UAS based remote sensing for rapid large-scale mapping of urbanized territories for sustainable urban planning: the case of Burgas and Stara Zagora, Bulgaria

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ABSTRACT

According to UN DESA (United Nations Department of Economic and Social Affairs) urban population will become 66 percent of the planet's population by 20501. Unmanned Aerial Vehicles (UAVs) are confirmed as rapid, efficient, low-cost and flexible acquisition systems for remote sensing data with high-resolution and accuracy (sub-meter to few centimeters)2. The urban environment observed at large scale is dynamic and ever changing due to the human activities, which is a real opportunity for UAV and its urban applications such as management of urban infrastructure3 building observation4, urban land cover classification using airborne LiDAR5 and automatic feature extraction for UAV-based cadastral mapping6. A typical photogrammetric UAV workflow consists of flight planning, image acquisition, camera calibration, image orientation and data processing, which can result in Digital Surface Models (DSMs), orthoimages and point clouds7. In this paper, we perform a rapid, multi UAV data acquisition on the territory Bulgarian city of Stara zagora for a single day. 3 fixed-wing UAV, model eBeeX, manufactured by the company AgEagle Aerial Systems, was used in the present survey. The urban mapping area covered by the drones is 31.215 km2. To gather the necessary information, the platform is equipped with a dedicated integrated photogrammetric sensor S.O.D.A with RTK functionality. All the imagery captured by the three drones are postprocessed in Pix4D Mapper v4.8. Highly accurate 3D point cloud, digital surface model (DSM) and high-resolution and accuracy orthophoto map are produced. The results obtained by the drones have a spatial resolution of 5cm per pixel and vertical accuracy between 5 – 10 cm. All the results are exported and published in easy-to-use formats.

Keywords: UAV, urbanized territories, photogrammetry

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Introduction

The planning and management of the territory is a complex and spatially determined process, the information provision of which requires a significant volume of diverse geospatial data and information. This particularly strongly affects these processes in urbanized areas. These territories represent specific geospatial systems that can be characterized as the habitat geosystems of the human population. Their formation is the result of a systematic transformation of large parts of the natural geosystems into structures of a hybrid nature, in which artificial objects, systems and surfaces predominate. Considering dynamics and high degree of heterogeneity and the complex multidimensional structure of urbanized territories, the UAV has a leading role in providing up-to-date data based on remote sensing.

Despite the huge advances in these technological solutions over the last few decades[8] the efforts for land cover/land use change (LCLUC) analysis and modeling, and the characterization of land surface geometry and morphology have so far relied primarily on passive remote sensing data as well as traditional analysis techniques. These remote sensing data are usually sourced from satellite platforms (most often Landsat and Sentinel), and the applied analysis methods are most often related to methods and approaches such as supervised and unsupervised classification of the images they provide[9,10]. Satellite images mainly reflect the two-dimensional (2D) dynamics of the development of urbanized territories, which, in the context of the significant vertical development of the cities, is obviously no longer sufficient and causes serious deficiencies in the information provision of the processes related to the planning and management of the territory[10]. At the same time, some geospatial technologies, including those based on unmanned aerial systems, have received very serious development in recent years. The same technologies find an increasing place in scientific research[11-13]. These systems work at a low height, have a lower cost, greater flexibility, and mobility[14]. With the development and introduction of UAVs, different digital photogrammetric modeling approaches and methods have been developed and implemented, which use high-resolution remote sensing images to create qualitatively new geoinformation products for the end user that can be applied with minimal technical knowledge[15, 16]. The creation of three-dimensional (3D) point clouds and planimetric models using Structure from motion (SfM) uses optical imaging and high redundancy of image connection points (image features) for a low-cost, high-quality result[17,18].

Due to these advantages, UAV-based remote sensing systems have been applied in topographic mapping[19], forestry monitoring[20], precision agriculture[21,22], natural disaster[23] and environmental monitoring[24] and many others. In recent years, this technology has also been successfully applied in the mapping of urban areas, but often with limited spatial coverage. This is due both to the technical features of the UAV, as well as to the capabilities of the sensors and systems for geographic positioning of the geographic data they collect. In addition, with the adoption of regulations in the EU related to the use of these technologies near people, UAVs should meet special requirements, as well as the pilots who operate them.

In this regard, the present article aims to present an approach and a technological solution for a rapid mapping of urbanized territories which can be successfully used in the processes related to the planning and management of urbanized territories.

Materials and methods

In the present study, an approach based on the use of a system of UAVs that perform simultaneous and synchronized flight missions for mapping urbanized territories is used. For this purpose, a specialized platform is applied, which allows the planning, management, and implementation of mapping in synchronized mode, as well as positioning of the collected data through RTK protocol. All this ensures high quality of the localization characteristics of the data, which significantly shortens and optimizes the processes of collecting the raw data in the field.

The research was carried out within one day in July 2023 and covers the territory of the city of Stara Zagora, Bulgaria (fig. 1)

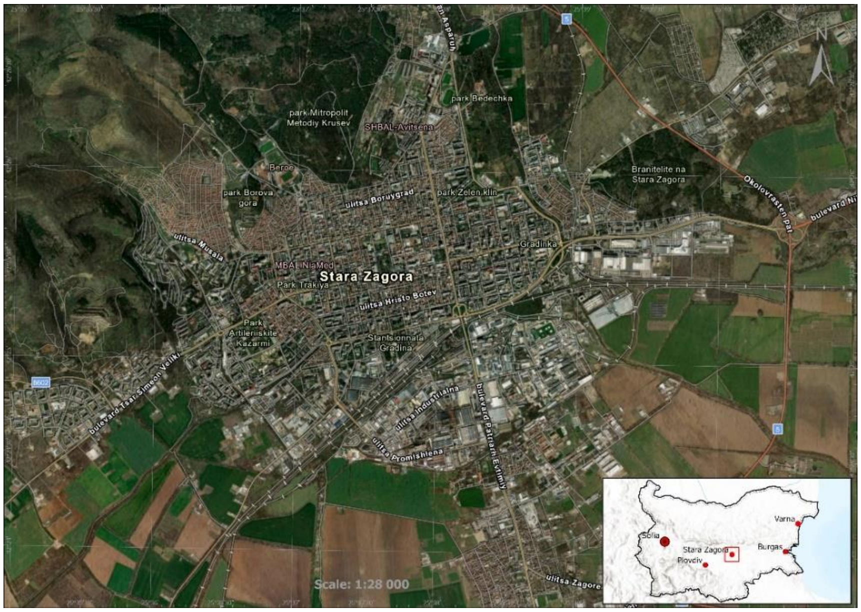
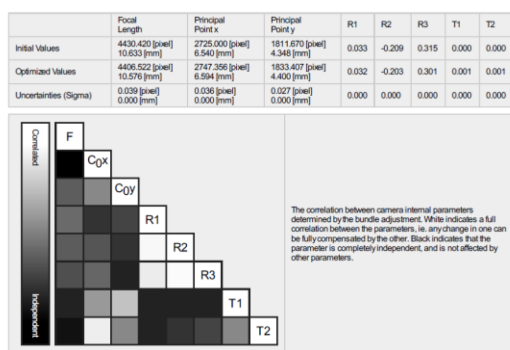


Figure 1. The city of Stara Zagora and its surroundings

Equipment and technology

For the purposes of the present study were used 3 fixed-wing UAV, model eBeeX, manufactured by the company AgEagle Aerial Systems. The drones are controlled by integrated autonomous flight software (eMotion version 3.2), data communication link and inertial measurement unit (IMU), this platform can provide a flight of 90 minutes using various interchangeable sensors. For the purpose of our study we used an integrated photogrammetric sensor for UAV applications (S.O.D.A) (fig. 2a) with a resolution of 20 MP (properties shown on fig. 2b) providing natural color images. The flight system is equipped with RTK (real time kinematic)/PPK (post processing kinematic) functionality, which allows image acquisition without the presence of ground control points (GCP). This type of UAV is the only certified Class A2 platform that can fly over people as well as in beyond constant visual line-of-sight (BVLOS) situations (Fig. 3). We processed all acquired images in Pix4D Mapper v4.8 software.

a)



	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	4430.420 [pixel] 10.633 [mm]	2725.000 [pixel] 6.540 [mm]	1811.670 [pixel] 4.348 [mm]	0.033	-0.209	0.315	0.000	0.000
Optimized Values	4406.522 [pixel] 10.576 [mm]	2747.356 [pixel] 6.594 [mm]	1833.407 [pixel] 4.400 [mm]	0.032	-0.203	0.301	0.001	0.001
Uncertainties (Sigma)	0.039 [pixel] 0.000 [mm]	0.036 [pixel] 0.000 [mm]	0.027 [pixel] 0.000 [mm]	0.000	0.000	0.000	0.000	0.000

(**b**)

Figure 2. S.O.D.A Photogrammetric sensor (a) S.O.D.A 10.6_5472x3648 (RGB), Sensor characteristics (b)

Figure 3. EbeeX fixed-wing UAV

Flight planning and image capture was managed by eMotion software. The software is easy to use and reliable, allowing multi-drone flights as is the specific case. A site allowing easy take-off, landing and control of the drones has been carefully selected and improvise field command center was organized (fig. 4).

Figure 4. Field command center

As already mentioned, the processing of the collected data was carried out using a specialized software platform for photogrammetric processing Pix4D, which has established itself as one of the most used ones for aerial and ground images captured by BLS or other imaging platforms. It is used to generate detailed 3D models, orthomosaics, digital surface models (DSM) and point clouds for a wide range of applications.

In a pervasive step, an algorithm is used after the import of the raw georeferenced images to identify common points in the images, calculate camera positions and orientations, and correct for lens distortion. Using the camera information and the identified tie points, the software generates a dense point cloud representing the 3D structure of the urban area. Pix4D subsequently creates a digital surface model (DSM) from the point cloud, which represents the height of the terrain and all above-ground objects, such as buildings and vegetation. Using the DSM and the individual images, Pix4D generates an orthomosaic, which is a high-resolution georeferenced aerial image of the study area with distortions caused by changes in terrain and camera angles corrected.

An important element of the processing is related to the classification of the point cloud, which is essential for the semantic characterization of the main land cover types and the different categories of objects within the study area. The classification involves two stages:

- Initial classification

This step involves a basic differentiation of points based on their elevation. For example, points that are close to the ground are classified as points on the ground, while higher points may be classified as points that are not above the ground.

- Application of automated classification algorithms

These algorithms use different characteristics of points, such as intensity, color, and spatial relationships, to classify them into different categories. For example, points with vegetation can be identified based on their green color and unique spectral reflectance. In addition to vegetation points and ground surface, the software also classifies other objects such as buildings, vegetation, vehicles, roads, etc. To recognize and classify them, the software uses the attributes of the points (such as color, intensity, shape)

Results

As a result of the flight missions, a total of 5770 individual images with ground sampling distance of 5.49 cm and with WGS 84/UTM zone 35N coordinate system was captured and processed in Pix4D Mapper v4.8 software. Figure 5 shows absolute geolocation variance of all collected images. Min Error and Max Error represent geolocation error intervals between -1.5 and 1.5 times the maximum accuracy of all the images. Columns X, Y, Z show the percentage of images with geolocation errors within the predefined error intervals. The geolocation error is the difference between the initial and computed image positions.

Min Error [m]	Max Error [m]	Geolocation Error X [%]	Geolocation Error Y [%]	Geolocation Error Z [%]
-	-4.22	0.00	0.00	0.00
-4.22	-3.38	0.00	0.00	0.00
-3.38	-2.53	0.00	0.00	0.00
-2.53	-1.69	0.00	0.00	0.00
-1.69	-0.84	0.00	0.00	0.89
-0.84	0.00	54.08	51.16	50.55
0.00	0.84	45.74	48.77	47.94
0.84	1.69	0.17	0.07	0.63
1.69	2.53	0.00	0.00	0.00
2.53	3.38	0.00	0.00	0.00
3.38	4.22	0.00	0.00	0.00
4.22	-	0.00	0.00	0.00
Mean [m]		-0.010349	-0.004464	-0.008178
Sigma [m]		0.126513	0.122091	0.175093
RMS Error [m]		0.126936	0.122173	0.175284

Figure 5. Absolute geolocation variance of all collected images

Highly accurate 3D point cloud, digital surface model (DSM) and high-resolution and accuracy orthophoto map are produced. The final results obtained by the drones have a spatial resolution of 5cm per pixel and vertical accuracy between 5 – 10 cm, some of the results are shown on figure 6, 7 and 8. All the results are exported in GeoTIFF and LAS files and published in PIX4DCloud platform.

Figure 6. Mosaic dataset based on acquired photos

The figure (fig. 7) below shows a fragment of the city territory, which visually presents the high spatial resolution of the orthophoto map. In this case, one of the main archaeological sites in the central part of the city is presented.

Figure 7. Archeology site Beroe fortress in Stara Zagora

Below is a fragment of the orthophoto map related to one of the park areas of Stara Zagora. The high resolution of the collected data allows their successful use for inventorying the elements of the green system of the city and urban ecosystems in general.

Figure 8. One of the city parks

One result that has a very high degree of applicability is the classified point cloud, which provides the ability to separate different land cover types. The latter is extremely important for land use planning and management, including the determination of environmental parameters, the assessment of natural climatic risks, and the analysis of the balance of different types of areas (Fig. 9).

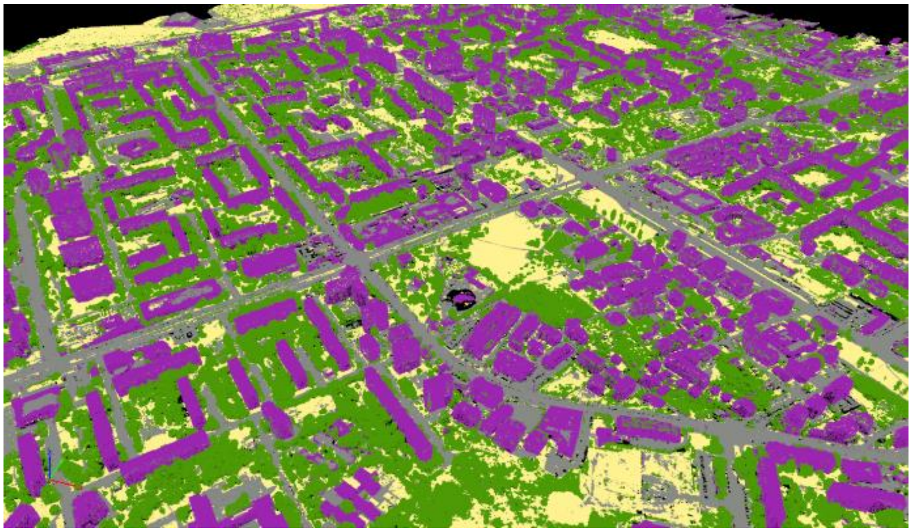


Figure 9 Classified 3D point cloud of the urbanized territory

Discussion

Correct and realistic replication of urban spaces is crucial for adequate planning and management of these areas. Due to the multidimensional nature of the sites and the geosystems that form them, 2D models are of limited application and cannot cover the needs of adequate information provision of the processes that are applied to this management. On the other hand, the actual 3D modelling of space and its semantic classification is a serious challenge, requiring significant resources, sophisticated technological tools and a number of constraints related to the fact that these are densely populated, dynamic territories. Undoubtedly, modern unmanned aerial systems represent a very powerful tool for geospatial data collection, but their limitations should also be borne in mind. These limitations are primarily related to their lethality, which often leads to the inability to map large territories. Secondly, there are limitations in the regulatory framework which are related to the use of most of the professional systems in densely populated urban areas. The present investigation is based on the use of a fixed-wing type system equipped with RTK functionality for georeferencing the images, which guarantees a high level of accuracy without the need of GCPs. Furthermore, the platform used allows for a so-called multi-drone approach, i.e. the simultaneous use of a single stance to control more than one unmanned aerial system (in this case three are used simultaneously). All this allowed us to map within one day the entire urbanized area of the city. Three types of products were generated- a high spatial resolution orthophotomap, a classified point cloud allowing the separation of the main land cover types, and a detailed digital surface model. These data are a very good basis for geospatial inventory of the territory as well as for analytical purposes related to the information support of procedures related to planning and management of the territory. Due to the fact that the present survey was carried out in one day, and with pre-planned and programmed missions, the whole process can be repeated an unlimited number of times, which in turn provides opportunities for effective monitoring of the development of urban areas.

Conclusions

The present investigation illustrates the strong capabilities of fixed-wing unmanned aerial systems to deliver information resources in a fast and efficient way, underpinning procedures related to sustainable planning and management of urban areas. The approach and methods used are efficient and at relatively low cost, while being easy to use and generating standardised products.

This in turn shows that modern geospatial technologies, such as those based on unmanned aerial systems, can and should be used in the process of planning and management of territorial systems. The information resources they generate have a variety of applications and can significantly improve decision-making processes. Their application should be seen in the context of the increasingly emerging concepts of digital twins of the territory and smart cities.

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