PHOTOGRAMMETRIC SMALL UAV IN GEOSPATIAL RESEARCH AND EDUCATION AT MICHIGAN TECH UNIVERSITY

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ABSTRACT

The Surveying Engineering program at Michigan Technological University is heavily involved in research related to acquisition and photogrammetric processing of UAV imagery. The Enterprise program at Michigan Tech gives interdisciplinary teams of students the opportunity to work for several years in a student-led, business-like setting to solve real world engineering problems via end-to-end product development and project management. The Photogrammetric Small UAV (PSUAV) platform was designed by the Student Aerospace Enterprise (SAE) in partnership with Surveying Engineering faculty. This PSUAV project presents significant improvements from previous UAV models, has a wingspan of 72 inches and a chord of 10 inches supporting an angle of incidence of 5 degrees. The PSUAV is equipped with Procerus autopilot system and can carry up to 10 pounds of payload. It is currently fitted with a Cannon Rebel EOS 12MP camera. Research has been started from the development of calibration sites deploying surveying quality equipment. Work on processing of the obtained datasets encompasses these tasks: camera calibration, bundle block adjustment, image co-registration, mosaic, and feature extraction from PSUAV imagery. Comparison of the results obtained from the PSUAV to respective results obtained from traditional aerial photogrammetry provides an excellent opportunity for investigative research directed at the accuracy and applicability of PSUAV imagery for specific mapping projects. Due to the high dynamics of some spatial processes such as emergency situation management, natural and anthropogenic disasters, and many other application scenarios, PSUAV data acquisition and processing can be suitable to fulfill accuracy, information and productivity requirements.

KEYWORDS: UAV, Geospatial/Surveying Education, DLT, Imaging

INTRODUCTION

At present, there is a high demand for the timely delivery of the local geospatial data, especially in emergency situations response application scenarios. Therefore, the pace of information collection and processing should be at an appropriate rate. Typically, these geospatial data obtaining processes are local in nature, affecting small areas, scattered in space and are quite numerous. In the land registration and land surveying applications - the concentration of changes occurring on land within the administrative and territorial units is also usually not large. Therefore the use of manned aircraft platforms, albeit small, will result in unnecessary costs. From an economic stand point it may become clearly unjustified. Even if there is a justification of this expense related to the urgency and importance of the task (such as emergency management situations), these aerial surveying projects are not seldom absent of favorable weather conditions, leading to the disruption of the project schedule. Use of ground only data collection methods and land surveys also increases the cost of work. In these described circumstances, the use of easy to transport, remotely-controlled aircrafts equipped with the necessary imaging equipment allows very quick performance of all the necessary project stages and allows for flexible adjustments to the ongoing technology, even in the absence of stable weather conditions needed for the traditional aerial survey ("window" is always there). This is very much a trend in recent years. To accommodate the above mentioned trend, the Surveying Engineering program at Michigan Tech University started research and development collaborative projects resulting in the design and first tests of the PSUAV geospatial data acquisition platform. This paper describes the research performed and preliminary results in more detail.

PSUAV AERIAL PLATFORM DESIGN

In 2010 SAE team developed aircraft platform which was first tested in April 2010. PSUAV aerial platform has a Wingspan of 72 in. and Chord of 10 in supporting an angle of Incidence of 5 degrees. Figure 1 depicts PSUAV design in more detail.

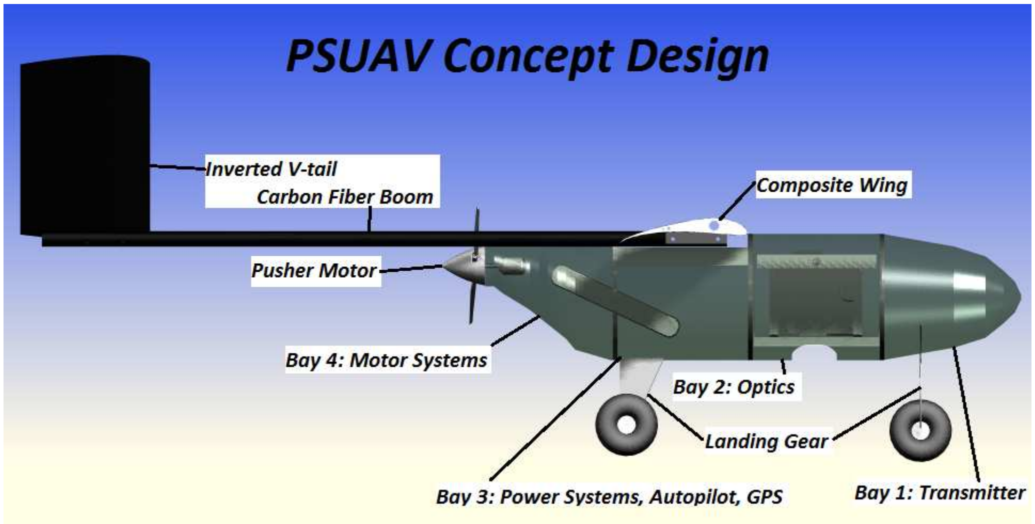


Figure 1. PSUAV design.

Design of platform is made based on S1223 [S1223] airfoil which provides high efficiency on low airspeeds. Control surfaces used to operate aircraft are ailerons. The platform deploys a V-tail which is the simplest design and allows for propeller clearance. After mathematical modeling 26” V-Tail size was ideal but 36” was used for stability. PSUAV is driven by Rimfire GPM4700 electrical motor [Rimfire]. Great Planes 12V battery allows operating airplane during 2.75 hour. Figure 2 depicts motor and batteries deployed in PSUAV.

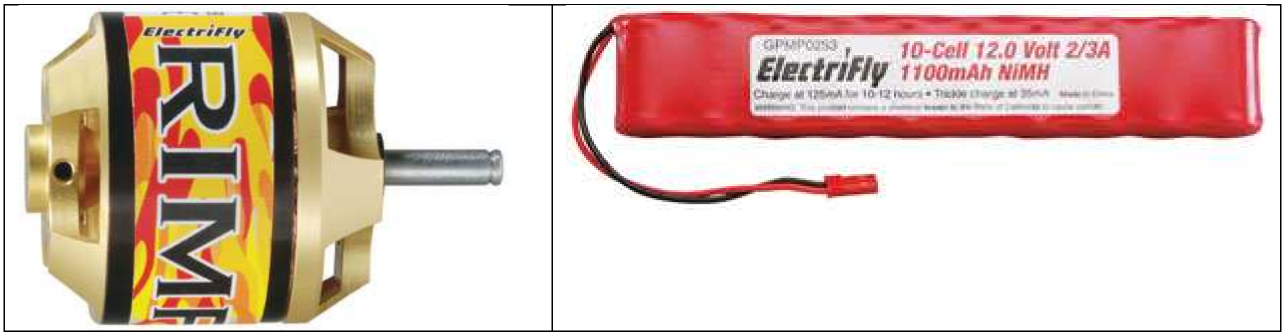


Figure 2. Electrical engine and batteries used for PSUAV.

Configuration described allows PSUAV to carry payload of minimum 1 and maximum 5 kilograms. After modeling SAE team performed airframe and fuselage construction. During this construction the following technological processes were performed:

1. Creation of fiberglass negative of the foam cutout
2. Carbon fiber laid on foam mold then pressed together with fiberglass negative. Vacuum sealed to insure complete form fit to the mold
3. Right halve of fuselage just out of the mold
4. Line up and assemble two halves of fuselage

Some of these processes are illustrated on Figure 3.

Figure 3. Airframe and fuselage fabrication.

One of the important elements of design is camera mount. Figure 4 shows camera mount construction developed for PSUAV. It allows keeping camera preferably vertical while airplane position gets deviations from the vertical line.

Figure 4. Camera mounts design and implementation.

Cannon Reibel EOS 12 MP camera with fixed 50 mm focal distance optical system was used during experimentations with SUAV platform. Camera setup for real flight in manufactured PSUAV is demonstrated on Figure 5.

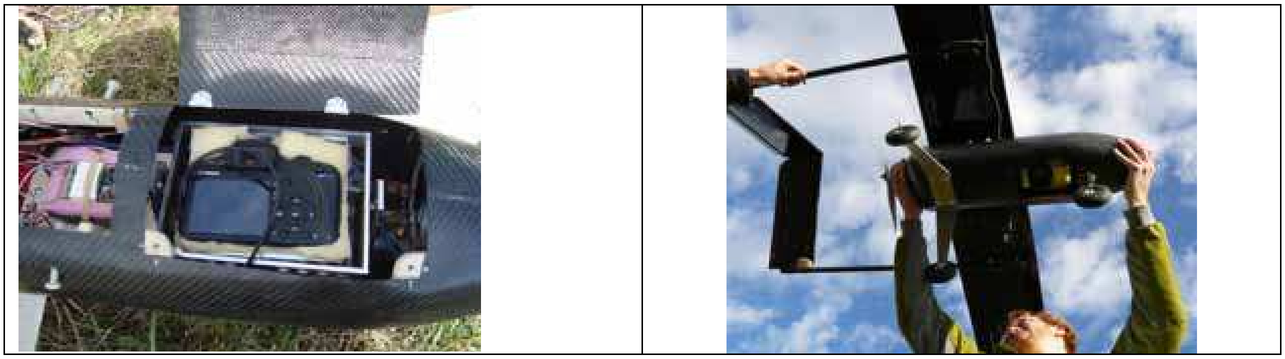


Figure 5. Camera installed into PSUAV mount during test flight.

PSUAV FLIGHT AND CAMERA CONTROL

PSUAV control electronics and software consist of two segments: *onboard*, in flight control system and *ground based* control system. Specifically onboard control segment include: autopilot, drive motors, actuators and camera control. Ground control encompasses: notebook with control software, commbox transceiver, RC Transmitter and USB gamepad. Aerial platform can be controlled from the ground in 2 modes: manual radio control (RC) or by means of an autopilot system (AUTO). Auto-pilot control is practical for the teaching process since the manual RC mode requires extensive pilot training and would increase the risk of damaging the high value PSUAV platforms. However, setup and adjustments of autopilot is very complicated process. Onboard autopilot hardware is crucial for the successful use of PSUAV in classes. This autopilot [Kerstel] is depicted on Figure 6.

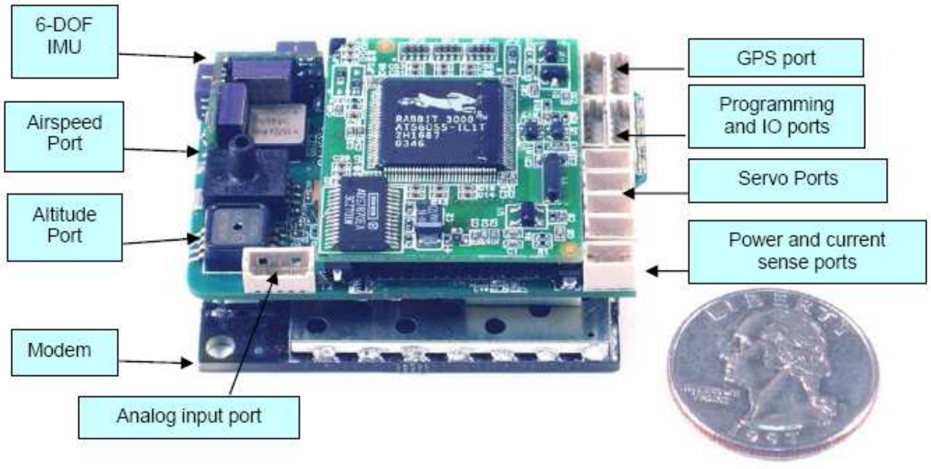


Figure 6. Kestrel autopilot onboard hardware.

This important element of the PSUAV consist of : Main Board, Rate Gyros, Serial Ports, Servo Ports, Pressure Transducers, Pitot Tube, GPS Antenna, 900 Mhz Modem, and Communications Antenna

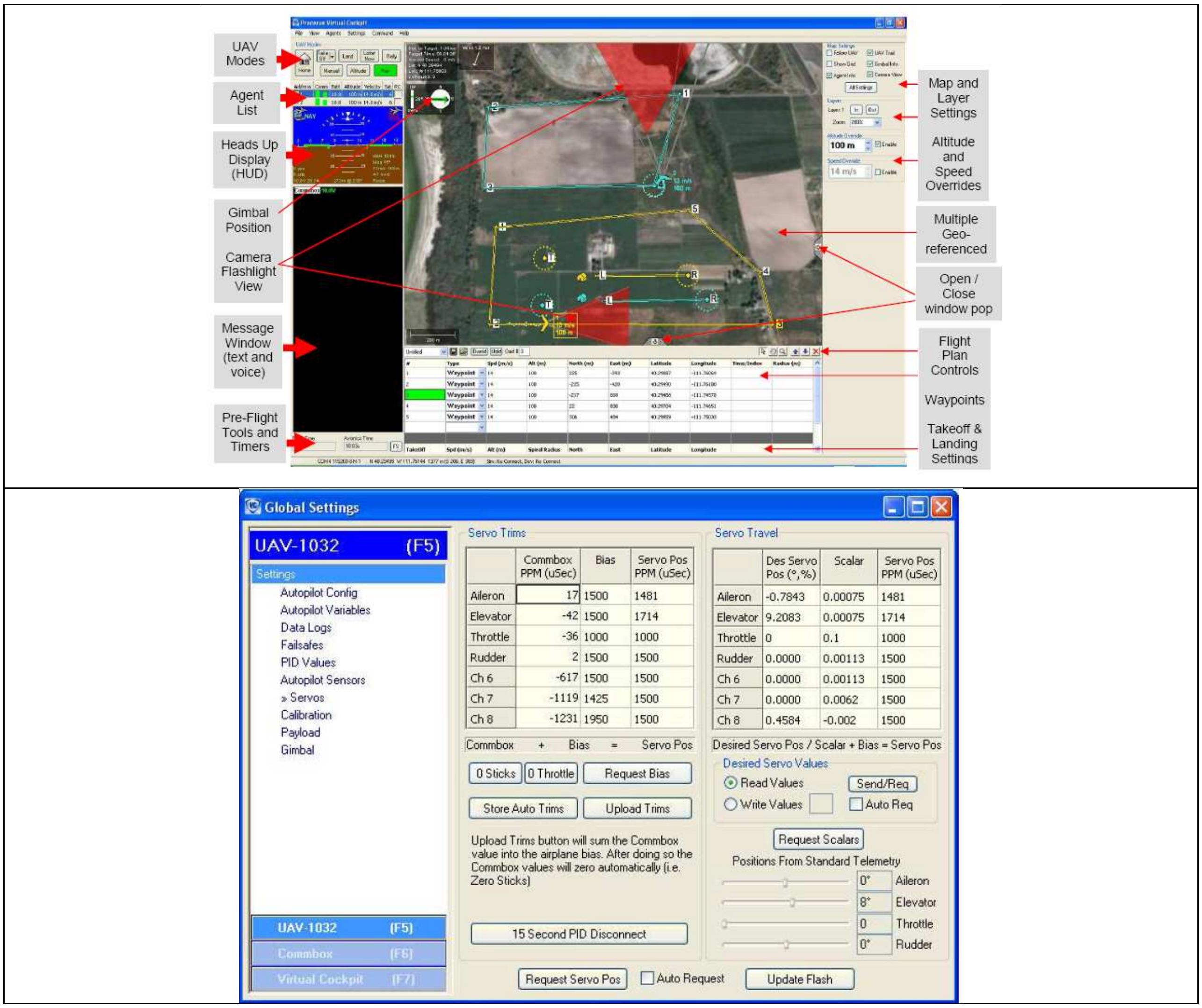
Auto-pilot is operational by means of ground station components which include: Commbox, Laptop, RC, Transmitter/Cable, GamePad Controller, Cockpit Software Interface. Figure 7 depicts Ground segment elements deployed in PSUAV.

Figure 7. PSUAV ground control system.

One of the important controls needed for proper use of PSUAV for mapping is remote control of camera during operation. It was implemented by two BJT transistors scheme(shown on Figure 8) as electrical switches to control the autofocus and shutter of the camera. Input high voltage (+5V) is provided from Kestrel Autopilot DIO pins. Both AF and Shutter pins must be set as high on camera to acquire images.

Figure 8 . PSUAV camera control block.

Man-machine interface of Ground Control system is realized by means of Virtual Cockpit software [Virtual Cockpit]. This software allows setup way-points on mapping base and browsing and changing all the setting of auto-pilot in easy to use manner. Samples of Virtual Cockpit control windows are shown on Figure 9.



Servo Trims

	Commbox PPM (uSec)	Bias	Servo Pos PPM (uSec)
Aileron	17	1500	1481
Elevator	-42	1500	1714
Throttle	-36	1000	1000
Rudder	2	1500	1500
Ch 6	-617	1500	1500
Ch 7	-1119	1425	1500
Ch 8	-1231	1950	1500

Commbox + Bias = Servo Pos

Upload Trims button will sum the Commbox value into the airplane bias. After doing so the Commbox values will zero automatically (i.e. Zero Sticks)

Servo Travel

	Des Servo Pos (°,%)	Scalar	Servo Pos PPM (uSec)
Aileron	-0.7843	0.00075	1481
Elevator	9.2083	0.00075	1714
Throttle	0	0.1	1000
Rudder	0.0000	0.00113	1500
Ch 6	0.0000	0.00113	1500
Ch 7	0.0000	0.0062	1500
Ch 8	0.4584	-0.002	1500

Desired Servo Pos / Scalar + Bias = Servo Pos

Desired Servo Values

● Read Values

○ Write Values

☐ Auto Req

Positions From Standard Telemetry

0°	Aileron
8°	Elevator
0	Throttle
0°	Rudder

☐ Auto Request

Figure 9. Virtual Cockpit man-machine interfaces examples.

Additional functionality appended to Virtual Cockpit by means of API is driver of camera control system. This driver deploys auto-pilot port signal control for working with the camera control block.

PSUAV FLIGHT PREPARATION AND PERFORMANCE

Typical operational workflow to perform aerial image acquisition flight includes the following steps:

I. Vehicle pre-checking:

- Confirm all Assembly Fasteners are Securely Attached
- Inspect Control Horns, Control Rods, and Servo Arms for Damage/Attachment
- Ensure Propeller Securely Fastened
- Ensure Prop Adapter not Rubbing Boltheads
- Check that Servo Extension/Adapter Wires are Firmly Attached to Servo Wires
- Ensure GPS Antenna Securely Attached

II. Final launch preparations:

- Insert Camera
- Attach Camera Actuator to Camera

- Plug-in and Insert Battery
- Attach Battery Door
- Perform Procerus Pre-Flight Process
- Turn On Camera
- Actuate Camera
- Fasten Canopy Door
- Launch

Procerus autopilot allows execution of the following flight control operations after the launch: Real-time Display of Flight Track, Change Flight Plan Mid Flight, Waypoint Triggered Servo Feature, and Data Logging.

EXPERIMENTAL RESULTS

During phtogrammetry class students designed a test-object flight near Michigan Tech campus. To develop this test-object flight, students made photogrammetric target “cross” from cardboard. (See Figure 10).

Figure 10. Photogrammetric target is installed on the ground.

The test–object design included 18 targets placed on the ground according to the scheme presented on Figure 11. Nine targets were placed within the projected footprint of a single image for calibration purposes, and the rest of targets were equally distributed over the projected flight strip.

Figure 11. a.)Targets distribution over test-objects. b) Surveying engineering students coordinating targets using GPS RTK system.

Each target was surveyed with a Trimble R8 GNSS system utilizing real-time kinematic (RTK) technology with positional accuracy of 10 mm horizontal and 20 mm vertical. PSUAV flight with image acquisition was then performed. Figure 12 depicts PSUAV in mission and view of photogrammetry class from PSUAV.

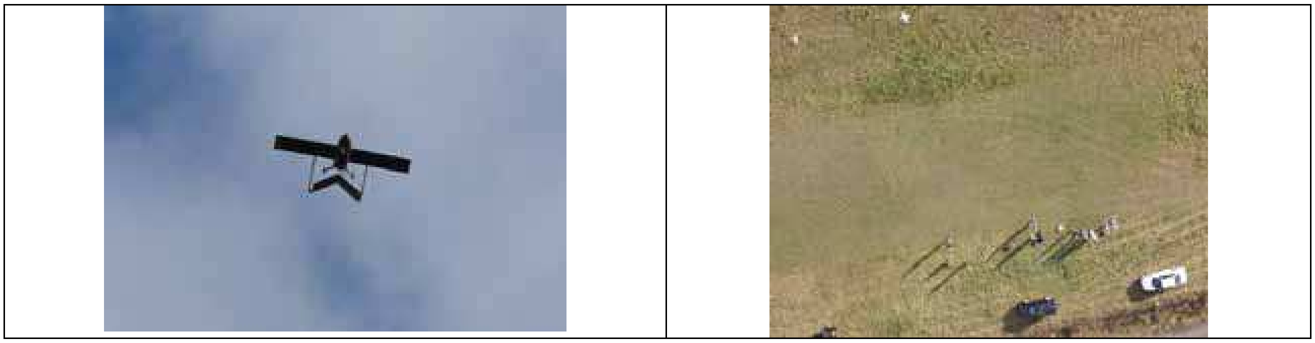


Figure 12. a. PSUAV during mission. b. Photogrammetry class – view from PSUAV.

Experiments were performed for the flying heights varied from 50 to 100 meters. Image sample used for experiments and capability of interpreting targets for measurements in terms of GSD are given on Figure 13.

Figure 13. Sample image overview and sample target on this image.

Processing the results from the PSUAV test-object flight is the final step. Since at the moment we have no camera calibration parameters – Direct Linear Transform [Abdel-Aziz, & Karara, 1971] method was applied instead of rigorous sensor model for PSUAV imagery processing. This method requires at least 6 ground control points. The rest of control points were used as a check points. Special Matlab program was developed to perform this processing. Sample of residuals we obtained on control points are given in Table-1 and for check points in Table-2 respectively.

Table -1 . Errors analisys on control points (units - **centimeters**)

Point	Residual X	Residual Y	Position Residual
117	-2.1084	-1.5611	2.6235
119	0.6099	0.9947	1.1668
113	-0.1519	-0.5130	0.5350
109	3.8583	2.1770	4.4301
108	-1.2500	-0.5113	1.3506
102	-0.9673	-0.5949	1.1356

Table-2. Errors analysis on Check points (units - **centimeters**)

Point	Residual X	Residual Y	Position Residual
118	-17.7434	3.9720	18.1826
116	-5.8124	40.7389	41.1515
115	-28.9724	1.8514	29.0315
114	-42.1072	-11.2191	43.5762
110	4.8258	-13.8923	14.7066
111	3.4105	-84.7896	84.8582
107	36.6145	-45.2785	58.2303

Point numbers on Tables 1 and 2 correspond to scheme on Figure 11a. Summary of statistic estimation including mean error and root mean square error is given in Table 3

Table 3. PSUAV imagery accuracy analysis summary

	Mean Error	RMSE
Control points	1.8736	1.4288
Check points	41.3910	24.4310

It is visible form Table-3 that accuracy of PSUAV imagery is comparable with surveying sub-meter accuracy of on-the-ground mapping. Thus, platform is potentially applicable to scenarios described in introductory section of the current paper. Rigorous senor modeling achieved in the future by means of calibration will significantly improve accuracy of results.

CONCLUSION AND OUTLOOK

PSUAV platform provides sub-meter mapping accuracy and thus can be considered as a useful asset for any mapping and/or GIS data obtaining processes. Michigan Tech's PSUAV photogrammetry class combines for students both elements of excitement and practical application of photogrammetry practices. Specifically, flight planning and calibration are considered a hands-on experience during PSUAV labs. Moreover, students are learning about different geospatial fields such as platform guidance navigation and control, robotics, and sensors. They will be able to use the skills and knowledge obtained from this lab for real-life scenarios.

FUTURE WORK

Future developments will be devoted to the finalization of the PSUAV data obtaining processes, including auto-pilot technology adapting and rigorous camera calibration and sensor model deployment. GIS and 3D visualization environments integration are also within scope of the future efforts. Moreover, applying various spectral filters may develop a valuable potential for remote sensing studies. For instance, infrared filters may be used for wildfire detection and prevention, etc. Fusion of the UAV imagery with aerial and satellite data opens another opportunity for graduate and post-graduate research.

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