A STRATEGY TO DETECT AND MONITOR COCA PRODUCTION IN COLOMBIA, PERU, AND BOLIVIA

by
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Abstract

South America produces 90% of the world's cocaine supply. Cocaine is the third most consumed illicit substance behind marijuana and abused pharmaceutical opiates. Trends in top consumer countries are pointing toward marijuana legalization, making cocaine more important to narcotic organizations as they compete with legitimate marijuana producers. Cocaine production itself is under threat due to the efforts of the Colombian government to reduce coca/cocaine production within their borders. Potential expansion in production and continued concealment efforts will require reliable means of identification by technical means. Identification and tracking efforts would focus on the three primary producer countries: Colombia, Peru, and Bolivia. This paper puts forth a framework for coca detection that limits costs and manpower. The primary method utilizes hyperspectral sensors, which obtain images across spectral bands. Spectra derived from technical sensors identifies and catalogs signatures associated with cocaine production. Utilizing a library of signatures, a substance can be identified with high fidelity. Utilizing the primary method areas of interest can be narrowed down the highest yielding regions. Adhering to a strict HIS collection window and acquisition of commercial imagery will yield the best results. The resulting data can be displayed in easily digestible products that can be disseminated rapidly. These results will alert the customer of any nefarious activity allowing them to act in a timely manner. An estimated budget of the first year's expenses is included along with operational recommendations to include hardware, software, and personnel.

Contents

Introduction

The Colombian government lead by President Ivan Duque implemented aggressive measures to reduce cocaine production in rural areas throughout 2020. The result of the coordinated effort was the destruction of 500 metric tons of cocaine hydrochloride and 130,000 hectares of planted coca. The prevailing assumption is the administration will repeat this feat in 2021.[1] The rippling effects of an effective coca destruction campaign could be felt across the region as Colombia is the primary supplier of the world's cocaine. Coca is a cartel cash crop and a major boon for local farmers and communist paramilitary forces (FARC) in the country. Effective destruction in Colombia may force procurers and consumers to look to other established producers such as Bolivia and Peru.

The efforts of the Colombian government are commendable but factors outside of their control may cause potential backsliding and conflict. A potential factor is the gradual legalization of marijuana in the United States. Legal marijuana producers may completely push out illegal producers, incentivizing illegal producers to restructure their business model. Cocaine is the second most consumed illegal substance after marijuana and like marijuana it is derived from agricultural cultivation, making coca a cash crop. The legitimization of marijuana may cause a cocaine expansion. The potential expansion could make identifying and tracking coca/cocaine production within the borders of the primary producers (Colombia, Peru, and Bolivia) even more crucial than it is at present.

[1] Reuters Staff 2021

The purpose of this capstone is to propose a potential model for geospatial intelligence collection and analysis that makes continuous monitoring of coca production possible. The primary goal of the program will be identification of illegal production in the three primary producer countries. Secondarily, a successful intelligence model would give affected countries another tool to combat cocaine production in their state. This model will utilize unclassified means to collect, analyze and report. The purpose of unclassified data is for the United States and other members of the international community to share this information while promoting accountability in the global war on drugs.

Background

South America produces over 90% of the worlds coca/cocaine every year. Chief among the South American producers is Colombia who historically produces 70% of the global product followed by Bolivia and Peru.[2]

- In 2018, 240,000 hectares (593,052.916 acres) of land was allocated to cocaine production to produce 1,723 tons globally. [3]
- In 2018, 99% of the 1,723 tons (Globally) are produced in Colombia, Peru, and Bolivia.[4]
- In 2018, 1,206.1 tons of pure cocaine was produced in Colombia (out of 1,723 tons globally) followed by Peru then Bolivia.[5]
- In recent years upwards of 60% of Colombia's coca was cultivated in the departments of Nariño, Norte de Santander, and Putumayo.[6]

[2] United Nations Office on Drugs and Crime 2020
[3] United Nations Office on Drugs and Crime 2020
[4] United Nations Office on Drugs and Crime 2020
[5] United Nations Office on Drugs and Crime 2020
[6] United Nations Office on Drugs and Crime 2020

- In Peru 67% of historical coca cultivation occurs in the river valleys of Apurimac-Ene.[7]
- In Bolivia 65% of historical coca cultivation occurs in Yungas La Paz.[8]

Primary method

The methodology behind this proposal centers around hyperspectral data collection. Hyperspectral sensors acquire images across narrow contiguous spectral bands. These spectral bands fall in the visible, near-infrared, short-wave, and mid-wave portions of the electromagnetic spectrum. Light absorption differs between materials and the difference is measured as a unique spectral reflectance signature. It is possible to track changes in foliage using the differences in absorption due to changes in levels biochemical factors. These factors include chlorophyll, carotenes, water, nitrogen, cellulose, and lignin.[9]

Utilization of a hyperspectral sensor makes the collection and cataloging of unique spectral signatures possible. In this case the target is coca plant (erythroxylum coca) and certain associated chemicals used in cocaine production. Using the logged signature, coca can be detected in new collections by comparing past signatures against newly collected ones. Algorithms are used to refine the data, magnify the minute differences, and sift out background noise. A catalog of lab captured spectral signatures and verified field collected signatures would greatly raise the chances of target detection.

In support of the primary method satellite imagery is also a necessary component in identifying nefarious coca cultivation. Electro-optical and infrared can raise the confidence of

[7] United Nations Office on Drugs and Crime 2020
[8] United Nations Office on Drugs and Crime 2020
[9] He, Rocchini, Neteler, Nagendra, retrieved 2021.

signature detections. Specific markers for coca paste cultivation may be present in the imagery that will corroborate signatures providing evidence of nefarious activity.

Support data

In support of the primary method a library of spectral signatures will need to be generated to execute the mission. The primary signature is the coca plant, particularly an erythroxylum coca plant. Secondary signatures would include any local flora with similar signatures that could confuse the software or analyst, and target chemicals associated with cocaine production. Specific chemicals will be listed in the analysis section. These signatures should be compiled into a library which a software can access for comparison and algorithmic identification of material once data is collected. It is recommended that all real-world samples collected through the collection are logged in efforts to create a historical detection database. This database can be used to strengthen analysis as the mission goes on.

Due to the favorable conditions necessary for coca cultivation there is a need for certain supporting datasets. To support mass cultivation, the elevation of the coca site will usually fall between 600 and 1,911 meters with little temperature fluctuation.[10] To properly identify areas that support coca cultivation, elevation data will be essential. Historical reporting has also placed high yield areas in select regions of Colombia, Peru and Bolivia making vector data representing boundaries a requirement.

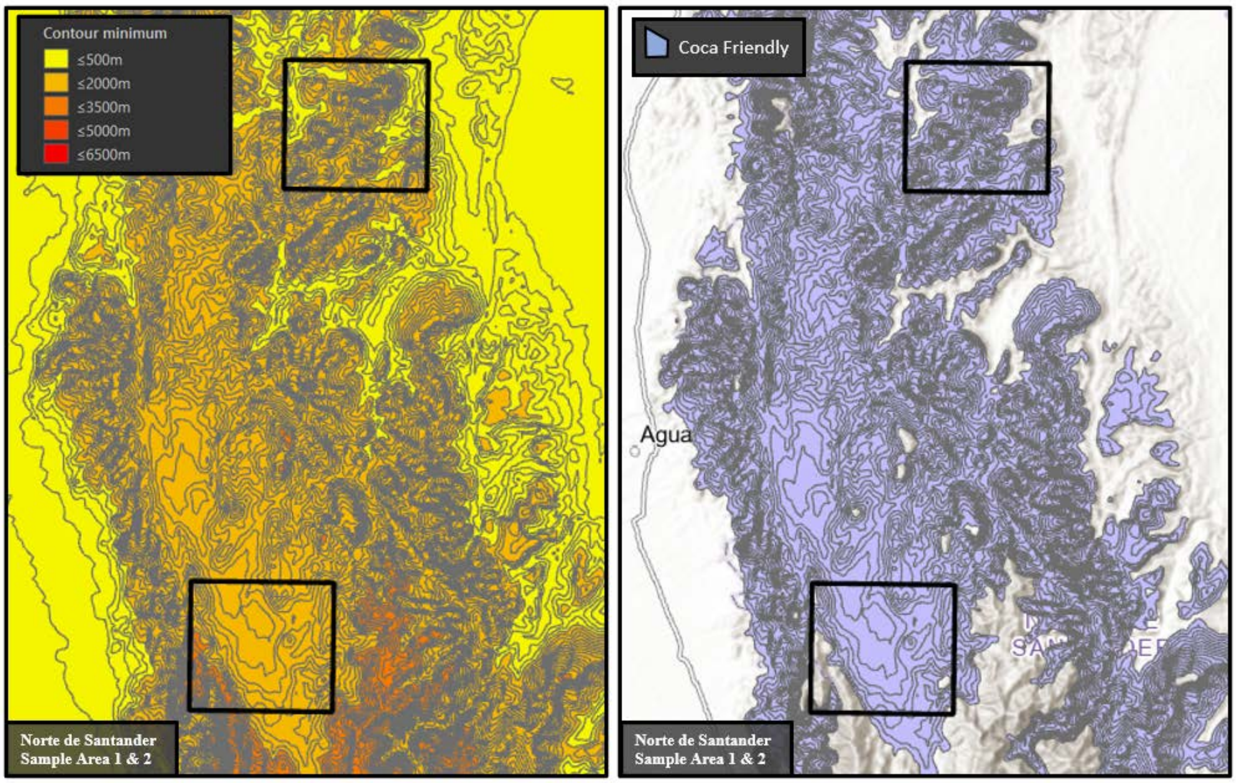
The potential area of cultivation is vast. Land cover will aid in refining the search area by providing defined geographic areas of human activity. Coca cultivation often takes place near traditional agricultural lands or on traditional agricultural land. Land cover can identify

[10] Drug Enforcement Administration Office of Intelligence 1991.

concentrations of agriculture in high yield regions which assists in identifying areas of interest and setting priorities.

Figure 1

An example of refined elevation data which isolates coca friendly elevation which falls between 600m-1911m.



All the listed support data can be gathered by utilizing open-source resources and databases. NASA disseminates global elevation data, and there are other different aggregators that compile elevation data for free download as well. The Food and Agricultural Organization of the United States hosts global land cover data for free use, there are other aggregators to fill this need as well. After the supporting data is gathered a collection strategy may be developed.

Collection

The collection is centered around an aerial collection preferably unmanned. The aircraft would be equipped with a hyperspectral imagery (HSI) sensor as its primary payload. The aircraft and payload will follow a track within an area of interest (AOI) using a push-broom method or whisk-broom method depending on the sensor configuration. The platform will collect along the track and at the end the sensor would collect the area within the area of interest.

As the sensor makes its way along the track it will store detected signatures in its onboard hard drive. After the platform lands the data will be extracted from the hard drive and uploaded on a desktop for analysis. This will prompt the next phase of collection which will be the collection/acquisition of satellite imagery. Signature related geocoordinates will be used to queue analysis of satellite derived electro-optical and infrared imagery.

The operational area is very large, there is limited hard drive space, and limited flight time. An initial sampling method is recommended to cope with these limitations. As previously stated, there is historical data and locations for coca production in Colombia, Peru, and Bolivia. Using the support data and coca production parameters, sample AOIs can be drawn up and subsequently collected. The search area may need to expand, or a selection of a new area for sampling depending on spectral returns may be required.

Two sample areas per high yield region is the recommended baseline for sampling. Utilizing elevation data and road data, two differently sloped areas can be identified and selected. The purpose of selecting areas of different slope is to identify activity in areas with greater denial. If no signatures are detected there would be a new round of selected AOIs until feasible collection options are exhausted.

Example of sampled AOIs:

Sample AOI	Upper Left	Lower Right	Optimal Facility	Facility Coordinates	Approximate Flight Duration
Norte De Satander SA 1	18PXQ 90615 90819	18PYQ 17225 71219	Ayacucho Airport	18PXQ 52600 51154	8hrs
Norte De Satander SA 2	18PXP 84233 99721	18NYP 10893 80052	Irho Airport	18NXP 72652 55303	7hrs
Narino SA 1	18NTG 47454 69341	18NTG 74048 49505	Aeropuerto San Luis	18NTF 02335 94999	9hrs
Narino SA 2	18NTG 11239 46383	18NTG 38007 26561	Aeropuerto San Luis	18NTF 02335 94999	7hrs
Putumayo SA 1	18NTG 82570 18883	18NUF 09164 99265	Aeropuerto de Villagarzon	18NUG 21542 08547	7hrs
Putumayo SA 2	18NTF 57547 81246	18NTF 84079 61236	Aeropuerto de Villagarzon	18NUG 21542 08547	8hrs
Apurimac-Ene SA 1	18LWM 97630 49353	18LXM 23678 29294	Aerodromo Kiteni	18LYM 12937 00822	9hrs
Apurimac-Ene SA 2	18LXL 52400 57794	18LXL 78237 37568	Aerodromo Kiteni	18LYM 12937 00822	8hrs
Yungas La Paz SA 1	19KFC 73436 07446	19KFB 98928 87364	El Alto International Airport	19KEB 87771 74468	8.7hrs
Yungas La Paz SA 2	19KFB 48679 94421	19KFB 74169 74423	El Alto International Airport	19KEB 87771 74468	8hrs

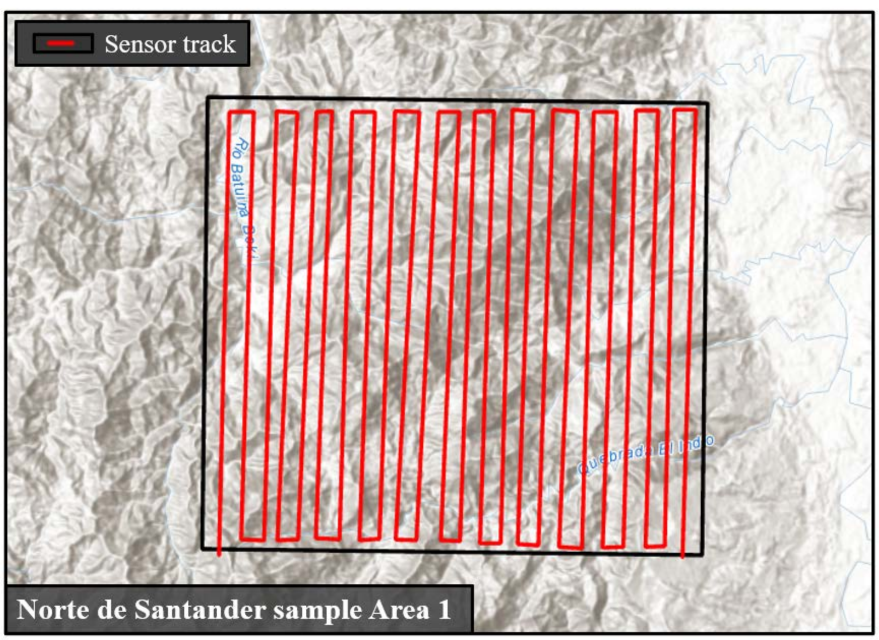
The AOIs in the example cover an area approximately 550 square kilometers. The sensor track is approximately 536 kilometers in length. An aircraft at a cruising speed of 90km/hr., could possibly fly the track in approximately 6 hours under favorable conditions. Next, the most direct route free from vertical obstruction from an accessible airfield is determined and added into the equation and the result yields the approximate flight duration.

If a sample area has significant returns a new sensor track could be developed to maximize collection in areas with similar characteristics. At the end of collection an area of significant activity would be prepped for greater scrutinization, or it would be eliminated, and new historical area would be incorporated. Example: If Nariño had no significant activity, it would be replaced with Amazonas.

Utilizing the estimated flight times the collection of each sample area could be accomplished in one day. All areas could be collected in ten days, utilizing a normal week and days for travel collection of AOIs could be completed in three weeks. Ten days for collection, six days of rest and 5 days for internal travel and travel between Bolivia, Colombia, and Peru. If the data collected cannot be uploaded post mission, shipping a hard drive or SSD would be a secondary option, however it may take over a month (25 business days) to arrive in the United States.

Figure 2

An example of a sensor track; this track is approximately 536km in length.



Determining the Best Collection Window

The climate in Colombia, Peru, and Bolivia heavily influences the collection window. Precipitation and heavy cloud cover would preclude collection from passive sensors. Passive sensors are microwave instruments that receive and measure natural emissions produced by the composition of the Earth's surface and Earth's atmosphere[11]. Collection of operationally acceptable imagery can be hindered by changes in the atmosphere. An example of this hinderance would be cloud cover, a factor that could make a swath of collected area unusable.

When determining a collection window ground visibility is a driving factor. Colombia, Peru, and Bolivia have high elevation land areas conducive to coca cultivation that are also difficult to capture. High elevation areas have a higher chance to yield clouds due to water vapor condenses due to the air rising and cooling over the Andes. The frequency of clouds requires optimization of collection limiting it to certain timeframes. Optimization of collection would dictate flying during the driest months of the year. The driest months are likely to have the clearest days for collection by passive sensors, and HSI sensor in this case.

Precipitation Data:

- Norte De Santander's driest month on average is July (1 inch of precipitation).[12]
- Narino's driest month on average is August (1.6 inches of precipitation).[6]
- Putumayo's driest month on average is August (5.7 inches of precipitation).[13]
- Apurimac-ene driest month on average is June (no precipitation).[14]

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[11] National Aeronautics and Space Administration 2017
[12] Weather & Climate 2021
[13] World Weather Online 2021
[14] Weather & Climate 2021

- Yungas La Paz driest month on average is June (no precipitation). [15]

The dry season is concurrent with coca harvests for crops at lower altitudes often occurring between June and July. The production of coca-paste (the precursor of cocaine) should occur during this interval as well. These intervals could provide the optimal window for collection as harvesting activity and cocaine production would potentially occur at the same location. Collection during periods of low cloud cover will up the chances of successful collection by minimizing potential barriers and maximizing potential of observing ground activity.

The month July falls within the reported dry season of Norte de Santander, Nariño, and Putumayo allowing for Colombian samples to be collected within the same month. The climates of Yungas La Paz (Bolivia) and Apurimac-ene (Peru) allow for a collection throughout the month of June. Collection of AOIs in La Paz and Apuramac-ene, followed by Norte de Santander, Nariño, and Putumayo in July offers the most effective collection window.

Commercial Satellite Imagery Acquisition

Much of Colombia's coca production occurs in the valleys and slopes of the Andes. Due to natural processes at those elevations cloud accumulation is a persistent problem which precludes overhead collection. There are commercial platforms that capture and catalog historical satellite imagery and allow for image query by date. The prime-time frame for satellite imagery acquisition is the same as for medium altitude collection; the dry season during June-August.

L3Harris's IntelliEarth was utilized to form the strategy for commercial collection of satellite imagery. Most of the imagery below 20% cloud cover was captured during the dry season. The second most notable amount of low cloud cover imagery occurred during January each year

[15] Weather & Climate 2021

between 2017-2020. There were sporadic instances of low cloud cover images in different months across each year between 2016-2020.[16]

Acquisition of commercial imagery should focus on acquiring imagery with a cloud cover threshold of below 50 percent. The primary focus for imagery acquisition should be the dry season (Jun-Aug) as it yields the most consistent results. The next recommended search would scan January as it was second to the dry season in yielding low cloud cover imagery between 2017-2020.[17] Lastly if all previous searches fail a freeform search should be implemented to fill the need in with consideration for the time of detection. had freeform search is previous searches yield little results. Coca production is a multiyear endeavor, and it is likely that contextual signatures could be observed in imagery from previous years.

Analysis overview

Coca processing has three stages: the conversion of coca leaf into coca paste, the conversion of paste into cocaine base, and the conversion of cocaine base into cocaine hydrochloride.[20] The focus of this proposal is the first conversion step, identifying coca leaves and coca paste which is often manufactured on-site. Analysis will determine if significant coca cultivation is present and whether its presence is nefarious.

Step	Chemicals	Substitute Chemicals
Coca Leaves to Coca Paste	Kerosene, Sulfuric Acid, Sodium Bicarbonate.[18]	Gasoline, Benzene, Hydrochloric Acid, Sodium Hydroxide.[19]

[16] Intelliearth, L3Harris 2021.
[17] Intelliearth, L3Harris 2021.
[18] Drug Enforcement Administration Office of Intelligence 1991.
[19] Drug Enforcement Administration Office of Intelligence 1991.
[20] Drug Enforcement Administration Office of Intelligence 1991.

Using the primary method, all the chemicals in the table may be detected using an overhead platform. The presence of the coca plant is not inherently nefarious in Colombia as it is consumed by the local population. Depending on the location it could be sanctioned growth that meets the local demand for coca which is often chewed or brewed in tea. There may be unsanctioned cultivation for legal consumption of the coca leaf. The undisputable signature lies in the chemicals used to generate paste and the associated activity.[21]

The presence of these chemicals at a coca leaf cultivation site rases the likelihood of nefarious activity. Location of the of the signature and the quantity of pixels (affected ground area) it occupies will be an important factor in determining the likelihood of cocaine production in a detection area. Coca paste production often occurs onsite in a shack or covered pit. A chemical solution is evacuated two times in the process. The solutions contain kerosene, sodium bicarbonate, and sulfuric acid.[22] There is a good chance that the liquid evacuations leave behind ground staining that could yield chemical signatures.

There is a smaller chance of cocaine production is occurring on-site. The most likely cocaine production that would occur on site would involve refining coca paste into cocaine base. This step in the production process happens indoors and uses water based chemical solutions to extract alkaline material. Once the alkaline material is extracted the solution is drained, and the remainder is dried using thermal lamps to evaporate any remaining solution, leaving behind the

[21] Drug Enforcement Administration Office of Intelligence 1991.
[22] Drug Enforcement Administration Office of Intelligence 1991.

target cocaine base. The evacuated solution would contain sulfuric acid or hydrochloric acid, potassium permanganate and ammonia hydroxide (See table below). [23]

Step	Chemicals	Substitute Chemicals
Coca paste to Cocaine base	Sulfuric Acid, Potassium, Permanganate, Ammonia Hydroxide.[24]	Hydrochloric Acid, Potassium, Dichromate, Sodium Hydroxide.[25]

Identifying nefarious activity in panchromatic or multispectral imagery will be important when looking to corroborate HSI returns on-site. Examples of nefarious activities are: large quantities of metal chemical containers in vicinity of coca cultivation, ground staining near structures associated with the agricultural activity, pits lined with tarp-like material, and ground drainage originating from structures or pits. Coca plants can be identified by their size when cultivated which is 3-6 feet due to pruning.[26]

Figure 3 Snapshot of coca cultivation.[27]

[23] Drug Enforcement Administration Office of Intelligence 1991.
[24] Drug Enforcement Administration Office of Intelligence 1991
[25] Drug Enforcement Administration Office of Intelligence 1991
[26] Drug Enforcement Administration Office of Intelligence 1991
[27] Muse, Toby 2020

Technical analysis

Spectral signature comparison is the bases of anlaysis in the primary method. Each object captured during collection will have an associated spectral signature. Commercially acquired HSI software will use algorithms to isolate signatures that are closest to the coca leaf or target chemical/chemical compound. The provided target signatures should be obtained from lab collection which gives a confirmable return. Real world collection will be less clean considering the altitude of collection and the surrounding matter that will also be collected simultaneously. Analysts will have to compare software identified signatures and compare it to the lab confirmed signature to gauge its similarity and determine whether the captured signature is coca leaves or a production chemical.

There is a chance for error with the software and analysis, secondary sources are recommended to better corroborate the primary method's returns. In nature there may be another object in this case a plant with a similar profile that may be unknown to the analyst. The supporting satellite imagery should help cover this lack of data by allowing the analyst to identify coca cultivation in associated imagery, corroborating the detection.

Product generation

The analysis will yield three product types, a written report and two annotated graphics. The written report will reference the target material list data (erythroxylum coca, Kerosene, etc.), what target materials were detected, confidence percentage associated with the detection, associated geocoordinates and any relevant information regarding the operational accuracy of the sensor or analytic software. This written report should contain all target material detections collected during the duration of the flight and accompany disseminated products, the purpose of this action is to alert the customer of detections even if analysis yielded no verifiable nefarious activity.

Two separate annotated graphics should be generated, the first would be the HSI image chip and the compared spectra, both the base signature (lab generated) and the real-world detection stacked side by side for comparison. There should also be a description block that hold the text that describing the analytic outcome. There should also be a header and footer, in the header there should be a designating name based on a collection ID, nearest geographical location, detected chemical, etc. The header should also have geocoordinates, country name region name (department), time of collection and north arrow, and team designation or logo. The footer should have the analyst's name, and any required license or copyright statements.

The second annotated graphic would have electro-optical, infrared, or multispectral imagery derived from commercial satellites. There should be a description box in the lower section of the product, which describes the analytical outcome. There should be a header which contains a name designation, north arrow, time of collection and team designation or logo. The footer should have the analyst's name, and any required license or copyright statements.

The purpose of the annotated graphics is to relay the analytical findings in digestible pieces to the user. The written report is to give the user the contextual data associated with the collection. The annotated graphics will convey the presence of nefarious activity with evidence and the report will alert them to areas where detections may have occurred and where they haven't. The products will be available for digital transmission through email or upload to the appropriate shared server and cloud services.

Dissemination

The program will use commercially available means to ensure the option of unrestricted information sharing. Due to the dangerous climate associate with coca production certain information and means should be withheld that would allow bad actors to cause harm to the participants. The reports and findings with respect to safety should be shared with as many entities as possible. Ideally the governments of Bolivia, Peru and Colombia could use this data as a tool to track production in their country.

With the intent to share the primary means of dissemination should be email, and web sharing. Web sharing includes websites, online databases, and web publications. Products should be posted as soon as they are quality checked. In the case of databases and web services the completed projects should be catalogued for future reference. These options allow for the maximum number of users to utilize the generated reports and annotated graphics.

Operational Recommendations

There are some recommended acquisitions of hardware, software, and personnel to fulfill the need to execute elements of this proposal. The first item for hardware acquisition is the aerial platform. The platform would need to have a ceiling of at least 14,000ft, a cruising speed of 90km and the ability to carry an HSI sensor. Preferably this platform would be unmanned to limit potential loss of life if the aircraft is downed by unforeseen circumstances. An example of a commercially available unmanned aircraft up to specification is the monitor M14 by Saxon Aerospace.[28] A second unmanned aircraft is recommended for mission versatility and continuity.

[28] Monitor, Saxon Aerospace 2021

An accessory to the unmanned aircraft is a system with a robust range to communicate with the aircraft and control it. This includes communications software, a ground control system and any equipment that help maintain connection between the pilot and the aircraft. Due to the terrain in the target area the optimal means of control would allow the platform to operate in a mountainous area.

Due to the potential loss of connection GPS components and software that allow the pilot to track of the position of the unmanned aircraft is recommended. GPS also has the potential to provide auto navigation, a valuable option if the command link between the pilot and platform is severed. There are commercially available products to fill this need such as combat proven technologies' Advanced Mini Link System that gives a range of over 100km with their long-range ground data terminal.[29] Appropriate antennas and GPS components are also available commercially, such as the 3DM-RQ1-45 GPS/INS by Parker Lord sensing.[30]

The second item is an HSI sensor which be used as the primary method to detect coca. High image resolution correlates with higher confidence returns in a heterogeneous environment. A sensor with high resolution and wide spectral range is ideal. Coca plantations will be large and most likely more homogenous than the surrounding area, however high resolutions hyperspectral sensor should still be the standard when it comes to sensor acquisition. The AISAFENIX 1K by Specim Spectral Imaging appears to meet the requirement with 620 available bands, 380 to 2500 nm spectral range and a 1m resolution at 1400m[31].

[29] Advanced mini link system (AMLS), Combat Proven Technologies 2021
[30] 3dm-rq1-45 GPS, Parker Hannifin Corporation 2021
[31] Aisafenix 1k, Specim 2021

The third item for hardware is desktops on which the analysis can be performed. Temple University recommends a specific setup for its GIS students to execute geospatial processes. For geospatial applications a high performing processor is optimal. Temple University recommends an i7 8th generation intel processor or an equivalent. As of 2021 a 11th generation i7 processor is available for purchase. Temple also recommeended16 gigabytes for web browsing and potential use of virtual machines. When it comes to storage one terabyte of storage with SATA interface is recommended for day-to-day tasks to help load times of application and software. Lastly, a GPU graphics card with 1 gigabyte of ram is recommended, according to Temple the GPU is for 3d rendering, some of the recommended software have three-dimensionally render capabilities.[32]

There are recommended analytical software to execute the mission. First recommendation is ArcPro, this software can ingest all types of data to include imagery for the purpose of analytical manipulation. Arcpro could be used to output desired data such as favorable elevations for coca growth, and generate annotated graphics, layers, shapefiles and KMLs. Second recommendation is SOCET GXP, this program is optimal for manipulating imagery, the orthorectification features are valuable ingesting imagery into ArcPro. The third recommendation is QT modeler an elevation software used for manipulating digital elevation models (DEMs). The final recommendation for software is the Microsoft office suite a versatile option for report writing and product presentation.

Personnel acquisitions recommendations are at least five professionals to fill the critical needs of the mission. The positions are: one senior imagery analyst, two imagery analysts, and two UAV pilots. The senior analyst role will need to be a subject matter expert that can be a resource to the

[32] Computer recommendations, Temple University 2018

other two analysts, oversee collection and ensure product quality, and fill the role of a manager. The other two analyst will cover the workload, one could cover HSI exploitation and the other could cover satellite imagery exploitation. Lastly, two pilots are needed to support the collection portion of the mission, allowing for the simultaneous flight of two unmanned platforms.

Acquisition and Budgetary Outlook

Acquisition Category	Name	# of	Approximate Cost per Unit (USD)	Approximate Total Cost (USD)
Personnel	Imagery Analyst	2	83000[33] + 37000	240,000
Personnel	Senior Analyst/Team Lead	1	93000[34] + 41850	134850
Personnel	UAV Pilot	2	70000[35] + 31500	203000
Hardware	Unmanned Aircraft (M14 Monitor Surrogate)	2	175000[36]	350000
Hardware	HSI Sensor	2	400000[37] (estimate)	800000
Hardware	GPS	2	750[38]	1500
Hardware	Datalink	2	40000 (estimate)	80000
Hardware	GCS	2	6600[39]	13200
Hardware	Desktop	5	1140[40]	5700
Software	ENVI	5	249(estimate)	1245
Software	ArcPro	5	4550[41]	22750
Software	QT Modeler	5	249 (estimate)	1245
Software	Socet GXP	5	249 (estimate)	1245
			Total=	1,854,735

[33] Imagery Analyst Salary, ZipRecruiter 2021
[34] Senior Goespatial Analyst Salary, ZipRecruiter 2021
[35] UAV Drone Pilot Salary, ZipRecruiter 2021
[36] Saxon Monitor M14 Long Duration UAV, OZ Robotics 2021
[37] Parc Scientists Develop Hyperspectral Cameras, Intrado 2021
[38] Advanced Autopilot System PIXHAWK2, Lavarma 2021
[39] Ground Control System, OZ Robotics 2021
[40] Dell XPS 8940, Newegg 2021
[41] ArcGIS Pro Pricing, ESRI 2021

Using discoverable and public pricing the item list of first year expenses was developed to a snapshot of potential expenses. This is not a reflection of overall cost, but an aide to determine a starting point in price. Some of the items are estimated based of some available pricing of similar products. Some expenses such as plane tickets, per diem and certain administration cost are not listed. The pricing of satellite imagery will vary, however a baseline estimate is 10$ per square kilometer.[42]

[42] News Desk, Geospatial World 2020

Bibliography

Advanced autopilot system PIXHAWK2 pixhawk 2 1 standard Here2 CAN GPS UAV UAS ROV autopilot flight controller. in Lavarma [database online]. 2021 [cited 8/5 2021]. Available from https://www.lavarma.com/accessories/17806-advanced-autopilot-system-pixhawk2-pixhawk-2-1-standard-here2-can-gps-uav-uas-rov-autopilot-flight-controller.html#/24256-color-pixhawk2_with_gps.

ArcGIS pro pricing. in ESRI [database online]. ESRI.com, 2021 [cited 8/5 2021]. Available from https://www.esri.com/en-us/arcgis/products/arcgis-pro/buy.

Dell XPS 8940 10th gen intel core i7-10700 8-core processor,16GB DDR4,256GB SSD plus 1TB HDD,intel UHD graphics 630, wifi-AC, bluetooth,HDMI,DisplayPort,windows 10 pro. in Newegg [database online]. Newegg.com, 2021 [cited 8/5 2021]. Available from https://www.newegg.com/dell-xps-8940-business-desktops-workstations/p/1VK-0001-5N3R6?Item=9SIAKKBDW70465.

Employer costs for employee compensation – March 2021. 2021. Department of Labor: Bureau of Labor Statistics, USDL-21-1094.

Ground control system for unmanned vehicles. in Oz Robotics [database online]. ozrobotics.com, 2021 [cited 8/5 2021]. Available from https://ozrobotics.com/shop/ground-control-system-for-unmanned-vehicles-12pcx-hotas-hd/.

Saxon monitor M14 long duration UAV. in Oz Robotics [database online]. 2021 [cited 8/5 2021]. Available from https://ozrobotics.com/shop/saxon-viper-m14-monitor/.

3dm-rq1-45 GPS/INS. in Parker Hannifin Corp [database online]. 2020 [cited 8/5 2021]. Available from https://www.microstrain.com/inertial-sensors/3dm-rq1.

Aisafenix 1k. in Specim Spectral Imaging [database online]. 2020 [cited 8/5 2021]. Available from https://www.specim.fi/wp-content/uploads/2020/03/AisaFENIX-1K-Technical-Datasheet-01.pdf.

Computer recommendations for GIS students and professionals. in Temple University [database online]. 2018 [cited 8/5 2021]. Available from https://sites.temple.edu/psmgis/computer-recommendations-for-gis-students-and-professionals/.

Parc scientists develop tiny, low-cost hyperspectral imaging cameras. in Intrado [database online]. Global News Wire, 2015 [cited 8/5 2020]. Available from https://www.globenewswire.com/news-release/2015/10/26/780079/0/en/Parc-Scientists-Develop-Tiny-Low-Cost-Hyperspectral-Imaging-Cameras.html.

Combat Proven Technologies. Advanced mini link system (AMLS). . Combat Proven Technologies, 2021 [cited 8/5 2021]. Available from https://cp-techusa.com/wp-content/uploads/2019/09/amls.pdf.

Drug Enforcement Administration Office of Intelligence. 1991. Coca cultivation and cocaine processing: An overview. Department of Justice.

He, S., Kate, Duccio Rocchini, Markus Neteler, and Harini Nagendra. 2011. Benefits of hyperspectral remote sensing for tracking plant invasions. Biodiversity Reveiw (21, March 2011), https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1472-4642.2011.00761.x.

L3Harris. Intelliearth service. in L3Harris [database online]. 2021 [cited 08/05 2021]. Available from ttps://intelliearth.harrisgeospatial.com/.

Muse, Toby. 2020. Kilo: Inside the deadliest cocaine Cartels—from the jungles to the streets.William Morrow and Company.

National Aeronautics and Space Administration Staff. What are passive and active sensors? in National Aeronautics and Space Administration [database online]. NASA.gov, 2017 [cited 08/05 2021]. Available from https://www.nasa.gov/directorates/heo/scan/communications/outreach/funfacts/txt_passive_active.html.

News Desk. 2020. Price breakthrough in high resolution satellite imagery via soar platform. Geospatial World, 06/05/2020, 2020.

Reuters Staff. 2021. Colombia targets repeat of last year's coca eradication in 2021. Reuters, 01/04/2021, 2021.

Saxon Aerospace. Monitor series. in Saxon Aerospace [database online]. 2021 [cited 8/5 2020]. Available from https://www.saxonunmanned.com/monitor-series-uas.

United Nations Office on Drugs and Crime. 2020. Booklet 3: Drug supply. in world drug report 2020. UNODC.

Weather & Climate staff. Average monthly snow and rainfall in Cúcuta (Norte de Santander) in inches. in Weather & Climate [database online]. 2021 [cited 08/05 2021]. Available from https://weather-and-climate.com/average-monthly-precipitation-Rainfall-inches,Cucuta,Colombia.

———. Average monthly snow and rainfall in La Paz in millimeter, Peru. in Weather & Climate [database online]. 2021 [cited 08/05 2021]. Available from https://weather-and-climate.com/average-monthly-precipitation-Rainfall,la-paz-bo,Bolivia.

———. Average monthly snow and rainfall in Pasto (Nariño) in millimeter. . in Weather & Climate [database online]. 2021 [cited 08/05 2021]. Available from https://weather-and-climate.com/average-monthly-precipitation-Rainfall,pasto-narino-co,Colombia.

———. Climate in Abancay (Apurimac), Peru. in Weather & Climate [database online]. 2021 [cited 08/05 2021]. Available from https://weather-and-climate.com/average-monthly-Rainfall-Temperature-Sunshine-fahrenheit,abancay-apurimac-pe,Peru.

World Weather Online Staff. Mocoa monthly climate averages, Putumayo, CO. in World Weather Online [database online]. 2021 [cited 80/05 2021]. Available from https://www.worldweatheronline.com/mocoa-weather-averages/putumayo/co.aspx.

ZipRecruiter. Imagery intelligence analyst salary. in ZipRecruiter [database online]. 2021 [cited 8/5 2021]. Available from https://www.ziprecruiter.com/Salaries/Imagery-Intelligence-Analyst-Salary.

———. Senior geospatial analyst. in ZipRecruiter [database online]. 2021 [cited 8/5 2021]. Available from https://www.ziprecruiter.com/Salaries/Senior-Geospatial-Analyst-Salary

______. UAV drone pilot salary. in ZipRecruiter [database online]. 2021 [cited 8/5 2021]. Available from https://www.ziprecruiter.com/Salaries/UAV-Drone-Pilot-Salary.