IIETA International Information and Engineering Technology Association
Advancing the World of Information and Engineering

Traitement du Signal
Vol. 41, No. 3, June, 2024, pp. 1473-1483
Journal homepage: http://iieta.org/journals/ts

Images Processing of Unmanned Aerial Vehicle (UAV) for Cannabis Identification

Yomi Guno[1,2], Muhammad Yudhi Rezaldi[3,4*], Fadjar Rahino Triputra[1], Ridwan Suhud[3], Arafat Febriandirza[3], Apid Rustandi[5], Aang Gunawan Sutyawan[6], Syahrul[7], Irfansyah Yudhi Tanasa[1], Guno Wicaksono[8], Alberto Leonardus[8], Karyawan[9,10], Widyawasta[11,12], Frandi Adi Kaharjito[1], Abid Paripurna Fuadi[13], Asyaraf Hidayat[1], Mukti Wibowo[7], Yohanes P.D.S. Depari[5], Dwi Raharjo[14], Rudiyono[8]

[1] Research Center for Electronics, National Research and Innovation Agency (BRIN), Bandung 40135, Indonesia
[2] School of Electrical Engineering and Informatics, Bandung Institute of Technology, Bandung 40116, Indonesia
[3] Research Center for Data and Information Science, National Research and Innovation Agency (BRIN), Bandung 40135, Indonesia
[4] Visual Communication Design, Faculty of Creative Industries, Telkom University, Bandung 40257, Indonesia
[5] Research Center for Transportation Technology, National Research and Innovation Agency (BRIN), Tangerang Selatan 15314, Indonesia
[6] Center for Data and Information, National Research and Innovation Agency (BRIN), Jakarta 10340, Indonesia
[7] Research Center for Artificial Intelligence and Cyber Security, National Research and Innovation Agency (BRIN), Bandung 40135, Indonesia
[8] National Narcotics Board of Republic of Indonesia (BNN), Jakarta 13630, Indonesia
[9] Directorate of Laboratory Management, Research Facilities, and Science and Technology Park, (BRIN), Tangerang Selatan 15314, Indonesia
[10] Department of Mechanical, Diponegoro University, Semarang 50275, Indonesia
[11] Research Center for Aeronautics Technology, National Research and Innovation Agency (BRIN), Rumpin 16350, Indonesia
[12] Mechanical Engineering Dept, Sepuluh November Institute of Technology, Surabaya 60111, Indonesia
[13] Research Center for Hydrodynamics Technology, National Research and Innovation Agency (BRIN), Surabaya 60112, Indonesia
[14] Research Center for Process and Manufacturing Industry Technology, National Research and Innovation Agency (BRIN), Tangerang Selatan 15314, Indonesia

Corresponding Author Email: myud001@brin.go.id

Copyright: ©2024 The authors. This article is published by IIETA and is licensed under the CC BY 4.0 license (http://creativecommons.org/licenses/by/4.0/).

https://doi.org/10.18280/ts.410335

Received: 22 August 2023
Revised: 18 March 2024
Accepted: 2 April 2024
Available online: 26 June 2024

Keywords:
cannabis, image processing, Orthomosaic, photogrammetry, UAV, visual analytics

ABSTRACT

This research purpose is to find new effective ways to search cannabis fields where there is an illegal plant in Indonesia. The remote sensing method was used, initial identification coordinates of the suspected area using satellite imagery, but due to limited image resolution it was not possible to analyze details in a small area, so it was continued by taking aerial photos using the Unmanned Aerial Vehicle (UAV) of Quantum Trinity F90+ on the coordinate point. The results of data processing aerial photos from UAV were analyzed using visual analytics, to obtain coordinate points that were positively suspected cannabis fields. For validation, the DJI Matrice 300 RTK drone is flown equipped with a camera that can zoom very well on suspected objects, so it can be ascertained whether the positive object on the coordinate point is cannabis or not. From UAV succeeded in finding 19 coordinate points suspected of cannabis fields, but after validation using a zoom camera drone, it was confirmed only 11 locations positive for cannabis fields. This research is very helpful for law enforcement officers who are tasked with destroying cannabis fields, ensuring the shortened time and discovery at the positive coordinate target point, when compared with the traditional methods they have used the whole time.

1. INTRODUCTION

Image processing, a cornerstone technique in the digital signal processing domain, enables the transformation and analysis of image data captured by cameras or sensors on various platforms, including spacecraft, airplanes, satellites, and even everyday devices. This field's expansive utility spans remote sensing, robotics, medical imaging, and satellite communications, facilitating advancements through techniques such as image enhancement, analysis, compression, and reconstruction [1-5]. Despite its broad applications, the novelty of our study lies in harnessing image processing within the context of UAV technology for a highly targeted application: the detection of cannabis cultivation areas in Indonesia, where cannabis remains an illegal substance [6-9].

The urgency and importance of this research are underscored by the challenges faced in cannabis detection - a critical task given the plant's illegal status and its associated psychotropic effects. Traditional ground surveys have proven inefficient, posing risks to personnel and yielding limited coverage. This study introduces a novel UAV-based approach, employing the EVTOL Trinity F90+ for initial identification and the DJI Matrice 300 RTK for validation, leveraging photogrammetry and visual analytics to map, search, and identify cannabis fields with unprecedented accuracy and efficiency.

Our research objectives are twofold: firstly, to develop and validate an effective UAV-based methodology for cannabis detection, and secondly, to demonstrate how image processing techniques can be optimized for this purpose. Through a collaborative effort between the National Narcotics Agency (BNN) and the National Research and Innovation Agency (BRIN), we offer a comprehensive solution that not only advances the field of image processing applications but also addresses a pressing legal and social issue.

This paper contributes to the current state of knowledge by providing a clear methodology for the application of UAV technology in law enforcement and crop monitoring, particularly in contexts where traditional methods fall short. By delivering a detailed account of our approach, from the photogrammetric processing of UAV-captured images to the visual analytics employed for identifying cannabis cultivation sites, we lay the groundwork for future innovations in the field.

Moreover, the relevance of our study extends beyond the technical community to policymakers, law enforcement agencies, and agricultural regulators, offering them a novel tool for addressing challenges in drug control and agricultural monitoring. As such, this paper not only enriches the academic discourse on image processing and UAV applications but also serves a pivotal role in societal efforts against illegal cannabis cultivation.

In summary, our research marks a significant step forward in the application of image processing techniques for UAV-based detection tasks, setting a new benchmark for efficiency, safety, and accuracy in cannabis detection efforts. Through this work, we aim to inspire further exploration and application of UAV technology in both academic and practical fields, contributing to the advancement of remote sensing and aerial surveillance technologies.

2. LITERATURE REVIEW

Cannabis is a genus of the Cannabaceae family of flowering plants. All parts of this plant (fruit, seeds, straw, leaves, and their products), including cannabis resin and hashish, are a type of narcotic type 1 prohibited for use and trade, even for medical purposes [9]. Narcotics are substances or drugs derived from plants or chemical compounds, both synthetic and semi-synthetic, which have the effect of reducing consciousness, losing taste, reducing and even eliminating pain, and can cause addiction [10-14].

Tetrahydrocannabinol (THC) is a substance in Cannabis that, if smoked like a cigarette, can have specific long-term and short-term effects. In the short term, it can reduce the level of body consciousness, changes of consciousness to the time, changes in vision or hallucinations, mood swings, psychiatric disorders, breathing problems, increased heart rate, fetal problems in pregnant women, and a sense of nausea and vomiting [15]. At the same time, long-term effects can affect brain development, such as the decreased ability to think, remember, and socialize with the environment. According to research, an active Cannabis smoker in adolescence with an age range of 13 years will have a sense of addiction and have a decrease in IQ of around 8 points on average, and would not experience a return to IQ even though they had stopped smoking Cannabis cigarettes. However, adults aged 38 did not have a marked decrease in IQ [16].

Some previous research literature has shown that UAV and satellite imagery have been used in various countries for legal and illegal crop analysis purposes. These include using quad-rotor UAVs to track the presence of wild animals in oil palm plantations [17]. Using LiDAR mounted on UAV to map and survey biomass from agricultural fields, monitor illegal logging, and use fixed-wing eVTOL to monitor illegal logging in Peru [18]; meanwhile, mapping and eradicating Silybum marianum weed in crops using the multispectral camera on a UAV [19]. Creating weed cover maps through a machine learning approach to UAV-generated image data using the Full Convolutional Network (FCN) method [20] and using Machine Vision algorithms to recognize and count cotton boll candidates from RGB images acquired from UAV [21]. Research in Morocco uses satellite imagery via EO-1 Hyperion hyperspectral data and uses Spectral Angle Mapper (SAM), through hyperspectral imagery it can distinguish cannabis plants from several types of vegetation around them. However, small spatial samples from many fields in the research area produce many mixed pixels which reduced pixel-based classification accuracy for 30m spatial resolution in Hyperion [22]. Research in Turkey used remote sensing in the form of high-resolution image data from the PlanetScope satellite to monitor cannabis growing areas, then analyzed using a machine learning algorithm, so that it could differentiate between cannabis and non-cannabis plants. This research has high accuracy, namely more than 93%. However, the spatial resolution of satellite image data is very limited, so in small areas, it cannot be detected. Therefore, in the future, the use of UAV (Unmanned Aerial System) can provide higher spatial resolution so that it can detect small areas [23, 24]. Research in Brazil, using IKONOS satellite imagery (remote sensing images) with a data-based ensemble method to detect cannabis plants in the Brazilian region. This method is successful in finding the location of cannabis plants and can correct acquisition errors so that it finds the best representation to distinguish cannabis plants from non-cannabis plants. However, in this research there were still several locations that were initially detected as positive for cannabis fields, but after further checking they turned out to be fake [25]. Using Spy Drones to detect and mark illegal plants for law enforcement, through Machine Learning or Deep Learning algorithms can classify and identify images of cannabis plants, however, the range and height of Spy Drones are very limited so they cannot be controlled from a very long distance [26]. Turkish security forces have equipped coast guard officers with UAV/drones, to be used to track and arrest drug smugglers by sea. This method has been successful in thwarting the smuggling of 1.5 tons of cannabis off the coast of Syria. This success has made Turkey one of the pioneers of new drone technology, namely the Bayraktar model, and this technology has been exported to several other countries such as Syria, Libya, and Azerbaijan. However, this method has not been used to search for cannabis fields [27]. From another perspective, for states that legalize cannabis such as Colorado, California, and Oregon. It turns out that UAV/Drones can be used as hydrostatic sprayers for the prevention and remediation of fungus on cannabis plants and help cannabis farmers identify male plants to support harvest optimization to increase tetrahydrocannabinol (THC) levels [28].

To obtain aerial photo data from the location of cannabis plants, Photogrammetry techniques are used, it is the art, science, and technology of deriving information on spatial or geometric measurements of a physical object and the environment based on a series of images through the process of recording, measuring, and interpreting photographic images and patterns of electromagnetic radiation energy and other phenomena [29, 30].

The collection of photo images from the photogrammetry technique is then further processed to be assembled/stitched into one unit better known as an Orthomosaic, it is a set of overlapping images that have been photogrammetrically corrected, where geometric distortions between the sensor and the object or terrain have been converted to a uniform scale and the images color-balanced to produce a seamless mosaic of datasets [31, 32].

The Orthomosaic results from the mapping will then be analyzed in plain view using visual analytics methods, it is an approach using data analysis and visualization to solve problems based on the observation and reasoning of an object against a visual representation of the human eye perception, computational transformation, and other visual analytical tools, including visual interface interaction and interaction techniques so that it can be used as a basis for making decisions and further planning [32-34].

3. RESEARCH METHOD

This research method begins with determining the location to be observed or the area of interest (AIO), then observing the area visually analytically by using Google Earth. Next, the unmanned aerial vehicle is flown for mapping and photogrammetry. The photogrammetry results from the mapping are processed to be assembled into an Orthomosaic, and this is continued by conducting visual analytics observations of the Orthomosaic results of the location suspected of being a cannabis field to be determined at the coordinate point. Then the drone is flown with a camera that can zoom toward the coordinate point of the suspected location. The results of the alleged location are monitored for visual analytics validation, and then the extermination of positive areas is performed. Figure 1 shows the sequence.

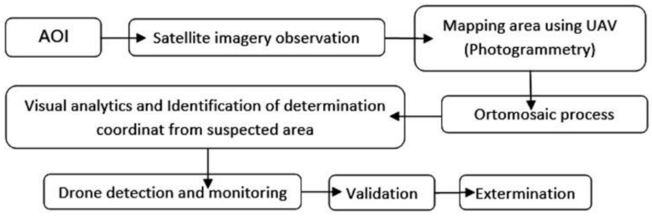

Figure 1. Research methods

Comprehensively, the methodology adopted for UAV-based mapping of cannabis cultivation areas focuses on the technical specifications of the UAV platform used and the strategic planning required to overcome the challenges posed by mountainous terrain.

The study employs two distinct UAV systems: the Trinity F90+ eVTOL fixed-wing UAV, equipped with a SONY RX1R II (RGB) 42MP camera, and the DJI Matrice 300 RTK drone. These platforms were selected for their complementary capabilities in wide-area surveillance and detailed inspection.

Trinity F90+ eVTOL Fixed-Wing UAV: Known for its extended endurance and broad coverage, the Trinity F90+ is outfitted with the high-resolution SONY RX1R II (RGB) camera. This setup is ideal for initial broad-area surveillance, offering detailed imagery crucial for identifying potential cannabis cultivation sites across vast landscapes.

a. Flight Time: Up to 90 minutes, facilitating extensive area coverage.

b. Coverage: Capable of surveying up to 700 hectares per flight.

c. Camera: SONY RX1R II (RGB) 42MP camera, providing high-quality, detailed images.

DJI Matrice 300 RTK Drone: Utilized for its precision and versatility, the Matrice 300 RTK is equipped with advanced positioning technology and can carry various payloads, making it perfect for close inspection and validation of identified sites.

a. Flight Time: Up to 55 minutes, suited for detailed inspection tasks.

b. Navigation Accuracy: RTK module ensures high precision in flight and image capture.

Mapping cannabis fields in Aceh's mountainous regions, with altitudes of 2000-3000 meters above sea level, introduced unique challenges, including unpredictable weather, varying wind speeds, and complex topography. These factors necessitated meticulous flight mission planning and monitoring using QBASE 3D GIS software.

Flight Mission Planning: Safety and moderate flight time were prioritized, recommending an altitude of 300-400 meters above ground level with a flight time below 48 minutes. Innovative flight path strategies, such as loiter and zigzag techniques, were employed to optimize flight time and ensure comprehensive area coverage.

Navigational Complexities: The rugged terrain and varying vegetation height posed significant maneuverability and communication challenges, impacting flight paths and data transmission. Strategic planning also addressed visual obstructions by clouds and the potential for blurred images due to the terrain's contours.

This methodology demonstrates the critical role of UAV technology in overcoming the challenges of mapping in complex environments. By leveraging the unique capabilities of the Trinity F90+ eVTOL and DJI Matrice 300 RTK drones, combined with strategic flight planning, this study advances the application of UAV-based photogrammetry in agricultural and environmental research, particularly in the detection of illegal cannabis cultivation.

Data Acquisition, Processing and Photogrammetry, Analysis, Visual Analysis and Image Analysis, and Validation, in UAV-Based Photogrammetry a comprehensive methodology was explored to be adopted in detecting and mapping cannabis cultivation areas using UAV-based photogrammetry and visual analysis. This guide outlines a step-by-step approach to data acquisition, processing, analysis, and validation, highlighting the tools and techniques used to ensure accuracy and reliability.

Data acquisition was conducted using two UAV platforms:

the Trinity F90+ eVTOL fixed-wing UAV equipped with a SONY RX1R II (RGB) 42MP camera for broad-area surveillance, and the DJI Matrice 300 RTK drone for detailed inspection. The Trinity F90+ was deployed to capture high-resolution, georeferenced imagery across extensive areas, while the Matrice 300 RTK was used for targeted inspection of identified sites.

Flight Planning: Utilized QBASE 3D GIS software for meticulous mission planning, focusing on optimal flight paths, altitudes, and times to navigate the challenging mountainous terrain effectively.

Data Capture: Employed the SONY RX1R II camera on the Trinity F90+ for capturing detailed RGB imagery and the DJI Matrice 300 RTK for close-up inspections with its advanced sensor payloads.

Data Processing and Photogrammetry, upon data acquisition, the imagery underwent processing using photogrammetry software to construct accurate, detailed Orthomosaic maps of the surveyed areas.

Software: Agisoft Metashape was selected for its robust capabilities in processing high-resolution images into precise Orthomosaic.

Process: Images were aligned to create a dense point cloud, from which a digital surface model (DSM) and Orthomosaic map were generated. This process involved rigorous calibration to correct for any geometric distortions and ensure uniform scale and orientation.

Visual Analytics and Image Analysis were applied to the processed imagery to identify and classify cannabis cultivation areas accurately. The analysis process involved segmenting the Orthomosaic maps into manageable sections, applying the classification models to each segment, and overlaying the results on the base map for visual inspection and further analysis.

Validation Methods, for validation of the identified cannabis cultivation areas was conducted through a combination of ground truthing and expert review.

Ground Truthing: Selected areas identified as potential cannabis cultivation sites were visited in person or inspected using the DJI Matrice 300 RTK drone for close-up validation, comparing the UAV-derived data with actual conditions on the ground.

Expert Review: Satellite imagery and inputs from local experts in agriculture and law enforcement were also employed to cross-verify the UAV findings, ensuring the accuracy and reliability of the identification process.

Criteria for Validation: Validation was based on specific criteria, including the presence of distinctive cannabis plant features, consistency with known cultivation patterns, and correlation with environmental conditions conducive to cannabis growth.

By integrating advanced UAV technology with sophisticated data processing, visual analytics, and rigorous validation procedures, this methodology presents a robust framework for the accurate and efficient detection of cannabis cultivation areas.

4. ANALYSIS

The Area of Interest (AoI) selection process is based on information from intelligence agencies and the history of previous ground surveys performed by the BNN, the Indonesian National Police, and the Indonesian National Army. In most cases, determining the area of interest is based on identifying land openings through satellite imagery. Furthermore, visual observation/analysis of the conditions in the land opening area is conducted. Preliminary observations were made of artificial objects, such as semi-permanent structures in huts, water reservoirs, fences, and others. The following observation included environmental conditions.

Further observations included natural conditions, especially the flow of the surrounding water around the cleared area. The distance between residential areas and the location of open land is also a consideration; since Cannabis is a prohibited plant, it is like cannabis growers hide the plants' location to avoid being easily discovered by other people/residents. Any land openings that meet some of the above criteria will then be determined as Areas of Interest.

Observation of the AoI is conducted through visual analysis by identifying objects in satellite imagery through Google Earth. There are limitations in conducting visual analysis through accessible satellite imagery, i.e., the limited resolution of satellite imagery cannot provide definitive information related to the visualization of cannabis plants, considering the size of cannabis plants is not too large. Therefore, observations are not made directly on cannabis plants but on other objects, usually in a cannabis field.

In this research, mapping of the area was performed with photogrammetry techniques using the Trinity F90+ - eVTOL fixed-wing UAV, the use of the UAV in general for mapping has been widely practiced because of their accurate results, shorter time used, and compact operation. In contrast to mapping in plantation areas, cannabis fields in Aceh were implemented in mountainous contours with altitudes ranging from 2000-3000 meters above sea level. According to the mission experiences, the typical contour tends to be challenging to predict due to the fast-changing weather and winds that blow above the eVTOL capability. Also, the region's natural vegetation is unpredictable in height based on sea level and above ground. In more detail, the valley and cliff contours make it difficult for eVTOL to maneuver during take-off to climbing and returning to landing. Moreover, communication data is often lost due to contour differences. In terms of photo results, clouds often block the photo results, and cliff sides produce blurred/parallax photos.

Mapping flight mission planning and monitoring is implemented using the geographical information system (GIS) software QBASE 3D.ver.2.30.77. In the planning phase, determine the take-off and landing positions simultaneously. In addition, the mission flying altitude is determined from various aspects such as safety, photo quality or graphic sample distance (GSD), flying time, and coverage area. For mountainous areas, safety and moderate flight time are preferred. Therefore, an altitude of 300-400 above ground level and a flight time below 48 minutes is recommended.

As for the flight plan climbing path to mission/return can use loiter, zigzag technique, and a combination of both; refer to Figure 2.

(a) loiter (b) zigzag (c) combination

Figure 2. Illustration of climbing path technique to the mission area

A loiter is used if the climbing area is close to the line of sight and is more straightforward. However, this option drains the battery, accelerates the motor temperature to rise, and takes relatively more time. Conversely, the zigzag technique is used if a loiter shortcoming needs to be avoided because the climbing path to the mission/return area is broader and farther away from the home base. Therefore, the loiter and zigzag combination effectively optimizes flight time.

Other technically important matters include determining the "safe return path" required during emergencies where signal loss has exceeded a specified limit and when the system automatically selects the return to base (RTB) based on the last location.

Contours and weather are the biggest obstacles in carrying out mapping missions. The contour of the operation area will determine the location of the nearest home base. During this mission, the home base location must meet the following criteria: accessibility, open airspace, utility, minimum distance, and safety. Accessibility is how the home base can be accessed using a car, and eVTOL has obstacle-free airspace. Additionally, the take-off and landing areas must be accessible in case of a crash. Utilities are the readiness of power sources, water sources, and shady places because the mission is carried out within 7-8 hours. The distance from the home base to the furthest point of the mission area is at most 5.5 km. The best time to fly is from 08:00 to 11:00. Flight time below 8 AM has a risk of fog that contains much water that can clog the pilot as shown in Table 1. Meanwhile, flight and mapping missions are at risk of strong winds and rain above noon.

Table 1. Summary of the best settings for eVTOL operation in mountainous areas

Item	Recommendation Home Base Criteria	Note
Place	An open field, such as a soccer field	The minimum requirement is to use a volleyball court, providing enough space for the aircraft to maneuver. Accessible by car
Time to start	08:00-11.00 and 13:00-16:00	<08:00 fog clogs the pilot, and the mountain peaks are still covered with clouds. Noon frequent rain
Wind speed	2-5 m/s	Moderate
Link loss	2400 s	Keeping up with flight time
Hover/ landing altitude	40 m	Maximum allowed
Homebase distance	4-5.5 km	Risk of loss of signal
Altitude and GSD	300-400 m (GSD 4-5.5 cm/px)	Above ground level
Flight time	45-48 minutes	
Climbing path	Combination	Loiter and zigzag
Loiter radius	120 m	<120 m, hot temperature motor
Safer return path	300-450 m	The aircraft will be cruising at a constant altitude

4.1 Image processing (Orthomosaic)

In the image processing stage, to produce this Orthomosaic image, the steps taken to start with the process of geotagging the photo, aligning the picture, building the dense cloud, building mesh, building texture, building DEM, building Orthomosaic, generating the report, as shown in Figure 3.

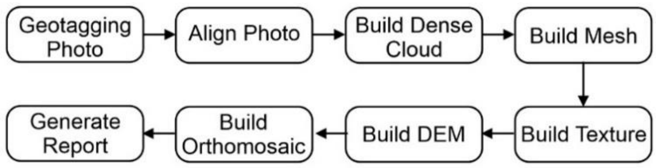

Figure 3. Image processing flow for building Orthomosaic image

4.2 Geotagging photo

The aerial photo images from the photogrammetry process are then processed by geotagging, which provides GPS data position information in the form of the latitude and longitude from a digital photo (reference) using QBase 3D software, which is compatible with the Trinity F90+ UAV. The figure below (Figure 4 and Figure 5) shows an example of the mapping results' aerial photo and an illustration of the geotagging process with QBase 3D software.

The total aerial photos processed by geotagging from 6 missions is 41,403 (Forty-one thousand four hundred and three), with a full aerial photo file size of 1,409.48 GB. Figure 4 shows the examples of aerial photos. The resolution used is 5.2 cm/pixel with a scale of 1:1; the file size varies according to the area of the aerial photos taken. Digital Elevation Model (DEM) Photo File Size with medium settings as shown in Figure 4, TIFF format. The Orthomosaic photo file size with a medium set of about 5 GB or more is adapted to the number and size of the photos, as seen in Figure 5.

Figure 4. Example of aerial photo results

Figure 5. Geotagging process using QBase 3D

Furthermore, the aerial photo image results that have been geotagged are then processed further through Orthomosaic image processing. This process is executed with two image quality results: medium and highest. The computer specifications used for processing are also different, as shown in Table 2.

The stages of processing aerial photos through image processing to build Orthomosaic images were made using Agisoft Metashape software as shown in Figure 6, with steps as described below:

Table 2. Computer specifications for image processing (Orthomosaic)

Image Output: Medium	Image Output: Highest
Laptop Advance	High-Performance Computer (HPC)
CPU: Intel Xeon W-11855M @ 3,2 GHz (12 CPUs)	CPU node HPE Apollo r2200 (Intel(R) Xeon(R) CPU 2.10GHz) consists of 28 nodes, 1008 cores, and 3.5 TB total memory (128 GB/node)
RAM: DDR4 3200MHz 64 GB GPU: Nvidia Quadro RTX A4000 8 GB Storage: SSD NVMe 1 TB	GPU Node HPE DL 380 Gen 9(Intel(R) Xeon(R) CPU E5-2695) consists of 4 nodes, 144 cores CPU, Tesla P100 GPU dan 2 TB total memory (512 GB/node)

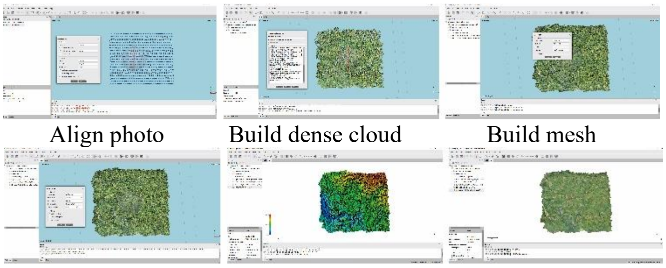

Figure 6. Data processing using Agisoft Metashape

(a) Align photo: The initial photogrammetry process is adding aerial images to the Agisoft Metashape application and then processing the aligned photos. The application will find each photo's camera position and orientation at this step and then build a sparse point cloud model.

(b) Build dense clouds: To generate and visualize thick point cloud models. Based on the camera positions, the Agisoft Metashape app calculates the depth information of each camera and then combines them into one dense cloud.

(c) Build mesh and build texture: These are optional if creating a 3D model is necessary. Both stages can be skipped if we only need 2D imagery. Based on the point cloud information (Dense Cloud, Sparse Cloud, Point Cloud uploaded from external sources), Agisoft Metashape can reconstruct a polygon-mesh model. The 3D model or mesh is one of the main outputs of aerial photo processing in Agisoft. The 3D model is later used to create DEMs, DSM and DTM, and orthophotos. The texture mode determines how the texture object will be displayed. Choosing the proper texture mode helps to get better visual quality in the final model.

(d) Build DEM: Based on Dense Cloud, Sparse Cloud, or Mesh. The best result is to use a dense point cloud. Moreover, Metashape also allows users to measure distances, calculate areas, calculate volumes, create cross sections or profiles by users, and generate contour lines.

(e) Build Orthomosaic: Orthomosaic is a combined image created by seamlessly merging the original pictures projected on the object's surface and transforming them into the selected projection. A polygonal model (mesh) or a digital elevation model can be selected as a surface to which the images will be projected. Metashape allows using one of the following projection types: Geographic, Planar, or Cylindrical. Geographic projection is the typical task of creating an Orthomosaic in a geographical coordinate system. Planar projection allows for selecting arbitrary orientations of the projection plane, which is helpful for projects concerning facades or other non-horizontal surfaces. A cylindrical projection type can be used to minimize distortions for objects of a cylindrical shape, like tubes, round towers, and tunnels.

(f) Generate report: This is the process of making a record of the work done in building a 3D Orthomosaic in the form of a detailed description of each operation carried out, such as the number of photos, the calibration process, the settings of each cycle, the total amount of work time, software and hardware used.

4.3 Results of Orthomosaic image

The results are DEM (Digital Elevation Model) image data files in TIFF format and Orthomosaic image data files in TIFF (Big TIFF) format. Figure 7 shows an example of the Orthomosaic result. DEM is a raster grid that references the starting point of the earth's surface. Therefore, this modeling will eliminate objects on the ground, such as buildings, vegetation, and other things. The DEM model is identical to the DTM (Digital Terrain Model). The Orthomosaic image data file is a composite image created by seamlessly merging the original image projected on the object surface and converted into the selected projection. A polygonal (mesh) or digital elevation model can be chosen as the surface on which the image will be projected.

Figure 7. Example Orthomosaic results from image processing

4.4 Visual analytics and identification of determination coordinate from the suspected area

Figure 8. The suspected area and its coordinates marked

The Orthomosaic image resulting from image processing is then observed by a researcher who already understands well the signs of cannabis-planted fields by using the visual analytics method, observing signs such as artificial objects, semi-permanent buildings in the form of huts, water reservoirs, fences, natural conditions, and waterways around the land opening area. In addition, observations are also made about the character of plants in the area. ArcGIS Map software will seek information on the site coordinates if a suspected location is found as shown in Figure 8. From this coordinate point, the drone is then flown to conduct validation.

4.5 Statistical analysis for cannabis field identification

Image processing to automatically identify the Cannabis field from the acquired photo was performed prior to analyzing the result statistically. Instead of the Orthomosaic image, the photo used for statistical analysis was the unprocessed images result directly from the camera. The captured images were gathered, sorted, arranged, and annotated. A sample from one district with a total of eight flights resulting on 4941 images. These images are then processed with classical image processing approach using the step of size scaling down, color conversion, edge detection, followed by repeated thresholding, and transformation [35]. For example, the results of aerial photo processing identify as a field of cannabis as seen in Figure 9.

Figure 9. The rectangular frame showing indicated Cannabis field. The thresholding based on the surface area of the field was used to determine whether the image contain object or not for statistical analytics

Different from the study [35] the scoring matrix used on this work analysis is Recall. Recall was used with the fact that failing to detect the Cannabis field could result in much greater loss. Recall is defined as the comparation of True Positive and the actual positive sample. The statistical analysis resulting in True Positive, False Negative, False Positive and True Negative as following 183, 35, 3189, 1534 respectively, with the Recall score of 0.839449541.

4.6 Drone detection and monitoring

The type of drone used is the DJI Matrice 300 RTK which has the DJI Zenmuse H20T camera as shown in Figure 10. The advantage of the combination of DJI Matrice 300 RTK with DJI Zenmuse H20T camera is the ease of operation of the drone because there are several sensors and automatic features. The sensors on the drone increase safety in the operation of the drone. The camera used has the advantage of a stabilizer and support for zoom capabilities so that the zoom capability can be used to visually identify in more detail the cannabis plants that are located quite far from the drone. Another advantage is the speed of the drone setup; the drone can be flown from a narrow location. However, the DJI Matrice 300 RTK drone also has the disadvantage of this combination is the low flight duration; the farther and higher the drone flies, the less the flight duration will be. The limited flying distance/cruising range and the limitation of signal transmission from the remote to the drone are one of the areas for improvement; with many obstacles in the field, often when operated, the drone loses the control signal from the remote. So, for the initial mapping stage, the research team used the Trinity F90+ UAV - eVTOL fixed wing.

Figure 10. Drone DJI Matrice 300 RTK

Drone flights are carried out manually with the sensors fully turned on. The preparation stage begins with a quick assessment of the environmental conditions at the flying location to the destination. Furthermore, mark-making is carried out at the site of the flight destination and measuring the distance to the destination location. In the flight stage, the drone is flown above the obstacle, generally given a distance of about 200-300 meters from the block. However, often the drone must be passed up to an altitude of 800-1500 meters above the remote, this is due to the location of the cannabis field, which is at the top of a high mountain, and this is useful for maintaining communication between the remote and the drone so that the signal from the remote can be straight with the drone and not blocked by obstacles. After reaching the location of the flight destination, identification takes place using a camera to ensure that there is illegal cannabis cultivation in the area and to get better details; the zoom capability of the drone camera is used to achieve this.

4.7 Validation

Figure 11. Cannabis zoom-in for validation

Validation is performed manually, which is determined entirely by personnel. The personnel conducting the validation must have knowledge related to the physical form of the cannabis plant. Regarding how much the zoom level used will be adjusted to the situation, the zoom function will be increased if it is felt that the plant is too far away. The cannabis plants found will be captured for documentation needs and further analysis. A recorded video is an available feature; the need for a recorded video is not used for mapping purposes but for documentation and analysis needs to be related to the situation at the location of the cannabis field at that time. From the results of the DJI Matrice 300 RTK drone camera zoom-in the form of images or videos, the plants are validated to ensure that the plants are Cannabis as shown in Figure 11.

4.8 Extermination

Once it is confirmed that the field is planted with Cannabis, send an extermination team to the location. The implementation of the extermination of cannabis plants is carried out by burning the fields as shown in Figure 12. This extermination is conducted because considering the applicable law in Indonesia that Cannabis is an illegal plant, it is closed to the possibility of utilizing Cannabis as a product that is processed into another product. The process is uprooting cannabis plants, collecting plants that have been uprooted at a point where no other plants are around them, watering the plants with liquid fuel (diesel), and then burning them.

Figure 12. Cannabis extermination process

5. RESULTS AND DISCUSSION

From the literature review, it is concluded that aerial photo images can be produced from satellites and UAVs/drones. Both have been used to identify types of cannabis plants and other plants that are not cannabis. Especially for the cannabis plant itself, if you look at it from a country's legal perspective, some countries declare cannabis plants illegal, and several other countries legalize cannabis plants. For countries that have a legal basis that cannabis plants are illegal, images originating from satellites or UAVs are used as analysis material to determine the location and tracking of the cannabis plant fields, so that legal action can then be taken in force in that country. Meanwhile, in several countries where cannabis plants are legal, UAV/Drones are used to help farmers improve the quality of cannabis plants, such as hydrostatic spraying, and identifying types of cannabis plants.

Some of the methods that have been implemented are the use of LiDAR installed on the UAV, machine learning using the complete convolutional network (FCN) method, machine vision algorithms, the collaboration of satellite imagery and hyperspectral data, as well as Hyperion data, remote sensing data, machine learning based on NDVI spectral band values, IKONOS satellite imagery, and machine learning/deep learning algorithms. Some of these methods start from satellite images in searching for cannabis fields, which have weaknesses in image resolution, because the resulting images from satellites have low resolution so they cannot detect and be accurate for details in small areas. Meanwhile, the use of UAV drones that have been carried out in other research using UAV/Spy drones has the weakness of limited flight range, so it cannot be flown from too long a distance.

In our research, using a combination of satellite and UAV/drone images succeeded in covering these two shortcomings. Satellite images are only used to determine the coordinates of the initial location suspected to be a cannabis field. Next, the Trinity F90 + UAV - eVTOL fixed wing was flown to take aerial photo images from coordinate points that had been determined from the images. The results of data processing from the UAV (photogrammetry) have high resolution so that using visual analytics methods can identify cannabis plants even in small areas. Finally, to be more certain, validation was carried out by flying the DJI Matrice 300 RTK drone which can zoom up to 20 X, so it can be truly believed that the plant is a positive cannabis plant.

Technical UAV and drone flights after 11.00 local time are very risky because strong winds > 9m/s cause drones to often make emergency flights back home (RTH); The best time to take aerial photos is 07.00 to 11.00 local time. Considering that the wind speed at that time was around 2 to 3 m/s, there was dense vegetation. To get good aerial photoy results, we must keep the GSD below 7 cm/pixel; The recommended maximum flying height for drones is 350 meters above ground level (AGL), with a photo density of 75% for the front and 75% for the sides.

Considering the flight location in the search for cannabis plantations, which are hills and mountains, and also considering the safety of team members, in flying the Trinity F90 + UAV - eVTOL fixed wing and the DJI Matrice 300 RTK drone, we set the flying distance from home base at around 2 km up to 5 km. This reach is further than other research that has been carried out previously using Spy drones.

In this research, a sample of 6 forest locations was used, each area was further divided into 6 to 19 UAV flying points, and from each place, there were 0 to 6 points that were thought to be the initial places identified (based on satellite image data). However, after observing and validating using UAV/drones, it can be confirmed that there are 11 positive places for illegal plants, or around 58% of the samples, while the remaining eight places or 42% are locations of harvest land or oil palm fields.

Statistical analysis performed using sampled data from one district gave the Recall score of 0.839449541. While the results are acceptable, the application of a more sophisticated method such as Machine Learning or Deep Learning algorithm could greatly improve the result compared to analysis using classical image processing approach.

This research has quite an important contribution because in Indonesia, cannabis is one of the prohibited plants that produce narcotic substances, this provision is regulated in Narcotics Law number 35 of 2009, therefore people are prohibited from growing it illegally. Therefore, the success of identifying cannabis fields using UAV in this research has indirectly provided the potential for social, legal and environmental impacts.

Viewed from the perspective of potential social impacts, most of the illegal cannabis cultivation is in remote areas where no one lives near the fields, so it is difficult to know its whereabouts. However, using the UAV as a survey tool for cannabis fields can reach these areas, so it can provide a deterrent effect for outdoor cannabis farmers because they can no longer hide cannabis plants.

Viewed from the perspective of potential legal impacts, mapping cannabis land or monitoring operations using UAV is very small. UAV operators are law enforcement officers, have a remote pilot certificate, and comply with all applicable laws, rules, and regulations. Law enforcement officials have direct authority under the Narcotics Law to collect information in the form of photos or videos from a public or state-owned area, which is the main location for illegal cannabis cultivation in Indonesia. If a problem occurs (e.g., loss of control of the UAV or crash of the UAV), the potential harm to civilians is very small, as the operating locations are mostly in remote areas and UAV noise is not a problem in remote areas.

Viewed from the perspective of potential environmental impacts, the UAV used in this research uses battery power, so there are no carbon emissions produced by UAV operation. Carbon emissions are only generated at the charging stage of the UAV battery because our power source uses reverse electricity generated from the running car engine. However, illegal cannabis cultivation in Indonesia is mainly carried out in forests and agricultural land. In forest areas, deforestation is the most common way to clear cannabis fields, which has a negative impact on forests and ecosystems.

The actions of the extermination team based on the findings are mentioned, but no ethical considerations or legal framework governing these actions are discussed. The authors must address the ethical and legal compliance implications of using the UAV to detect cannabis fields and subsequent destruction.

With ethical implications, research to eradicate cannabis fields is carried out by law enforcers in carrying out the mandate of the Narcotics Law, where cannabis is included in class 1 narcotics. Based on Article 111 of the Narcotics Law, anyone without the right to or unlawfully plant, maintain, possess, store, control, or provide Class I narcotics in the form of plants is punishable by imprisonment.

The National Narcotics Agency of the Republic of Indonesia, in collaboration with local governments, agencies, and the private sector, has developed an alternative development program for former cannabis farmers, so that they can take part in the program and earn a living by growing legal production plants.

For further destruction, referring to Article 92 of the Narcotics Law, Indonesian National Police Investigators and National Narcotics Agency Investigators are required to destroy found plants within a maximum period of 2 x 24 (twice twenty-four) hours from the time they are discovered after a small portion of the plant is found. Set aside for investigation, prosecution, and examination before the court, and can be set aside to develop science and technology, as well as for the purposes of education and training.

6. CONCLUSIONS

Aerial photography from both satellites and UAVs/drones is effective for identifying various types of plants, including cannabis. Each country has a different legal stance regarding the cultivation of cannabis, some declare it illegal and others legalize it, while in Indonesia the law is illegal.

Due to limited resolution, satellite imagery cannot provide detailed analysis in small areas, therefore combining it with UAVs/drones can help with the limitations of satellite imagery. In addition, weather conditions, such as wind speed, and time of day affect UAV/drone flight operations and image quality.

This research succeeded in identifying cannabis fields even in small areas, this research contributes valuable insight into the use of remote sensing technology to detect cannabis, highlighting the implications for law enforcement, environmental conservation, and ethical considerations in eradication efforts.

ACKNOWLEDGMENT

The authors' appreciation and deepest gratitude to Head of the National Research and Innovation Agency of the Republic of Indonesia, Head of the National Narcotics Agency of the Republic of Indonesia, Head of Electronics and Informatics Research Organization-BRIN, Head of Research Center for Electronics-BRIN, Research Center for Data and Information Science-BRIN, Head of Research Center for Transportation Technology-BRIN, Director of Directorate of Laboratory Management Research Facilities and Science and Technology Park-BRIN, Head of Research Center for Aeronautics Technology-BRIN, Head of Research Center for Hydrodynamics Technology-BRIN, Head of Research Center for Artificial Intelligence and Cyber Security-BRIN, Head of Research Center for Process and Manufacturing Industry Technology-BRIN, Director of Directorate of Narcotics, Deputy of Eradication, National Narcotics Board of the Republic of Indonesia, data processing uses MAHAMERU BRIN HPC, and all parties who we cannot mention one by one who have helped carry out this research.

REFERENCES

[1] Viswanadha, V., Reddy, S.C., Venkatesu, B. (2018). Dynamic time allocation for traffic control system using image processing. International Journal of Creative Research Thoughts, 6(2): 370-376.

[2] Choudhary, D., Lather, A., Yadav, S. (2014). Overview of image processing. International Journal for Research in Applied Science & Engineering Technology (IJRASET), 2(X): 120-125.

[3] Tombe, R., Viriri, S. (2022). Effective processing of convolutional neural networks for computer vision: A tutorial and survey. IETE Technical Review, 39(1): 49-62. https://doi.org/10.1080/02564602.2020.1823252

[4] Ravi, P., Ashokkumar, A. (2017). Analysis of various image processing techniques. International Journal of Advanced Networking and Applications, 8(5): 86-89.

[5] Feng, C., Yu, D., Liang, Y., Guo, D., Wang, Q., Cui, X. (2019). Assessment of influence of image processing on fully automatic UAV photogrammetry. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 42: 269-275. https://doi.org/10.5194/isprs-archives-XLII-2-W13-269-2019

[6] The President of the Republic of Indonesia, Laws of The Republic Indonesia Number 35 of 2009 About Narcotics. 2009. https://www.dpr.go.id/dokjdih/document/uu/UU_2009_35.pdf, accessed on Aug. 18, 2023.

[7] Erridge, S., Coomber, R., Sodergren, M.H. (2022).

Medical cannabis, CBD wellness products and public awareness of evolving regulations in the United Kingdom. Journal of Cannabis Research, 4(1): 56. https://doi.org/10.1186/s42238-022-00165-6
[8] Aviram, J., Atzmony, D., Frenklakh, A., Kroll, A., Zaks, I., Hazekamp, A. (2022). THC degradation does not impair the accuracy of THC doses aerosolized by the metered-dose SyqeAir inhaler: A 24-month stability trial. Journal of Cannabis Research, 4(1): 55. https://doi.org/10.1186/s42238-022-00166-5
[9] Hadorn, D. (2008). A review of cannabis and driving skills. In Guy, G.W., Whittle, B.A., Robson, P.J. (eds) The Medicinal Uses of Cannabis and Cannabinoids. Pharmaceutical Press, pp. 329-365.
[10] Baker, L. (2004). Dictionary of medical terms (4th edition). Reference Reviews, 18(7): 37-37. https://doi.org/10.1108/09504120410559708
[11] Colbert, M. (2015). Indica, sativa, ruderalis-did we get it all wrong? https://www.theleafonline.com/c/science/2015/01/indica-sativa-ruderalis-get-wrong/, accessed on Aug. 18, 2023.
[12] Volk, G.M., Richards, C.M. (2008). Availability of genotypic data for USDA-ARS National Plant Germplasm System accessions using the genetic resources information network (GRIN) database. HortScience, 43(5): 1365-1366. https://doi.org/10.21273/HORTSCI.43.5.1365
[13] Clarke, R.C., Watson, D.P. (2007). Cannabis and natural cannabis medicines. In Marijuana and the Cannabinoids, pp. 1-15. https://doi.org/10.1007/978-1-59259-947-9_1
[14] Lambert, D. (2009). Cannabinoids in Nature and Medicine. Wiley.
[15] Groce, E. (2018). The health effects of cannabis and cannabinoids: The current state of evidence and recommendations for research. Journal of Medical Regulation, 104(4): 32-32. https://doi.org/10.30770/2572-1852-104.4.32
[16] Meier, M.H., Caspi, A., Ambler, A., Harrington, H., Houts, R., Keefe, R.S., McDonald, K., Ward, A., Poulton, R., Moffitt, T.E. (2012). Persistent cannabis users show neuropsychological decline from childhood to midlife. Proceedings of the National Academy of Sciences, 109(40): E2657-E2664. https://doi.org/10.1073/pnas.1206820109
[17] Christiansen, M.P., Laursen, M.S., Jørgensen, R.N., Skovsen, S., Gislum, R. (2017). Designing and testing a UAV mapping system for agricultural field surveying. Sensors, 17(12): 2703. https://doi.org/10.3390/s17122703
[18] PIX4D. Helping to protect the rainforest in Peru with drone mapping. https://www.pix4d.com/blog/aerial-drone-mapping-amazon-rainforest/, accessed on Aug. 18, 2023.
[19] Tamouridou, A.A., Alexandridis, T.K., Pantazi, X.E., Lagopodi, A.L., Kashefi, J., Moshou, D. (2017). Evaluation of UAV imagery for mapping Silybum marianum weed patches. International Journal of Remote Sensing, 38(8-10): 2246-2259. https://doi.org/10.1080/01431161.2016.1252475
[20] Sharma, A., Shoval, S., Sharma, A., Pandey, J.K. (2022). Path planning for multiple targets interception by the swarm of UAVs based on swarm intelligence algorithms: A review. IETE Technical Review, 39(3): 675-697. https://doi.org/10.1080/02564602.2021.1894250
[21] Bawa, A., Samanta, S., Himanshu, S. K., Singh, J., Kim, J., Zhang, T., Chang, A., Jung, J., Bordovsky, J., Barnes, E., Ale, S. (2023). A support vector machine and image processing based approach for counting open cotton bolls and estimating lint yield from UAV imagery. Smart Agricultural Technology, 3: 100140. https://doi.org/10.1016/j.atech.2022.100140
[22] Houmi, M., Mohamadi, B., Balz, T. (2018). A hyperspectral based method to detect cannabis plantation in inaccessible areas. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 42: 547-551. https://doi.org/10.5194/isprs-archives-XLII-3-547-2018
[23] Bicakli, F., Kaplan, G., Alqasemi, A. S. (2022). Cannabis sativa L. spectral discrimination and classification using satellite imagery and machine learning. Agriculture, 12(6): 842. https://doi.org/10.3390/agriculture12060842
[24] Roslim, M.H.M., Juraimi, A.S., Che'Ya, N.N., Sulaiman, N., Manaf, M.N.H.A., Ramli, Z., Motmainna, M. (2021). Using remote sensing and an unmanned aerial system for weed management in agricultural crops: A review. Agronomy, 11(9): 1809. https://doi.org/10.3390/agronomy11091809
[25] Ferreira, A., Felipussi, S.C., Pires, R., Avila, S., Santos, G., Lambert, J., Huang, J., Rocha, A. (2019). Eyes in the skies: A data-driven fusion approach to identifying drug crops from remote sensing images. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 12(12): 4773-4786. https://doi.org/10.1109/JSTARS.2019.2917024
[26] Kumar, G.A., Yamini, P., Maheswari, R. (2021). IoT automated spy drone to detect and alert illegal drug plants for law enforcement. In Applied Learning Algorithms for Intelligent IoT, pp. 241-264.
[27] Frantzman, S.J. (2021). Turkish UAV drone stops 1.5 tons of Cannabis being smuggled out of Syria. Jerusalem Post, May 17, 2021. https://www.jpost.com/middle-east/turkish-uav-drone-stops-15-tons-of-Cannabis-being-smug, accessed on Aug. 18, 2023.
[28] Zoldi, D.M.K. (2022). Drones and Autonomous Systems Take Cannabis Industry Profits Higher. Mar. 17, 2022. https://insideunmannedsystems.com/drones-and-autonomous-systems-take-cannabis-industry-profits-higher, accessed on Aug. 18, 2023.
[29] ASPRS. (2018). What Is ASPRS? https://www.asprs.org/organization/what-is-asprs.html, accessed on Aug. 18, 2023.
[30] Mallela, J., Mitchell, A., Gustafson, J., Olsen, M.J., Parrish, C., Gillins, D.T., Kumpula, M., Roe, G. (2018). Effective use of geospatial tools in highway construction (No. FHWA-HIF-19-089). United States. Federal Highway Administration. Office of Research, Development, and Technology. https://trid.trb.org/view/1673389.
[31] Goel, L., Nagpal, J. (2023). A systematic review of recent machine learning techniques for plant disease identification and classification. IETE Technical Review, 40(3): 423-439. https://doi.org/10.1080/02564602.2022.2121772
[32] Cui, W. (2019). Visual analytics: A comprehensive overview. IEEE Access, 7: 81555-81573. https://doi.org/10.1109/ACCESS.2019.2923736
[33] Keim, D.A., Mansmann, F., Schneidewind, J., Thomas, J., Ziegler, H. (2008). Visual analytics: Scope and

challenges, visual analytics: Scope and challenges. In: Simoff, S.J., Böhlen, M.H., Mazeika, A. (eds) Visual Data Mining. Lecture Notes in Computer Science, vol 4404. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-71080-6_6

[34] Patil, S.M. (2015). A study on visual analytics. International Journal of Computer Science and Information Technology Research, 3(1): 303-308.

[35] Tanasa, I.Y., Hidayat, A., Wibowo, M., Budiarti, D.H., Guno, Y., Purwanto, A., Yunata, A.S., Purnamastuti, F.N., Wicaksono, G., Domiri, D. (2023). Segmentation of drone-captured images for illegal cannabis plantation detection. In AIP Conference Proceedings, 2941(1): 030005. https://doi.org/10.1063/5.0181482