Prediction of Population in Urban Areas by Using High Resolution Satellite Images

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Abstract—**Up to date population of an urban area is vital for any planning decision for the urban area as well as intelligence by using open source information. The conventional method of collecting data for population mainly relies on census which is time consuming and costly. A rule of thumb for estimating the census cost in developing countries is given to be $1 USD per enumerated person, which requires allocating more resources for collecting population data for dense urban areas. Although the population data collected by census is more precise and accurate, due to long time intervals between censuses, it becomes outdated a few years after the census. Hence use of remote sensing for urban environments has potential for predicting urban population with low cost and up to date data. Recently, the availability of high spatial resolution satellite imagery provides development of methodologies for accurate and up to date population predictions for urban environments.**

In this study, a methodology developed for predicting population from high resolution satellite remote sensing is proposed. In the proposed methodology, the first step is obtaining building height values from Stereo IKONOS imagery. The heights of buildings are determined by subtracting the digital elevation model (DEM) from the digital surface model (DSM) acquired from the stereo IKONOS imagery. Then the area occupied by each building is estimated from the difference map. In the next step, the surface area and height of the building are used to estimate the number of block and the apartments in the buildings. Finally the dwellings in the buildings are predicted by multiplying the blocks, apartments and average household size in each apartment. Hence the population of the urban environment is estimated from sum of the probable census for each building.

The proposed methodology is implemented in Cumhuriyet Neighborhood of Eskisehir. The selected neighborhood had high building density with varying building heights. In the case study area, there were 394 buildings in 123 000 m^2 area. The stereo IKONOS imagery had 1 m. spatial resolution with rational polynomial coefficients, which allows the construction of DSM. The accuracy of the proposed method is assessed by comparing the obtained building height values and the predicted population values with the ground truth data. The accuracy assessment showed that accurate prediction of building height from the remotely sensed imagery plays important role in the population prediction. It is also observed the urban structure of the area have to be taken into account in the prediction.

Keywords- Population prediction; remote sensing; DEM; DSM; IKONOS

I. INTRODUCTION

Population information of an urban area is vital for decision making for governments and urban planners, as well as military applications. In Turkey consensus is carried out every five years. Despite of high precision census data, the collection of population based census is a labor-intensive, time consuming and costly process. Hence it is worth to study low cost and time-efficient methods for estimating population. Recent developments in remote sensing, GIS, and spatial analytical techniques, however, have demonstrated the potential of improving the accuracy of population estimation by using satellite imagery and then searching for the dynamic changes in the population.

There are different approaches for the estimation of population. [1] examine residential population dynamics from 1991 to 2006 for the Twin Cities Metropolitan Area (TCMA) of Minnesota using multi-temporal satellite remote sensing. [2] was explored residential population estimation based on impervious surface coverage in Marion County, Indiana, USA. The impervious surface was developed by spectral unmixing of a Landsat Enhanced Thematic Mapper (ETM +) multispectral image. Regression analysis was conducted to develop population density estimation models. [3] attempts to explore urban small-regional population estimation by remote sensing technology, using a residence count method, area (density) method and model method, incorporating the application experience of American scholars. [4] estimates population density of every kind of habitation types based on mathematical models and the best estimation is calculated with the least square principle. [5] and [6] modeled population data using GIS technology. [7] estimated urban population using multispectral imaginary by using density algorithm.

In this study, it is aimed to develop a methodology for predicting population from high resolution stereo satellite remote sensing. The application of the methodology is illustrated by a case study in Cumhuriye Neighborhood of Eskisehir, Turkey, as well as analyzing the accuracy of the estimates.

II. PROPOSED METHODOLOGY

The proposed methodology starts with obtaining the building height values by subtracting the digital elevation model (DEM) from the digital surface model (DSM) of Stereo IKONOS imagery. The surface area and height of the buildings are then used to estimate the number of block and the apartments in the buildings. In the next step, the number of dwellings in the buildings is predicted by multiplying the blocks, apartments and average household size in each apartment. Hence the population of the urban environment is estimated from sum of the probable census for each building. Finally the accuracy of the estimates are assessed.

III. STUDY AREA AND DESCRIPTION OF DATA

The study area is Cumhuriye Neighborhood of Eskişehir Metropolitan Area, which is one of the cities of Turkey and in 39°47′N latitude and 30°31′E longitude of geographic coordinates (Fig. 1). Cumhuriye Neighborhood has approximately 123.000 m^2 area with 394 buildings. The study area is a good representation of a typical urban area in Turkish cities with dense mixture of low and high rise buildings.

Figure 1. Location of the study area

There are three types of data for the study area: Field studies, ground plan of the study area and IKONOS Satellite Stereo Images. The height values of buildings obtained from the field study is used for accuracy assessment as ground truth data. For this purpose, building height values are measured with a TruPulse 200 Laser Range Finder instrument, which has an accuracy of 30 cm in distance and 0,25 degrees in inclination in the range up to one kilometer. The building layer of the study region was obtained from Eskişehir Greater Municipality. The preparation year of the data was 2002. The floor numbers which were obtained from municipality and dated 2002 were updated during the field study.

For the study region, the IKONOS precision stereo images of Eskişehir with 1 m resolution for 2002 were also obtained. These products were having 1 meter horizontal (RMSE) and 2 meter vertical (RMSE) accuracy with 8796x7900 pixels and 8708x7480 pixels respectively.

IV. OBTAINING BUILDING HEIGHTS

The height values of the buildings are obtained from Digital Terrain Model (DTM) and Digital Elevation Model (DEM), which are automatically generated from IKONOS Precision stereo images.

A digital terrain model (DTM) is a 3D digital representation of the Earth's terrain or topography. A digital surface model (DSM), also called digital elevation model (DEM), represents the elevation associated with the Earth's surface including topography and all natural or human-made features located on the Earth's surface. The primary difference between a DSM and a DTM is that the DTM represents the Earth's terrain whereas a DSM represents the Earth's surface [8].

Digital Terrain Model (DTM) or DEM is generated for the study area with the aid of 124 points which are selected from IKONOS Precision Stereo Images. They are selected homogenously in the study area. Kriging method is selected as raster interpolation method. In Fig. 2 generated DEM is illustrated. As seen from Fig. 2, the selected study area is almost flat area that the maximum difference of the height is 2,62 m.

For automatic generation of Digital Surface Model (DSM) from satellite stereo images, fifty tie points has been selected on the overlapping images. Tie points are the common points in overlapping areas of two or more images. They connect the images in the block to each other and are necessary input for the triangulation. Tie points are necessary for accuracy checking of the generated DSM.

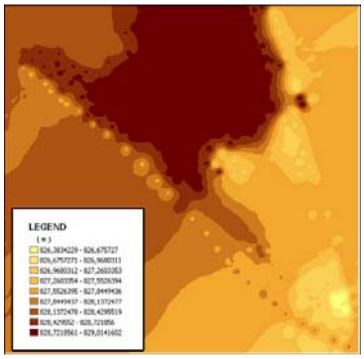

Figure 2. Generated DTM

In order to generate DSM from precision stereo images, ERDAS IMAGINE / Leica Photogrammetry Suite OrthoBASE & OrthoBASE Pro, is used as a software tool [9]. In Fig. 3 the generated DSM with building polygons is illustrated.

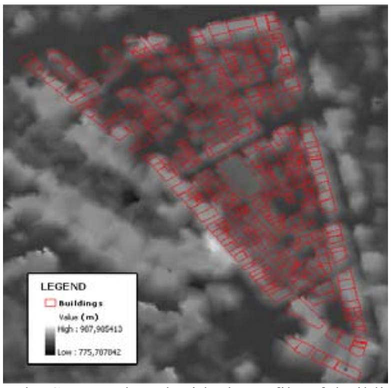

Figure 3. Generated DSM overlayed with shape file of building polygons

The root mean square error for vertical accuracy of the generated DSM was 1.33, which is within the acceptable error range. In order to get height values of the buildings, raster calculation should be performed over generated DTM and DSM data. The building heights are calculated by subtracting DTM raster data from DSM raster, (Fig 4). The difference (DSM-DTM) is called normalized DSM (nDSM) (1) [10].

$$nDSM = DSM - DTM \qquad (1)$$

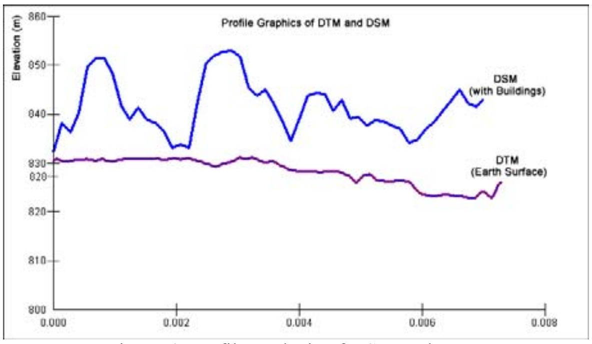

Figure 4. Profile analysis of DSM and DTM

The nDSM is obtained by performing the raster calculation, which is simply performing mathematical calculations using operators and functions on raster data. Generated DEM and DSM are used as input raster for the calculation The calculated raster data is used as an input for zonal analysis, to find the height value for each building. To obtain average building height, mean zonal statistic is calculated for each zone defined by building polygons based on the values from calculated nDSM (Fig. 5).

The height values of buildings in the study area are estimated based on the nDSM. In order to obtain the number of floors of the buildings the height values are first subtracted from the base height of building then the result is multiplied to a constant height value which is defined by municipal zone regulations [11]. According to regulations about structure of buildings, the floor number of the buildings should be calculated by using (2):

$$n = \frac{h - 0.5}{3,00} \qquad (2)$$

Where;

h : Building height

n : Floor Number

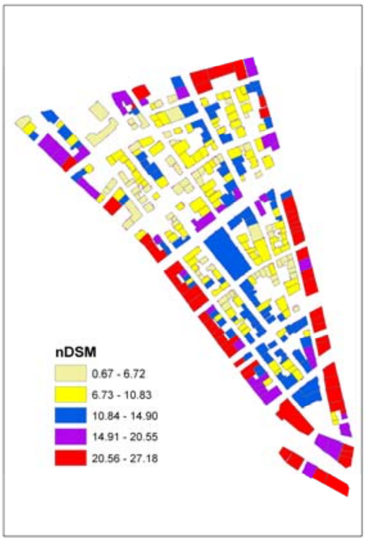

Figure 5. Average building heights calculated for each zone defined by building polygons in shape data retrieved from nDSM

V. ERROR ANALYSIS

In order to find error in the height values retrieved from nDSM, they are subtracted from the building height values obtained from the field study. Descriptive statistics of the error values are calculated (Table I). Furthermore, the descriptive statistics for error value of nDSM data is calculated grouping the data according to the floor numbers. Line graph of mean error for different floor numbers are presented in Fig. 6.

The buildings which are 9 floored have maximum mean error and on the contrary the 3, 6, 7 and 10 floored buildings have small mean errors. In order to explore how the mean error value varies across the study area, "Spatial Moving Average" method is applied, and generated map is illustrated in the Fig. 7. Moreover, Table II contains mean error ranges and numbers of buildings in percentages are listed. According to Table II, %20 of the buildings have mean error values are in between +0,50 and +2,00 m.

TABLE I. DESCRIPTIVE STATISTICS FOR THE ERROR IN THE HEIGHT VALUES

Number of Measurements (N)	359
Mean Error	1,494
Std. Deviation (σ)	2,13
Std. Error ($\sigma_{\bar{x}}$)	0,112
%95 Confidence Limits	1,274 – 1,714
%95 Confidence Length	0,44
Variance	4,541

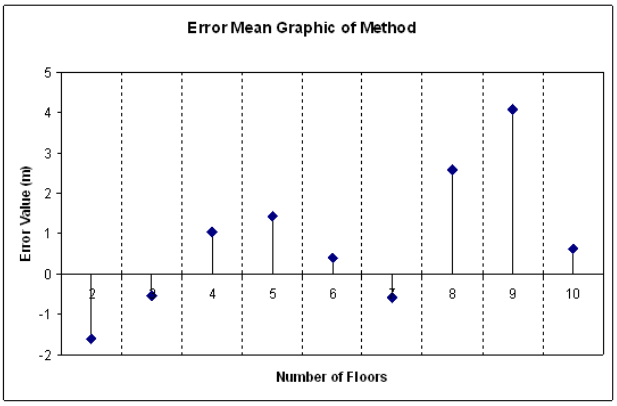

Figure 6. Graph of mean error for applied method

The values in between -2,00 and +2,00 m are considered to be acceptable error levels and totally 50% of the buildings have an mean error value between -2,00 and +2,00 m according to height estimation of the applied method.

TABLE II. MEAN ERROR RANGES AND PERCENTAGES OF BUILDINGS FOR THE APPLIED METHOD

	Mean error Ranges (m)	Percentages of Buildings	Comment
	-17,62 - -8,00	3,06%	Overestimated
	-7,99 - -6,00	1,67%	Overestimated
	-5,99 - -4,00	5,01%	Overestimated
	-3,99 - -2,00	8,64%	Overestimated
	-1,99 - -0,51	18,38%	Acceptable Level Of Accuracy
	-0,50 – 0,50	14,21%	Acceptable Level Of Accuracy
	0,51 – 2,00	19,50%	Acceptable Level Of Accuracy
	2,01 – 4,00	14,48%	Underestimated
	4,01 – 6,00	7,24%	Underestimated
	6,01 – 8,00	3,90%	Underestimated
	8,01 – 21,08	3,90%	Underestimated

In Fig. 7, the locations of the buildings which have minimum and maximum error amounts are defined in zones and labeled. As seen in the legend, blue colored zones represent underestimated calculations in the applied method. In the zone A, there are buildings which have an error value more than 6 m and 8 m to 18 m.

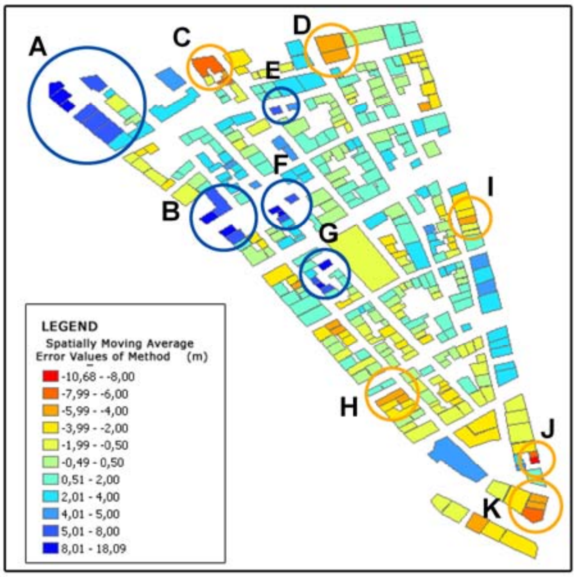

Figure 7. Spatial moving average applied to method

These error values are too much and most probably, the reason for these high error values is propagation of errors in DTM and DSM. Zone B, E, F, and E also represent high error values and the reasons of these results are the same with Zone A.

In Zones C, D, I, H, J, and K, there are buildings which have overestimated height values and they are illustrated with orange and red colors as in the legend of the map. The common reason for the high amount of error in these buildings is their location among the surrounding buildings which are quite high. In Fig. 8, an example to this situation in zone K is illustrated.

Figure 8. An example building in zone K

VI. POPULATION ESTIMATION

To identify the population, the characteristics of the buildings should also be considered. During the data collection in the field study, the information about existence of shops or garages in the basements is added to databases as an additional attribute. Fig. 9 represent buildings which have shops in their basements with dark color. The buildings that have shops in their basements were defined and checked with floor numbers data in the municipality database. As a result, it is found that these buildings have been entered with extra 2 floors to the database.

Figure9. Buildings with or without Shops

For example the buildings labeled in Zone A of the Fig. 10, has 9 floors according to database of the municipality. However, as it seen in Fig. 10, it has 7 floors and a shop floor in its basement. The building labeled as Zone B has 5 floors according to database of the municipality, but in fact it has 3 floors and a shop. The building labeled as C has also same specification, it is 4 floored building and has a shop, but it is seen 6 floored building in the database.

Figure 10. An example building with shop at their basements in zone A

Therefore, the height of the shops is excluded in the database, for population computations.

The area of each building is calculated to identify the number of apartments at each floor (Fig. 11). It is assumed that the area of buildings smaller than 150 m^2 can contain only 1 apartment at each floor, the area of building between 150 m^2 and 300 m^2 can contain 2 different apartments, the area between 300 m^2 and 630 m^2 can have 4 apartments, and the area of buildings larger than 630 can have 8 apartments.

The areas larger than 1200 m^2 and smaller than 35 m^2 excluded from the analysis considering that there can be no flat at these dimensions. In the data there was only one flat larger than 600 m^2 which are around 1200 m^2 and this building can be combination of two different buildings and may contain 8 apartments at each floor.

Figure 11. The areal extend classification of each building given with m^2

After excluding the buildings which are not providing an adequate size of a building, the area of each building is classified into four different classes and for each class an apartment number is assigned for each building. The areal classification of buildings is presented at Fig. 11. As a result for each building the apartment number is estimated and assigned to each building.

Figure 12. Spatial distribution of dwellings estimated based on the methodology described.

The dwellings in the buildings are predicted by multiplying the blocks, apartments and average household size in each apartment. The average household size is considered as 3 [12]. Hence the population of the urban environment is estimated from sum of the probable census for each building as given (3).

$$c = \sum b * a * h \quad (3)$$

Where; c is the census, b is the blocks or number of floors at each building, a is the apartments estimated based on the areal extend of each building and h is the average house hold size.

As a result 4593 population is estimated based on the analysis. The distribution of the result is given in the map presented in

Fig. 12. The estimated population result is compared with the actual population of the neighborhood which is 4668. As a result it is seen that there is 75 person underestimated by the applied method. Hence the method can estimate the population in a very short time, with low cost compared to the conventional ways and with quite nice estimation result.

VII. CONCLUSION

The developed methodology, for up to date population prediction for urban environments leads to considerable results. Compared to the time consuming and costly conventional method of collecting data for population, use of remote sensing has potential for predicting urban population with low cost and up to date. Automatic generation of DSM and DTM from high resolution satellite images is a rapid method for obtaining height values of the human made structures in urban areas. However the accuracy of the satellite images used in the analysis is very important.

The accuracy assessment showed that accurate prediction of building height from the remotely sensed imagery plays important role in the population prediction. In this study, IKONOS Precision Stereo images are used, which has 1 meter horizontal (RMSE) and 2 meter vertical (RMSE) accuracy. As a result of the applied methodology 1,495 m is found as mean error and 2,13 as standard deviation values for the height values of the buildings. The ranges of the error is between -17,62 m to 21,08 m and these error ranges are too much and most probably, the reason for these high error values is propagation of errors in DTM and DSM. The accuracy achieved in the DTM and DSM generation would be improved with using IKONOS Geo with precise Ground Control Points (GCPs) which are collected from study field.

It is also observed that the urban structure of the area have to be taken into account in the prediction. Depending on the area of each block, the number of apartments at each floor is estimated. In addition in the prediction of the population at each building the estimation of average household size in each apartment has an important effect to the result. If the government has a policy or restriction on the number of people dwell at each apartment, depending on the size of the apartment then more precise estimations can be made depending on remote sensing technology.

As a result this methodology can be effectively adapted to the other population estimation studies. It is an efficient way for estimating the census for short time requirements and for low cost compared to conventional way.

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