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Integration of UAV and GNSS Data for Accurate Land Use Mapping at Wasit University

Aqeel A. Abdulhassan[1]
[1] Department of Civil Engineering, College of Engineering, Wasit University, Wasit, Iraq.

Corresponding Author Email: aqeel@uowasit.edu.iq

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ABSTRACT

Aerial surveys of Unmanned Aerial Vehicles (UAVs) in conjunction with Global Navigation Satellite System (GNSS) surveying offer high resolution, accuracy, and completeness of data that is necessary in developing detailed digital models and maps. High-resolution drone images have highly enhanced land use mapping. It is a significant part of urban planning management because of the abundance of geographical information that it offers. By combining various drone-based approaches with multi-domain technology, complex operations can be optimized and completed more efficiently. The current research paper proposes a new idea for acquiring land-use maps of the campus of Wasit University based on a combination of UAV aerial photography and GNSS surveying. The aerial survey was conducted at a flight altitude of 125 meters using a multirotor drone equipped with a MAVIC2 PRO photogrammetric camera. Waypoints 2.0 application was used to plan and organize the best flight route for the autonomous mission. With real-time kinematic application of the GNSS used as a source of data within the survey area, we were able to obtain the coordinates of fourteen Ground Control Points (GCPs). The Agisoft Metashape and ArcGIS 10.8 were used to process the 652 aerial photographs that were produced by the flight plan. The results demonstrated the capability of UAV data, when combined with GNSS surveying, to obtain land use maps at very high spatial resolution. The resulting orthophoto achieved a positional accuracy of 9.60 cm Root Mean Square Error (RMSE), confirming the reliability of the data for topographic mapping. These outputs highlight the effective integration of drone technology and GIS in supporting urban planning efforts.

Keywords: UAV Photogrammetry, High-resolution Orthophoto, Topographic Mapping, Urban Planning, GIS Integration

1. Introduction

Unmanned Aerial Vehicles (UAVs), often called Drones, have become extremely popular due to their adaptability, user-friendliness, affordability, and capacity to safely operate in hazardous or inaccessible regions. Drone technology is currently experiencing rapid growth and extensive use, which aligns with the demands of modern living. A UAV system can have either fixed wings or rotatable wings. Although the number of rotors distinguishes a rotary from a helicopter, the two share many basic concepts. Note that modern drones can be seen as instruments for collecting data on aerial photography [1].
There has been a recent uptick in the use of Geographic Information System (GIS) software for storing and analyzing spatial data due to its layered data processing capabilities. Regardless of technological advancements, the blueprint for all digital database designs is a base map. One reliable method for making a digital base map is to use aerial images taken by drone surveys [2]. The integration of drones with GIS is advantageous, as it reduces expenses and enhances accessibility for geospatial data acquisition. Conventional aerial photography has a steep budget because it involves the use of planes, pilots and photographers. With highly advanced cameras and Artificial Intelligence (AI) programs, drones can replace traditional means and be time and cost-efficient.

The application of high-resolution cameras on drones may enhance the current development of smart cities, emergency health response, urban planning, and disaster management through the acquisition of accurate aerial photographs and maps of any particular area [3]. Some of the various uses of these maps are environmental surveillance, land domain management and city planning [4]. Other than that, surveyors may use drones to collect topographic data to generate Digital Elevation Models (DEMs), which have a number of applications in the field of mining, civil engineering, etc. [5]. The drone technology has progressed much further, following multiple installations, optimizations and adjustments and can be used to achieve many different studies [6]. The advanced sensors, such as LiDAR Ligth Detection And Ranging and hyperspectral cameras, introduced into drones broadened the initial purpose of these devices (photography and aerial photography) to refer to data regarding the quality of water bodies, terrain, and flora health [7]. With advancements in platforms and software, the integration of drone-acquired data into GIS workflows, such as land-use planning and natural resource management, has become increasingly streamlined and effective [5]. The study of the drone's ability to use GIS might be productive in the future, as there is a trend toward the universal use of these products today.

Many benefits are possible as a result of merging GIS systems and drones in urban planning. High-tech drones are equipped with advanced cameras and sensors capable of capturing precise urban data, which can be effectively utilized in generating accurate GIS-based maps. Using this data, urban planners can potentially understand geographical relationships between the different components and infrastructure and make informed choices in the areas of land use, transit and infrastructure development. This is because drones facilitate the faster and higher-magnitude collection of information when compared to traditional forms of surveying, and urban planning projects will save them money. GIS applications may also be added to drone footage to develop three-dimensional images of cities. The use of drones is crucial in disaster response and recovery, as they can quickly assess damage and gather information after natural disasters [8].

The application of drone-integrated GIS has been applied in several urban planning projects around the world. The data collection using multiple UAVs was proposed in [9], which was used to generate 3D buildings in response to an emergency, and a path planning system was used to assist in data collection. Furthermore, the process of developing a land use map to manage infrastructure was elaborated using aerial images captured by a multirotor drone [10]. The drones in Indonesia provided a precise orthophoto with high resolution that was utilized to mark the exact borders and land use information of Pandanrejo hamlet in Central Java [11]. Other than that, the survey of green spaces around Singapore was carried out through drones, and GIS software was then used to analyze the data and identify the trouble spots [12]. To explore the issue of urban sprawl and preserve cultural heritage, 3D models of Kota Bharu were developed with the multirotor drones [13]. In Mosul, Iraq, scholars have created a GIS system that uses drones to scan an ancient Nineveh site [14].

In the orthophoto model, all of the urban feature such as buildings, roads and open spaces are digitally represented. A robust method is necessary to digitally model and capture all the geometric and visual aspects of urban areas, enabling the creation of accurate maps of these locations. Drones have recently been used to collect 3D models and maps, which can generate digital maps using either nadir or oblique imagery. However, the best model incorporates both types of data [13]. For computer programs to generate orthophoto maps, a multitude of overlapping still photos is necessary. For example, flight planning configuration includes flying path, altitude, sensors, image count, overlap percentage, and geo-referencing [15]. Hence, Agisoft Metashape was selected for photogrammetric processing due to its compatibility with our dataset, user-friendly interface, and its successful application in previous aerial mapping studies.

Utilizing data collected from a multirotor drone, an orthophoto covering the entire university campus, including buildings, land uses and roadways, was generated and analyzed to provide detailed spatial information crucial for campus planning and management.

The outline for this study is presented below. Section 2 discusses the parameters of the study area. In Section 3, the material and software are displayed. Data gathering, image processing, orthophoto creation, topographic mapping, and accuracy evaluation are covered in Part 4. Meanwhile, Section 5 presents the findings and discusses them in detail. Conclusions are provided in Section 6.

2. Study area

The location of Wasit University is in Zone 38N of the UTM System. The university's rectangular coordinates lie between 578,600 m and 579,200 m east, and between 3,595,600 m and 3,596,600 m north, which is located in Kut City, the center of Wasit Governorate. It is considered one of the middle governorates of Iraq, about 180 km south of the capital, Baghdad. Consequently, it is adjacent to each of the governorates (Al-Qadisiyah, Babel, Baghdad, Dhi Qar, Diyala, and Maysan), as well as the Iranian border to the southeast [16]. In addition to the streets and green spaces, the Wasit University campus comprises the university presidency, twelve colleges, the central library, student housing buildings, and several scientific and cultural centres, occupying an area of approximately 25 hectares. This area was selected as a research site due to its diverse range of buildings, streets, and land cover. Fig. 1 illustrates the administrative borders of Wasit Governorate and the city of Kut, where the study area is located.

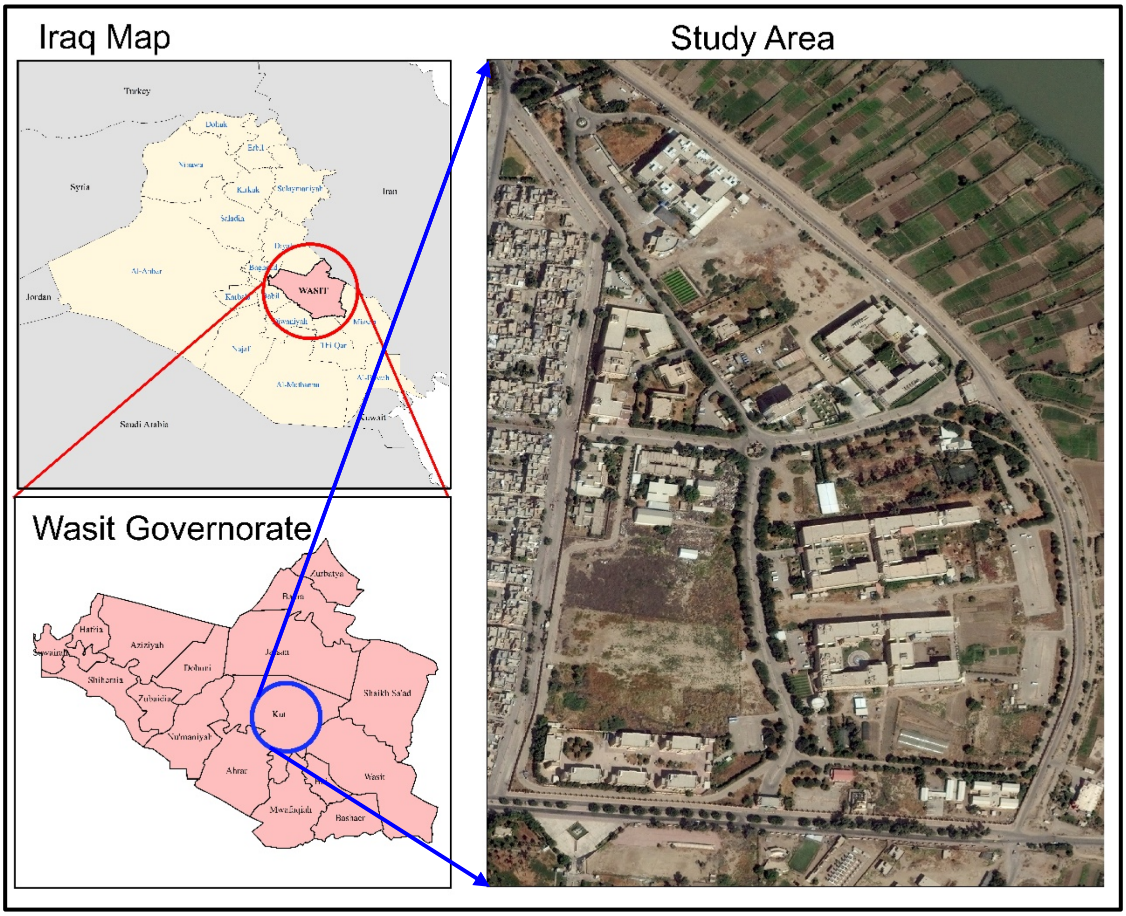

Figure 1. Location of the Study Area within Wasit Governorate.

3. Material and software

This article utilized two sorts of data: primary and secondary data. Satellite photos, land use maps, field reconnaissance, and GIS data are examples of secondary data sets that include information pertinent to the university campus. In contrast, data collected by the multirotor drone is referred to as primary data. These data are categorized as the materials required to build the model of the orthophoto map. There are numerous factors to consider when selecting a drone model for research, such as price, area coverage, and software compatibility. The DJI Mavic 2 Pro was chosen as the multirotor drone utilized for acquiring aerial imagery data. Table 1 details this equipment's specifications.

Note that numerous software programs are utilized for data sorting, processing, orthophoto map creation, and analysis of results. Therefore, the Waypoints 2.0 tool was employed to prepare and plan the UAV flight mission.

This tool is a built-in feature of the DJI application that allows users to program autonomous drone flights by setting predefined waypoints and actions. Meanwhile, the Agisoft program was used to process the aerial images captured by the drone. The urban form analysis and mapping were finalized using GIS software such as ArcGIS and MapInfo.

Table 1. Technical Specifications of the UAV Platform Utilized for Aerial Survey

Specification	Detail
Model	DJI Mavic 2 Pro
Drone System	Multi rotor
Resolution	2.93 cm/pixel
Flight speed	10.3 m/sec

4. Methodology

Preparation for the flight, data pre-processing, orthophoto generation, and analysis of urban areas are the four main steps that make up the methodology of this study. Refer to Fig. 2 below for an illustration of the process flow.

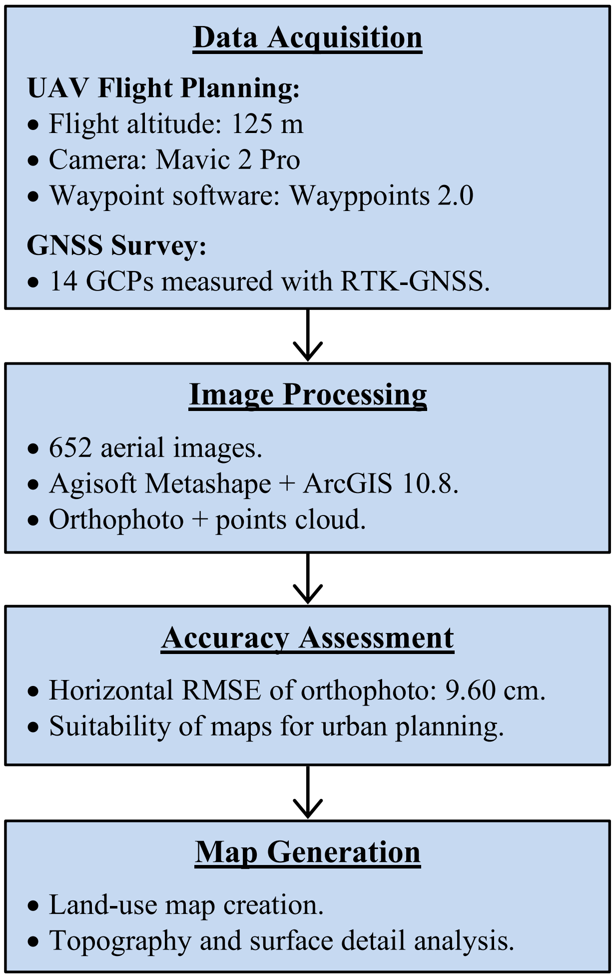

Figure 2. Workflow of Data Collection and Map Production.

4.1. Flight Preparation

At this stage, the flight planning was initiated. To guarantee quality and align the imagery with our goals, meticulous coordination of several crucial components is necessary. The drone captured aerial images on March 7, 2024, utilizing elements that included the path, sensor, height, image overlap, and geo-referencing. Drone mapping missions are built to take photographs that overlap each other just enough for processing software to merge them efficiently. Thus, achieving the desired image overlap requires balancing factors such as flying at the right speed, altitude, spacing between transects, capture interval, and camera internal geometry. The Waypoints 2.0 program was used to set up the flight path in a rectangular route and adjust the drone's altitude to 125 meters, enabling it to circumvent tall structures and mitigate signal degradation caused by nearby cell towers. There was an 80% minimal overlap configuration for the front view and a 70% minimal overlap configuration for the side views. The concept of aerial surveying using drones is illustrated graphically in Fig. 3.

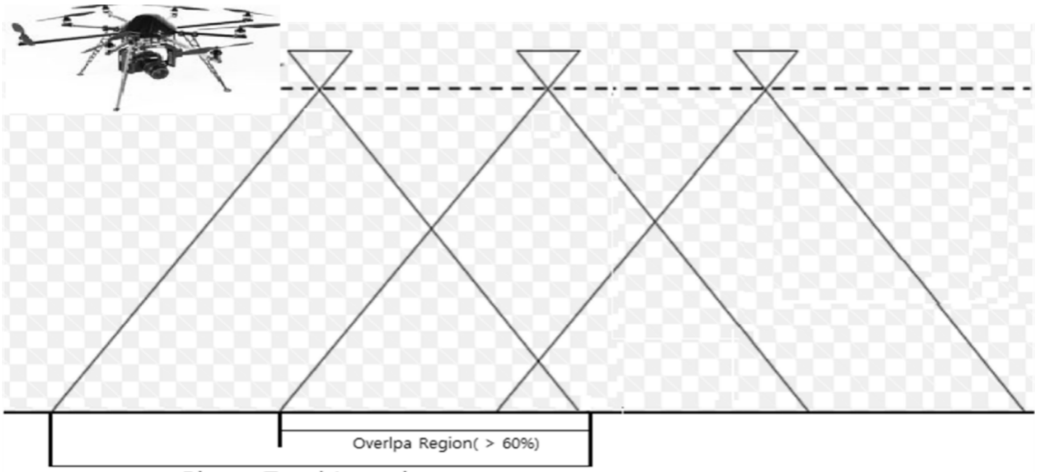

Figure 3. Schematic Diagram of the Drone Surveying Concept [17]

To improve geo-referencing accuracy, fourteen Ground Control Points (GCPs) were strategically placed over the study region, as depicted in Fig. 4, increasing the precision of the survey data [18]. The GCPs were located with a kinematic Global Navigation Satellite System (GNSS) receiver, whose coordinates are listed in Table 2.

Table 2. The Rectangular Coordinate of Ground Control Points

UTM zone 38N / WGS84			
G.C.Ps	E_m	N_m	$Elv._m$
G.C.P1	578636.915	3595682.704	20.195
G.C.P2	579085.688	3595698.148	20.007
G.C.P3	578901.616	3595702.315	20.998
G.C.P4	578655.557	3595847.609	20.077
G.C.P5	578869.498	3595847.721	21.007
G.C.P6	578765.806	3595862.409	20.334
G.C.P7	579209.173	3595883.247	20.830
G.C.P8	578909.248	3595933.788	20.644
G.C.P9	578842.881	3596127.411	20.985
G.C.P10	578907.836	3596140.854	19.393
G.C.P11	578696.985	3596157.064	19.812
G.C.P12	579083.560	3596183.975	19.910
G.C.P13	578973.439	3596384.651	20.196
G.C.P14	578685.380	3596574.358	20.692

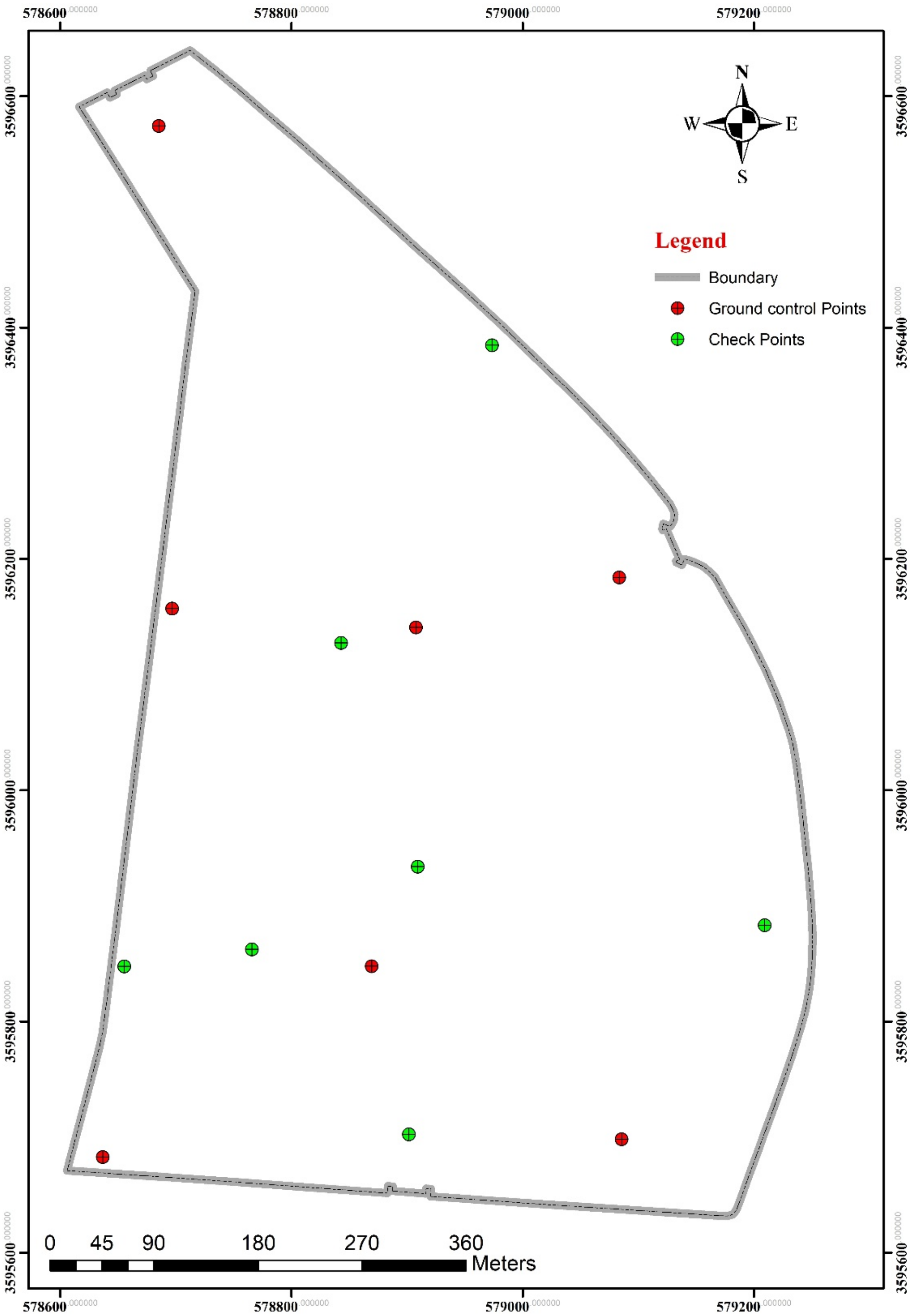

Figure 4. Survey Control Points Distribution.

To generate the orthophoto map of the college campus, a total of 652 aerial photographs were captured. A sample of drone images of the research region is portrayed in Fig. 5.

Figure 5. Sample of Drone Images.

4.2. Data Pre-Processing

The first step in processing raw drone photos is transferring the images to a computer once the mission has ended. Following their storage in JPEG format, we assessed the quality of every image. During a flight operation, variations in altitude can cause image defects, such as blurriness and color imbalance. For this research, all captured images were imported into Agisoft software, with the default image coordinate system set to WGS84. Here, adequate overlap between multiple aerial photos is essential for successful processing in Agisoft, as it ensures accurate image matching and high-quality orthophoto generation. The output coordinate system was automatically recognized based on the image geolocation. Technically, the software will search for corresponding points, match photographs, and simultaneously pinpoint the exact position of each image. This image processing task adheres to a standard 3D Maps processing template, aiming to produce a high-resolution digital orthophoto model. To begin, GCPs were imported, and the default parameters of the geospatial map template were used for preliminary processing. This photogrammetric procedure is used to create an orthophoto map.

4.3. Orthophoto Generation

An image overlap of 80% was achieved during data collection, effectively covering the research region. The data collection was found to be sufficiently precise for use in aerial mapping.

Using Agisoft Metashape, the images were processed to generate the final orthophoto map. Fig. 6 illustrates the orthophoto map of the research region. Note that determining the quality of the output requires defining a specific parameter. One of the characteristics of image processing is the creation of key points. These points signify unique places inside the image. In this investigation, a multitude of key points are produced for each image. Correspondingly, the areas of image overlap can be identified by matching key points, known as tie points, representing the same regions across different photographs. Matching picture pairings is the next option, specifying the type of photo pairings that align with the key points. Following the aerial grid technique, images are arranged in a grid or corridor flying pattern. Consequently, we densified the point clouds to improve spatial representation quality.

Figure 6. High-Resolution Orthophoto Map Depicting the Detailed Features of the Study Area.

To evaluate the positional accuracy of the generated orthophoto, the Root Mean Square Error (RMSE) was calculated based on seven checkpoints, as portrayed in Fig. 4, with coordinates measured using a kinematic GNSS receiver [19]. The discrepancies between the RTK-GNSS coordinates and those derived from the orthophoto are summarized in Table 3. The formulas used for the accuracy assessment are as follows [20]:

Table 3. Discrepancies Between RTK-GNSS and Orthophoto-Derived Coordinates.

	GNSS Coordinates		Orthophoto Coordinates		Residuals	
Check Points	E_m	N_m	x_m	y_m	V_x	V_y
G.C.P3	578901.616	3595702.315	578901.689	3595702.242	0.073	-0.073
G.C.P4	578655.557	3595847.609	578655.489	3595847.549	-0.068	-0.060
G.C.P6	578765.806	3595862.409	578765.7387	3595862.475	-0.067	0.066
G.C.P7	579209.173	3595883.247	579209.2469	3595883.313	0.074	0.066
G.C.P8	578909.248	3595933.788	578909.1795	3595933.714	-0.069	-0.074
G.C.P9	578842.881	3596127.411	578842.9502	3596127.353	0.069	-0.058
G.C.P13	578973.439	3596384.651	578973.3664	3596384.710	-0.073	0.059

$$V_x = x_{UAV} - E_{GNSS} \tag{1}$$

$$V_y = y_{UAV} - N_{GNSS} \tag{2}$$

$$RMSE_x = \sqrt{\frac{\sum {V_x}^2}{n}} \tag{3}$$

$$RMSE_y = \sqrt{\frac{\sum {V_y}^2}{n}} \tag{4}$$

$$RMSE = \sqrt{{RMSE_x}^2 + {RMSE_y}^2} \tag{5}$$

where x_{UAV} and y_{UAV} are the coordinates derived from the orthophoto, E_{GNSS} and E_{GNSS} are the GNSS-observed eastings and northings, V_x and V_y denote the residuals in the *X* and *Y* directions, and n is the number of GCPs used. The calculated RMSE values were 7.04 cm in the *X*-direction and 6.53 cm in the *Y*-direction, resulting in an overall RMSE of 9.60 cm, indicating high positional accuracy suitable for precise aerial mapping.

4.4. Analysis of Urban Forms

The incorporation of GIS technologies and drone systems has revolutionized urban planning methodology in numerous places around the world. Over the past few years, drones have become popular due to their ability to capture high-resolution aerial imagery and provide data collection in both an economical and non-invasive manner. This strategy has proved to be helpful to city planners in terms of grasping the dynamics of the built environment, identifying problem areas and sober decision-making in relation to land use and expansion [21]. The purpose of the urban form analysis is to examine the university campus with respect to buildings, roadways and land use. The physical structure of this urban form was analyzed using the orthophoto map previously obtained based on GIS databases and visualization. Subsequently, we cross-checked the results of the data-driven methodology with those of the overlay method used to analyze the structures of urban form.

5. Result and Discussion

The positional accuracy of the orthophoto was evaluated based on GCPs, resulting in high accuracy suitable for detailed aerial mapping. The results confirm the reliability of the data for urban planning and land use analysis.

Note that every object in the orthophoto is precisely geo-referenced to its coordinates. Since the low-altitude survey will produce data with a better resolution, drone-based photography improves feature clarity compared to satellite remote sensing methods. Given that it is possible to take direct measurements of features on the orthophoto, it is an ideal base map.

The orthophoto serves as an accurate base map and as a wealth of data. The fundamental components can be digitized by hand or automatically extracted using state-of-the-art computer vision techniques. Urban planners and resource allocators have found enormous success with GIS-drone technology's potent spatial analysis capabilities. Fig. 7 illustrates the topographic map of the region, depicting the three primary components: roadways, land use, and buildings. The urgent need for meticulous land use planning to identify new urban growth zones has been heightened by the rapid depletion of land. Drones will be a fantastic tool for creating detailed 3D models of cities, which will greatly assist in comprehending the complexities of smart city infrastructure.

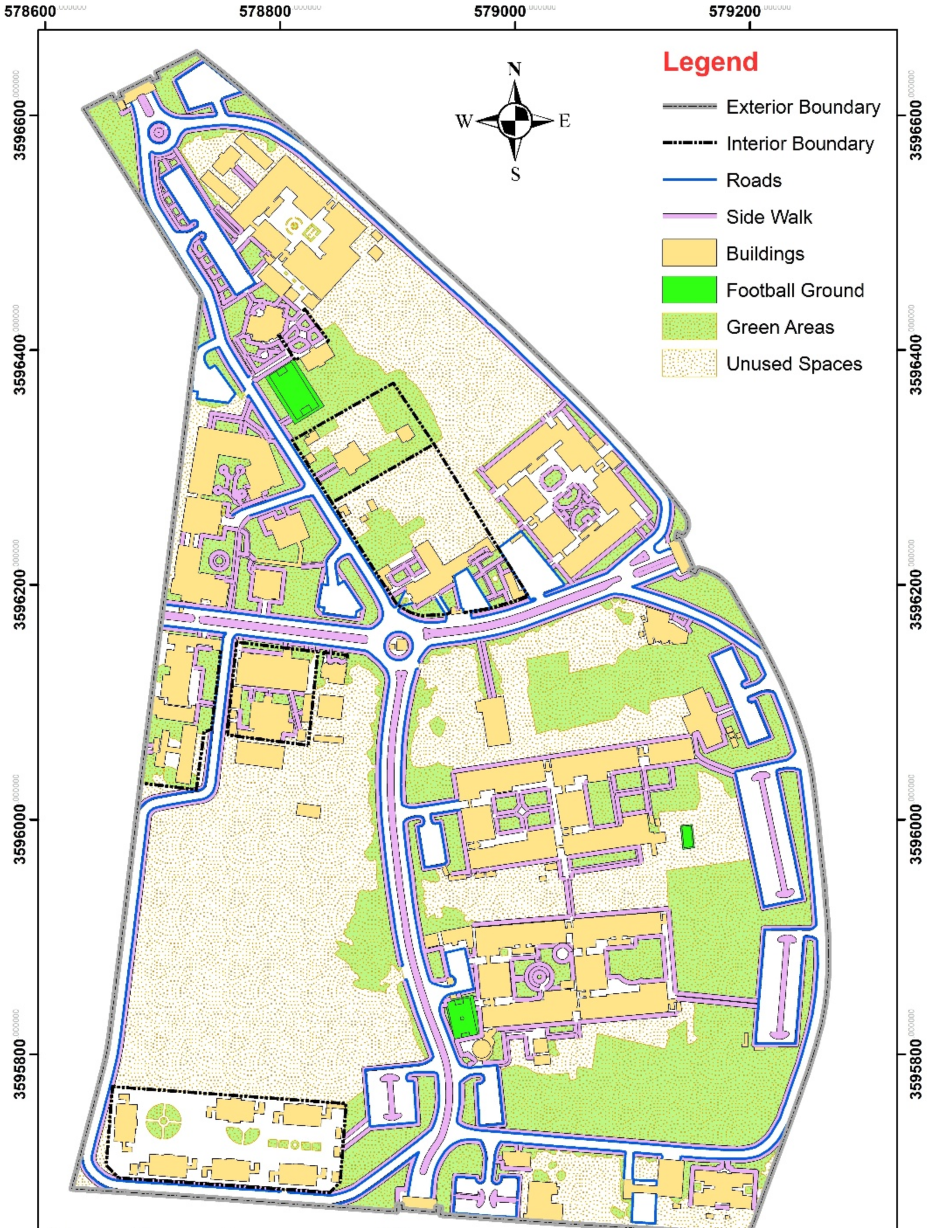

Figure 7. The Topographic Map of the Region, Depicting the Three Primary Components: Roadways, Land Cover, and Buildings.

6. Conclusions

The present study was able to generate high-resolution orthophoto maps of the university campus using the combination of UAV-based aerial imagery and GNSS-surveyed control points with an estimated position accuracy measure of 9.60 cm RMSE. The subsequent topographic maps, which are enriched with information on land use, reflect the high potential of using UAV technology coupled with GIS in planning urban areas. Although the existing issues concerning data processing and environmental circumstances exist, the method will offer an economical and flexible alternative to conventional mapping techniques. From a future perspective, it is imperative that future studies introduce some machine learning and AI features to streamline the UAV-GIS technologies application in terms of automating feature analysis and data processes to enhance the development of smart cities. Overall, the study would be a good guide to researchers and professionals who demonstrate interest in adopting the UAV-GIS technologies in order to build sustainable and efficient urban development.

Declaration of Competing Interest

The author declares no conflict of interest.

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Data Availability Statement

Data are available from the author upon reasonable request.

Author Contributions

The author independently identified the research problem and conducted the entire study and preparation.

Notation list

Abbreviations	Meaning
AI	Artificial Intelligence
GCP	Ground Control Point
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
LiDAR	Light Detection and Ranging
RMSE	Root Mean Square Error
UAV	Unmanned Aerial Vehicle
UTM	Universal Transverse Mercator coordinate system
WGS84	World Geodetic System 1984

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