementation and calculation in multi-technology wireless network design and optimization platform Atoll.

Keywords: DTM, DEM, DSM, CHM, clutter, clutter height, radio propagation, 5G, LTE.

Introduction

The fast-moving development of 5th generation (5G) mobile networks all around the world and the regular use of LTE (4G) network in everyday life, encourages the improvement of network planning and optimization. This is implemented in software such as Atoll Forsk, ICS Telecom, Asset Aircomm and others. It is known that the minimum set of geospatial data to provide the process of network planning and optimization includes the digital terrain model of the territory, clutter, and clutter height (Prymak, 2018). We recall the following terms and concepts that were used in this article:

Digital elevation model (DEM) is a set of elevation values of the Earth's surface, without considering artificial (buildings, bridges, etc.) and dynamic (vegetation, cars, etc.) obstacles.

Digital surface model (*DSM*) is a set of elevation values of the Earth's surface including artificial (buildings, bridges, etc.) and dynamic (vegetation, cars, etc.) obstacles.

Canopy height model (CHM) is a set of height values of the artificial (buildings, bridges, etc.) and dynamic (vegetation, cars, etc.) obstacles.

Raster data set (Karpinskyi & Hrachov, 2001) or *raster* is determined by formula:

$$R = \langle M, P, r \rangle, \quad (1)$$

where M – value matrix, P – a set of attributive characteristics, for example, colors, r – resolution. An element of matrix M is a pixel which contains an attributive characteristic from the set P and is determined by coordinates (i, j), where i is the row number in the matrix M, j is the column number.

Clutter – a model of radar obstacles in raster where M and P represent, respectively, the values and the set of classes of obstacles that cause radio signal pass losses. The term "clutter" belongs to the field of radiolocation and is used as a definition for unwanted echoes especially in radar electronic systems.

Clutter height – raster CHM where M is a set of height values of obstacles. It can be determined by formula:

$$CHM = DSM - DEM. \quad (2)$$

The geospatial data accuracy and specification requirements for 4G and 5G radio propagation and optimization are much higher than those used in planning 2G and 3G

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networks. The recommended geospatial data resolution is in the 1–2 meter range (International Telecommunication Union [ITU], 2012), and there are already some attempts to improve it. One meter resolution allows the display of the smallest parts of buildings, chimneys on roofs, a single bush or tree. It requires the use of aerial images or LiDAR data as a source to create geospatial data for the purpose of radio propagation and optimization for 4G and 5G networks.

Digital elevation models (DEM) and clutter technologies are quite well studied and are discussed in literature. DEMs thus can be collected by map digitizing or by the stereo method from remote sensing or aerial images. Machine learning technologies are already involved in the classification of remote sensing images (Maxwell et al., 2018), the building footprints can be obtained from images using the mathematical morphology (Gavankar & Crosh, 2018), etc.

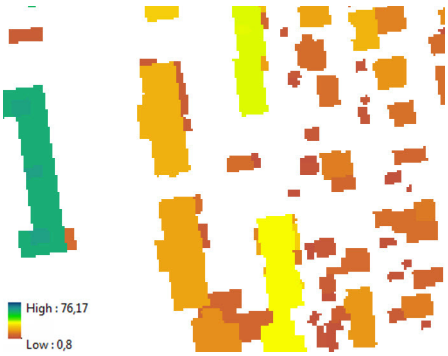


Figure 1. Building clutter height with one height value for one building feature

Figure 2. Study area in Lviv city, Ukraine

The importance of accurate representation of the clutter height is emphasized in (Jimoh et al., 2015; Chizhik, 2011). Today, the technology of obtaining the clutter height is mainly based on manual stereo height measurements of obstacles (buildings, vegetation). The disadvantage of this method is that the entire contour of the obstacle is determined by one average or maximum value of height, regardless of the shape of the roof or tree's crown (Figure 1). Another method based on the automatic digital surface model technology, includes high resolution remote sensing imagery and machine learning for obstacles. Typically, geospatial data examples made with this method are Geoscape geodatabase of Australia (Wallace, 2017). However, in our opinion, without manual adjustment, such data cannot be used in radio propagation and optimization for all of 4G and 5G networks, as it does not have enough detail because of remote sensing imagery resolution, which also leads to a large number of artifacts in DEM and DSM.

Modern photogrammetric systems such as Inpho (Trimble) make it possible to transform aerial images into accurate point clouds and surface models (Trimble, 2019). These can serve as sources of heights to create the clutter height, the third necessary component for radio propagation and optimization. In this article, we make an attempt to describe the technology and its practical implementation to produce an accurate clutter height with the existing digital terrain model, obstacles (buildings and vegetation) and DSM cloud points using the geographic information system ArcGIS.

1. The study area

The region of the Lviv city (Ukraine) was chosen as an experimental area. It includes different types of buildings: the private sector, "Soviet-style" urban buildings, industrial facilities, and new high-rise buildings (Figure 2). Approximate area of the selected region is 1 sq. km.

Aerial images were provided by LLC "Aviation Accounting Center" (http://www.avia.org.ua/en/) in order to conduct the research. Aerial survey was performed in spring 2019 with an UltraCam Eagle Prime camera, focal length of 212.1 mm, scale 1:10279 (pixel 0.0473 m). Images were orientated in Local Coordinate System for Lviv region UA_UCS_2000/LCS_46 (The State Service of Ukraine for Geodesy, Cartography and Cadastre, 2017).

Figure 3. General views of DEM and obstacles (buildings and vegetation) at the study area

The next softwares involved in the processing of aerial images: were Inpho (Trimble, USA) and Digitals (Analityka Ltd, Ukraine).

The digital elevation model was produced in automatic mode for undulating territory with point cloud density of 1 pixel with Match3DX module (Inpho) and corrected by collecting breaklines.

Building footprints and vegetation were collected within the Digitals (Analityka Ltd, Ukraine). The general views of geospatial data are shown in Figure 3.

Also within the Match-3DX module (Inpho), the DSM point cloud was built with a point cloud density of 1 pixel. An example of the 3D view for point cloud of buildings is shown in Figure 4.

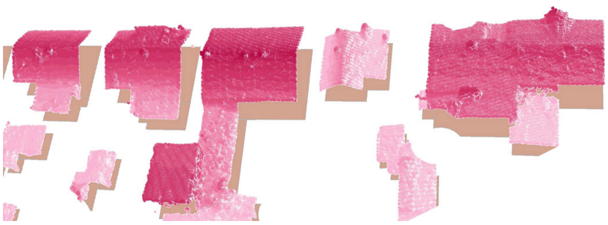


Figure 4. 3D view of obstacles point cloud

2. Methodology

The aim of the study is to integrate the DEM, DSM, and obstacles data into the geographic information system ArcGIS and their processing in order to build accurate clutter height for radio propagation and optimization for LTE and 5G networks. Figure 5 shows a block diagram of the study.

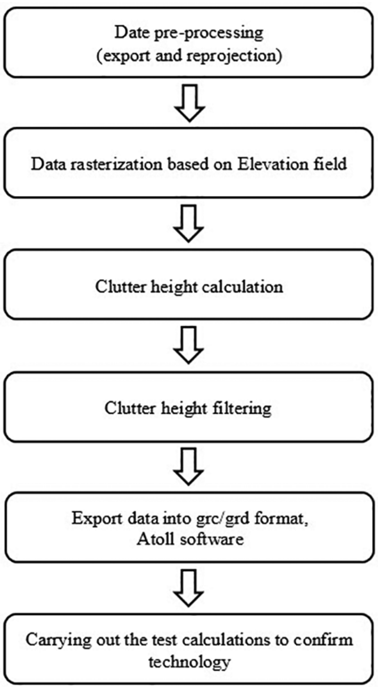


Figure 5. The clutter height production technological scheme

2.1. Pre-processing and data rasterization

The input data for clutter height production were:

1. Building footprints and vegetation boundaries as polygons.
2. Digital elevation model in points and breaklines.
3. DSM point cloud with elevation data for each point.

The conversion of data into shapefile format (ArcGIS) was done by the software GlobalMapper. For point cloud tiling was applied. The size of each tile was 100×100 m.

Data pre-processing in ArcGIS consisted of:

- Reprojection of vector data into a coordinate system known for wireless network design and optimization platforms. In our case it is Universal Transverse Mercator Zone 35 (WGS84) coordinate system.
- DEM rasterization into geotif format.
- DSM rasterization into geotif format.

DEM and vector obstacle data reprojection into UTM35 (WGS84) was done by BatchProject function with Ukraine_2000_to_WGS1984 transformation. Data rasterization of DEM points and breaklines was made by Create TIN and TIN To Raster functions of 3D Analyst extension within ArcGIS. The resolution of DEM grid was 1m.

DSM point cloud consisted of blocks (files) of points, that were produced automatically by Inpho. An approximate size of the block was 100×100 m. The number of blocks in our case was 121. So, DSM data pre-processing was performed in package with ModelBuilder and includes:

- DSM data reprojection into UTM35 (WGS84) by Project function (Figure 6a);
- Data sorting in elevation ascending order by Sort function (Figure 6b);
- Data rasterization into geotif format by Feature To Raster function (Figure 6c);
- Data aggregation into one raster file by Append function.

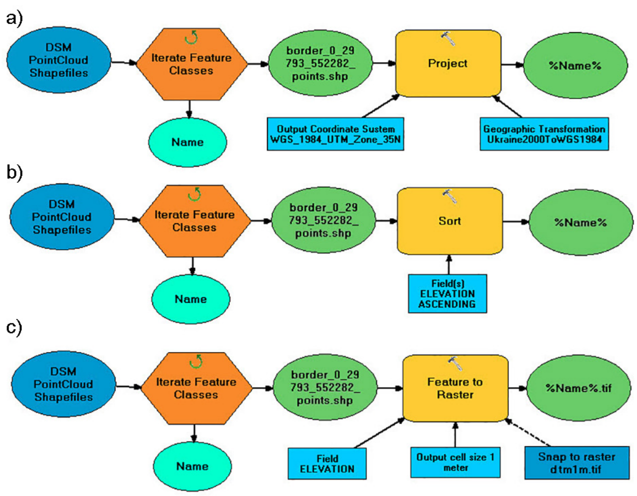


Figure 6. ArcGIS geoprocessing models for DSM pre-processing a) reprojection; b) sorting; c) rasterization

2.2. Clutter height calculation and filtering

Clutter height calculation according to the formula 2 was performed by Raster Calculator function within the obstacles polygons (buildings and vegetation). To avoid the wrong heights in clutter height the values less than 1 meter were deleted by Extract by Attributes function.

The filtering of wrong values at the edges of the obstacles polygons was performed using such filters as Focal Statistics and Low Pass Filter with a preliminary half pixel size reduction to preserve the exact polygon boundaries. After filtering the data, the pixel size was returned to 1 meter.

Detailed function settings and their order are given in Figure 7.

The clutter height general view within the study area is given in Figure 8. Several close-up views of clutters heights of buildings are shown in Table 1.

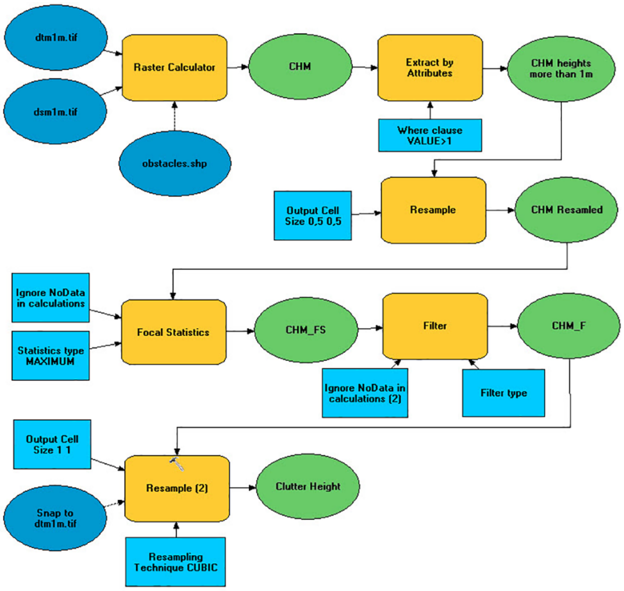


Figure 7. ArcGIS geoprocessing model for clutter height calculation and filtering

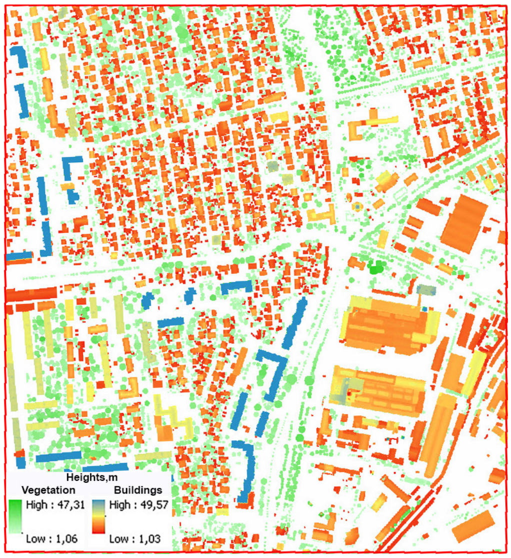
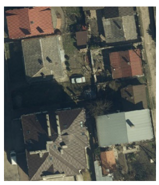
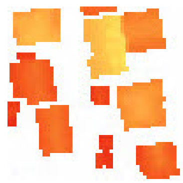
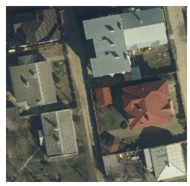
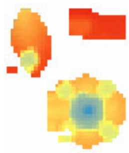
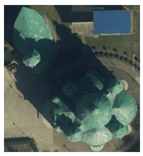
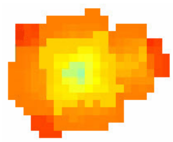
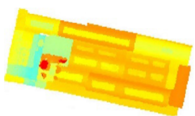
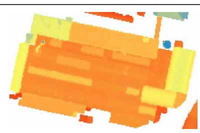
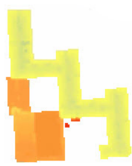
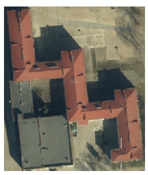
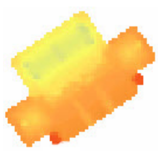
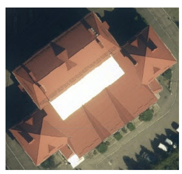


Figure 8. Clutter height general view

Table 1. Clutter height examples for buildings

Obstacles type	Clutter height	Image	Clutter height	Image
Private buildings				
Churches				
High buildings				
Industrial buildings				
Other buildings				

2.3. Experimental calculations in Atoll

The clutter height from geotif format was converted into grd format which is used by multi-technology wireless network design and optimization application Atoll. The data integration platform FME was used for this conversion.

After data was imported into Atoll the Path Loss Matrix was recalculated for LTE network. The accuracy of the calculation was evaluated by drive test data which includes more than 25 000 measurements (Figure 9) for the site located within the study area. The mean square error compared to drive test data is 2.04 dB, which is less than the allowable value of 6–7 dB for urban areas (Parsons, 2000).

Figure 9. Drive test data within the study area

Conclusions

The proposed clutter height production technology for radio planning and optimization of LTE and 5G networks is based on the aerial images but can be adapted to use the LiDAR data as source of input data about the territory.

The technology includes data integration between the softwares Inpho (Trimble), Digitals (Analityka Ltd), ArcGIS (ESRI), and Atoll (Forsk). For data conversion FME and GlobalMapper were used.

Using the proposed technology, it was possible to significantly increase the height detail of such obstacles as buildings and vegetation for the radio propagation and optimization.

The clutter height built according to the proposed technology was successfully loaded into the wireless network design and optimization application Atoll, where Path Loss matrix test calculations were performed. Comparing the calculated results with the drive test data, we can conclude that the proposed technology of clutter height production meets the requirements for built-up urban areas.

Discussion

There are some questions raised during the current study that can be the subject of further discussions.

In order to reduce the cost of software used in the clutter height production technology, it theoretically seems to be possible to replace the Inpho functions by the functions of Agisoft Metashape (Agisoft LLC), and the ArcGIS functions by the functions of free, open-source GIS SAGA.

It is necessary to pay attention to the date of survey for deciduous areas while using aerial images as a source of data. Tree canopy from deciduous trees introduce obstacles but could be avoided if imagery were captured when the trees are leafless However, the use of different time images allows analysis of seasonal changes in the radio planning and optimization, which is also insufficiently studied.

During this research, raster filters were used, which leads to insignificant data smoothing; research of the sufficient data filtering may also be the subject of further discussion.

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