Bringing drones to the people: Development of a low-cost fixed-wing UAV and multispectral camera for custom application in earth science field work, education, and outreach

Casey Duncan[1], David Wheatley[2], and Sam Chesebrough[3]

[1]University of Utah
[2]Chevron Corporation
[3]Sarcos Robotics

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Abstract

Incorporation of Uncrewed Aerial Vehicles (UAVs) has greatly enriched earth science field data collection but the cost of acquiring UAVs, particularly those with customizable payloads, can be high, thus creating a barrier to using these valuable systems. We set out to design and build a low-cost 'student budget' drone and multispectral camera that could be customized for a variety of field, education, and outreach applications. UAV development followed an iterative design process guided by open-source plans resulting in a progressive series of 5 design iterations each incorporating lessons learned from previous versions. The final aircraft incorporates a flight controller for autonomous flight and a removable/customizable payload pod. Cheap components allow for easy and inexpensive repairs when damaged in the field. The final design cost is $625, but this is a max cost as a simpler system could be built based on the design for <$300. The multispectral camera was built with the popular Raspberry Pi 2 computer, standard and infrared cameras, and low-cost/well-characterized filter material. The resulting multispectral camera collects imagery in the visible and near-infrared spectrum, with a total cost of ~$230. The UAV and camera cost ~1/5 & ~1/10 that of commercial systems, respectively. Unfortunately, the camera did not yield research-grade results due to image inconsistencies. Despite the lower cost, there are additional considerations when choosing a UAV and imaging platform including data needs, data quality and repeatability, ease of data collection and processing, required UAV pilot skill, and time investment for UAV construction. Given the ease of use and minimal pilot training time, commercial systems (e.g. DJI quadcopter) provide the best fit for many research applications like aerial photography or 3D outcrop modeling. However, for more complicated data needs (e.g., multispectral imaging) and/or projects with small budgets, a low-cost UAV with a customizable payload can open up new data collection avenues and scientific inquiry that was previously unavailable. Additionally, this approach has applications in STEM education to teach engineering processes, aeronautics, remote sensing, etc., and is useful as an outreach tool to educate general audiences about UAVs and their responsible use.

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Casey J. Duncan[1], David F. Wheatley[2], Sam Chesebrough[3]

1- University of Utah, SLC, UT; 2- Chevron Corporation, Houston, TX; 3- Sarcos Corporation, SLC, UT

THE UNIVERSITY OF UTAH
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Introduction

Uncrewed Aerial Vehicles (UAVs) have become ubiquitous in field-based studies within many fields and has greatly enriched earth science field data collection. However, the cost of acquiring UAVs, particularly those with customizable payloads, can be high, thus creating a barrier to using these valuable systems. Fortunately there exists a side to the remote control airplane hobby wherein hobbyists construct aircraft using very cheap and widely available materials (i.e. foam board, hot glue, tape) to create a wide array of aircraft designs. In addition, other hobbyists are beginning to incorporate off-the-shelf flight controllers, long-distance transmitters, etc. to make their own autonomous UAVs. Merging these two hobbyist approaches then represents an opportunity to create a UAV usable for research and education/outreach as well as to overcome barriers of entry to UAV usage.

The Challenge

'Typical' steps in a UAV-derived map/model workflow:

	1. Image/Data Collection	2. Image Processing/ Photogrammetry	3. Map Creation
Barriers to Use	- Access to aircraft, cameras - FAA Part 107 Cert.	- Software (photogrammetry) - Computer requirements - Data storage	- Software - Computer requirements - Data storage - Data sharing

The Challenge: Build a fully autonomous UAV using simplified construction methods/materials, on a 'grad student' budget.

Overall Budget/Considerations

Spirit of MarahUTE	
Item	**Cost**
Aircraft Materials	$ 25.37
Plane Motor/Servos	$ 72.70
Transmitter/Receiver	$ 127.83
Pixhawk Flight Controller	$ 199.00
Telemetry Hardware	$ 27.99
GPS Receiver	$ 101.40
Batteries	$ 63.99
Total	**$ 618.28**

SpectroscoPi	
Item	**Cost**
Raspberry Pi 2	$ 45.00
Pi Camera	$ 71.88
NoIR Camera	$ 20.00
Multiplexer	$ 52.99
Battery	$ 9.99
Filters	$ 2.03
Flash Drive	$ 23.50
Case Materials	$ 5.00
Total	**$ 230.39**

The UAV and camera together cost ~$850, more within reach of many individuals and organizations that wish to use drones. However, factoring in time required to build the plane (~30 hrs) and compared to commercial cameras, this approach might be better used for educational applications, outreach, etc.

Conclusions

- It is possible to create a low-cost alternatives to commercial drone systems and multispectral cameras.
- Whereas building the plane saved money, it is easier (and time-saving) to buy an aircraft and incorporate the flight controller and cameras.
- Piloting skill and software/hardware barriers are additional constraints to using these solutions.
- The best application of this system is in educational and outreach applications for engaging students and teaching skill-based curriculum.

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References
1. Flite Test, 2017, Retrieved from www.flitetest.com.
2. Clark, R.N., Swayze, G.A., Wise, R., Livo, E., Hoefen, T., Kokaly, R., Sutley, S.J., 2007, USGS digital spectral library splib06a: U.S. Geological Survey, Digital Data Series 231.

Spirit of MarahUTE: UAV Development

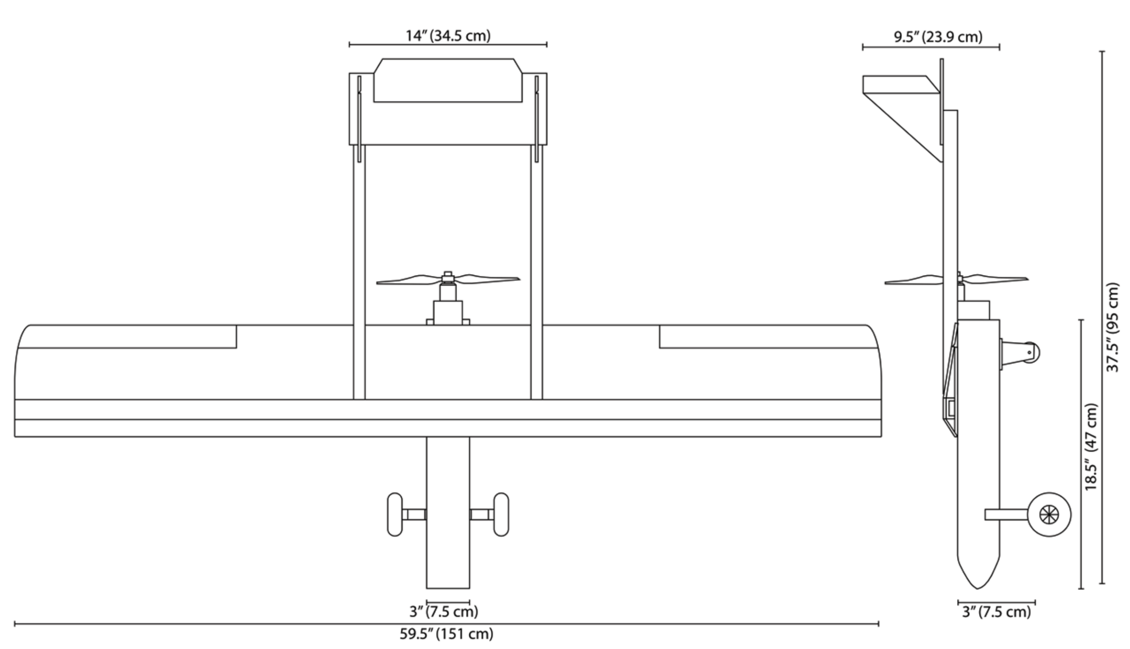
Goals/Features

1. Low cost (<$800).
2. Fully autonomous.
3. Flight times >15 min.
4. Simple Construction and maintenance.
5. Easily obtainable parts.
6. Durable for field use.

Design Evolution: Trial and Error

Ailerons, cargo room in fuselage (Design 'FT Mini Guinea' from Flite Test) + "Pusher" motor, wider fuselage (Design 'FT Explorer' modified from Flite Test) + Twin tail boom for cargo room in fuselage + Twin tail boom, Instrument tray, shorter tail = External instrument tray, longer fuselage, 3D printed landing gear

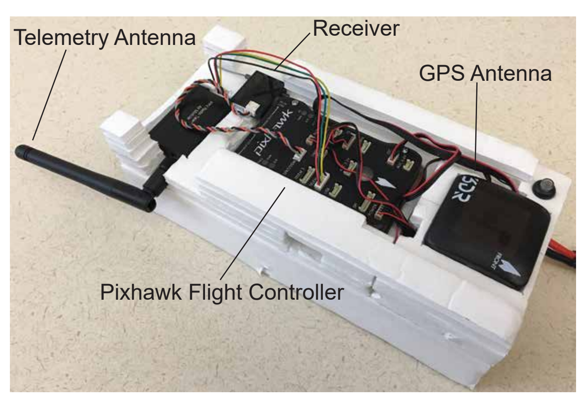
Final Product



Attributes

Empty Weight: 870.2 g	Payload: 615 g
Flight Time: up to ~30 min	Autonomous
Top Speed: 21.3 m/s (48 mph)	GPS Position Tracking
Cruise Speed: 10 to 15 m/s (22 to 34 mph)	Flight logs
	Customizable

Payload



UAV "Brain": Pixhawk Flight Controller

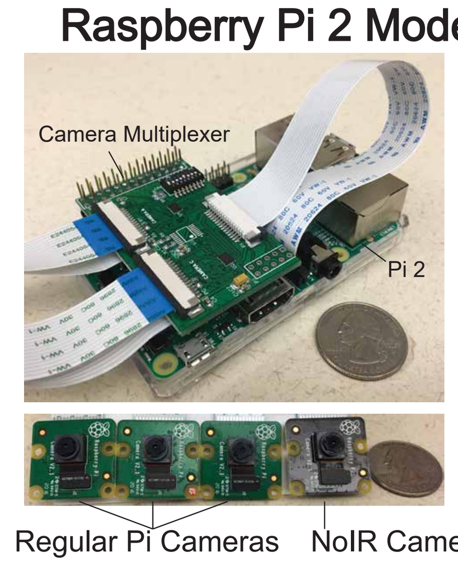
Imaging instrument tray

SpectroscoPi: Multispectral Camera Development

Goals

1. Low cost (<$500).
2. Easily constructed for 4-spectral band imaging.
3. Ability to be integrated into the UAV.
4. Camera script designed to:
   - Run on boot.
   - Cycle through the cameras.
   - Capture and move images to external flash drive.
5. Easily customizable for user's specific application.

Raspberry Pi 2 Model B and Cameras



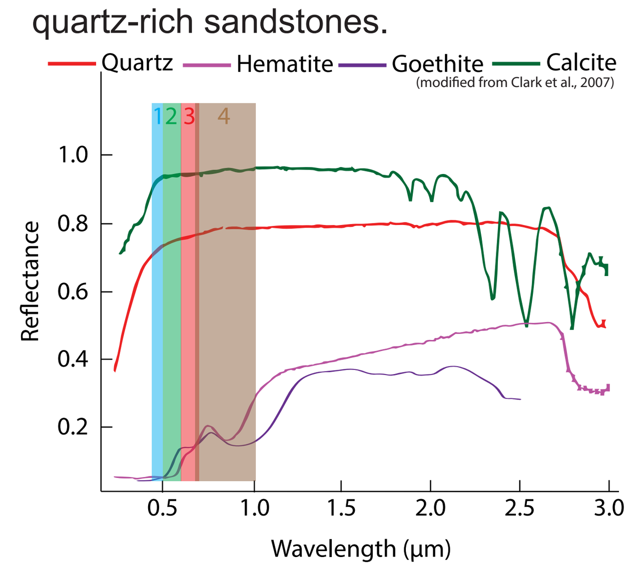
- Multispectral camera based on the popular Raspberry Pi 2 computer.
- Camera multiplexer used to attach 4 cameras to a single Raspberry Pi 2.
- 3 regular cameras and 1 'NoIR' camera (infrared filter removed).
- Allows for imaging of 4 spectral bands in combination with Roscolux color filters.
- Tradeoff between spatial resolution (5MP) for greater spectral resolution.

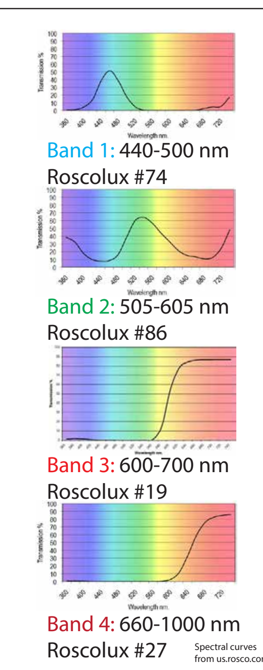
3D Printing/Python Coding

- Camera case was custom designed in Autodesk Fusion360.
- Lulzbot Taz 5 printer used to 3D print the case, filter plate, and UAV parts.
- Python 3.0 script triggers cameras and stores images.
- Removable filter plate = customizable.

Filter Selection

Filters chosen to map iron oxides in quartz-rich sandstones.





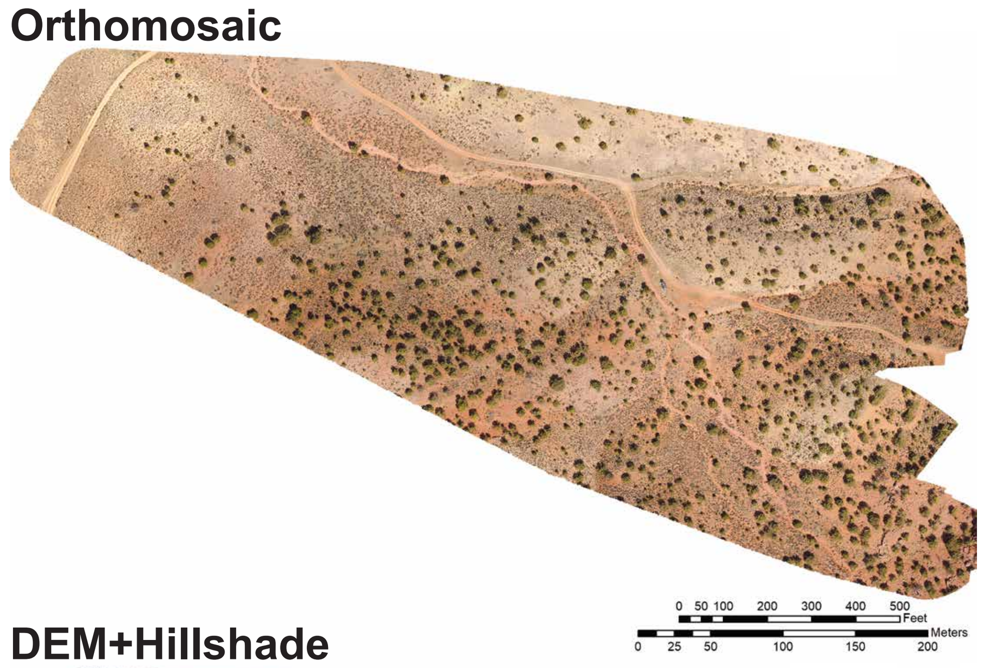
Test Images

- Test images indicate that cameras are working as expected.
- Image compositing (RGB and NIR) dependent on accurate positioning of images, but layout of the cameras introduces slight position changes for close-up images.

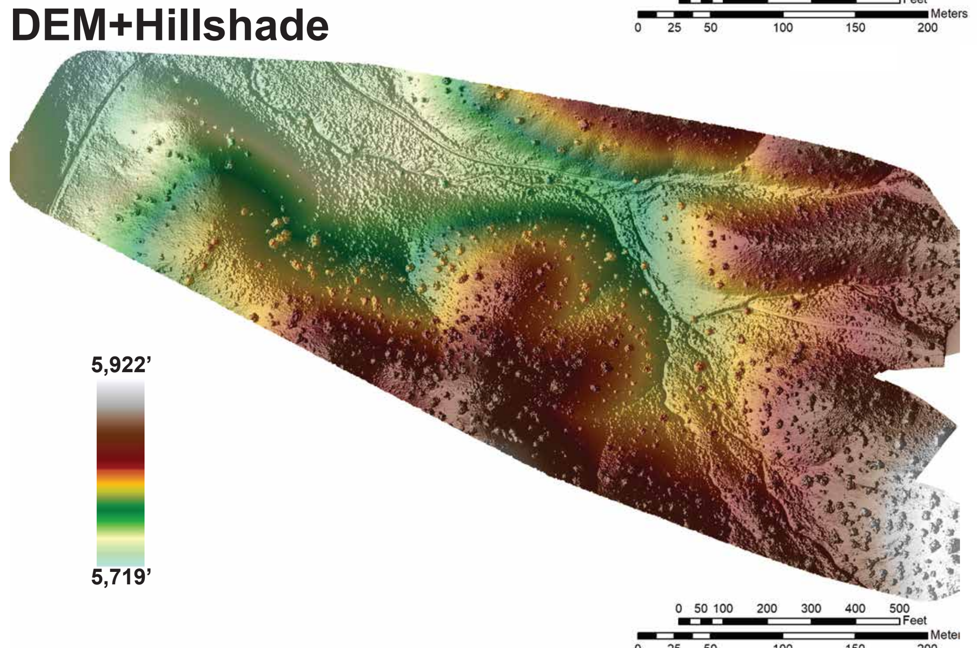
Spirit of MarahUTE Sample Data Products

Comparison of map/DEM created with commercial Phantom vs the DIY solution

Orthomosaic

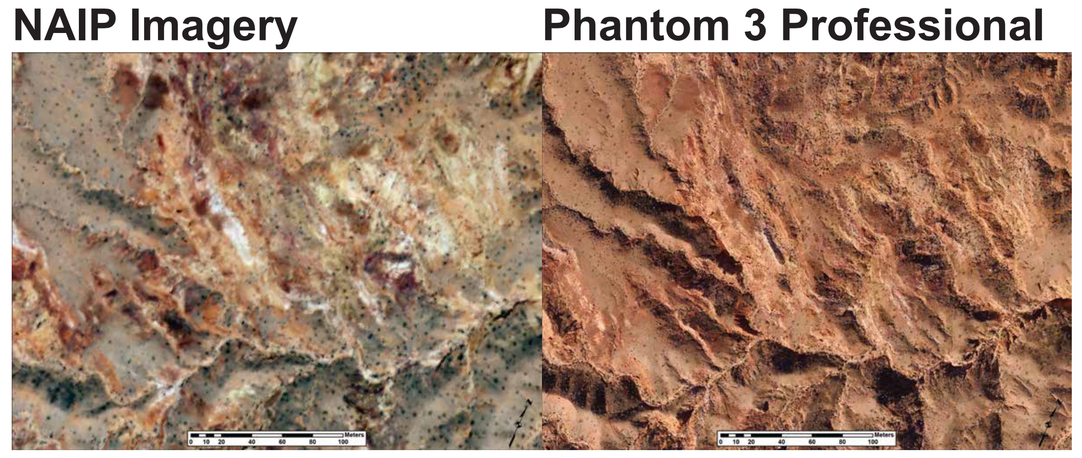


DEM+Hillshade

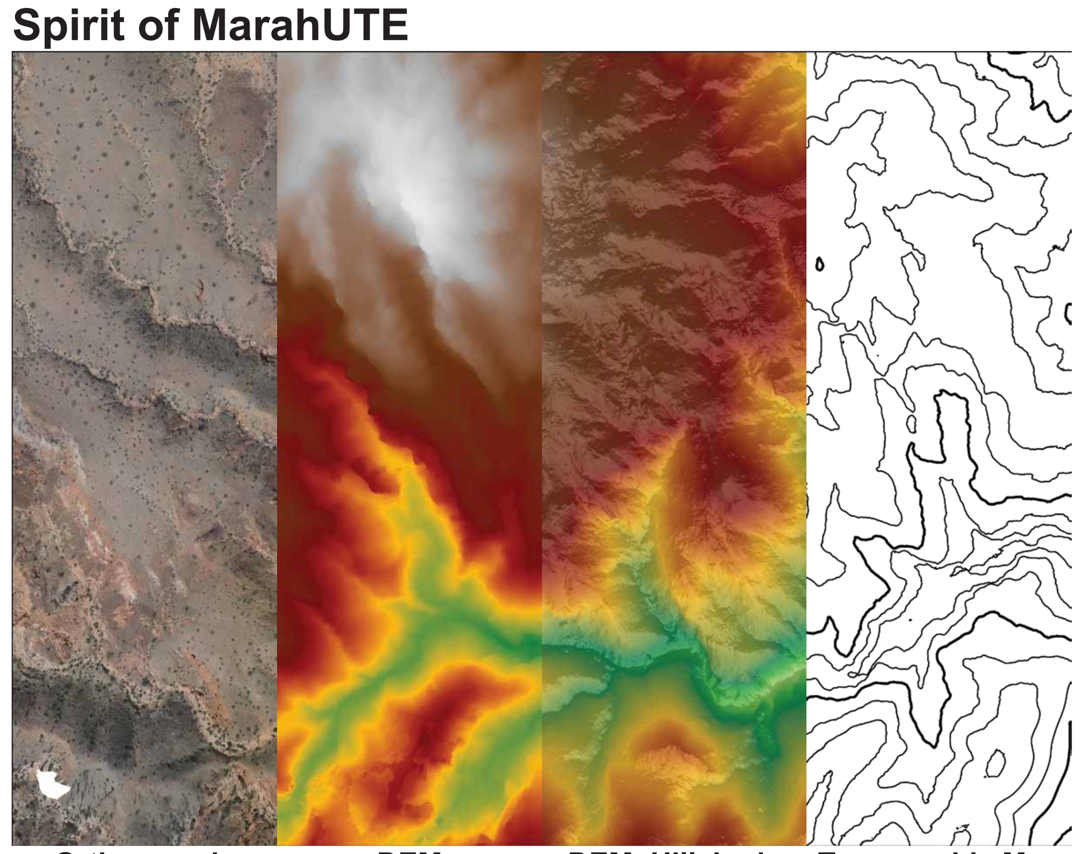


Left: This simple orthomosaic and DEM from Parowan Gap, UT was created using a DJI Phantom 3 Professional illustrating what can be done with a commercial system.

Right: Images and derived data products for a site in southern NV, comparing available NAIP imagery, orthomosaic created with a commercial quadcopter (Phantom 3 Professional), and those created by using the Spirit of MarahUTE and a GoPro Hero 5. panels are parts of the same frame.

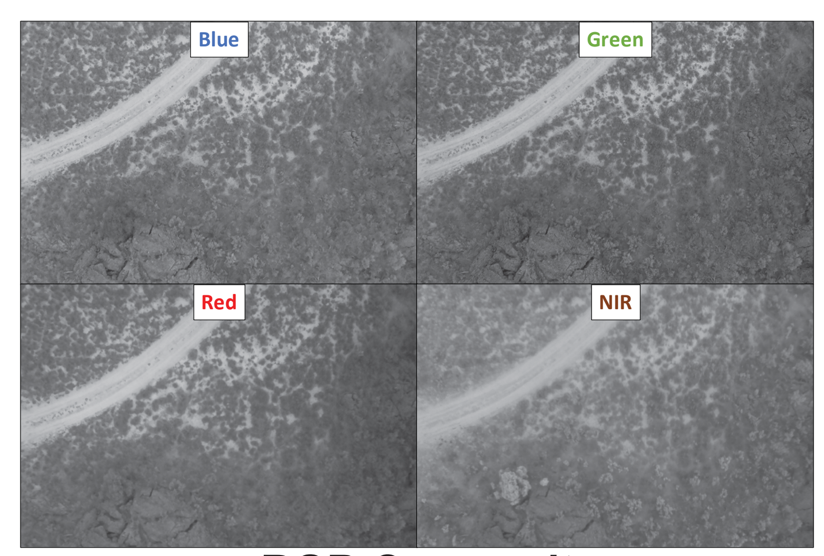


Spirit of MarahUTE



SpectroscoPi Sample Data Products

Example 1: Imagery from Quadcopter



For these images, the SpectroscoPi was flown aboard a DJI Phantom 3 Professional, which allowed for consistent image collection from a stationary aircraft. Resultant frames were georeferenced and composited in ArcMap.

RGB Composite

CIR Composite

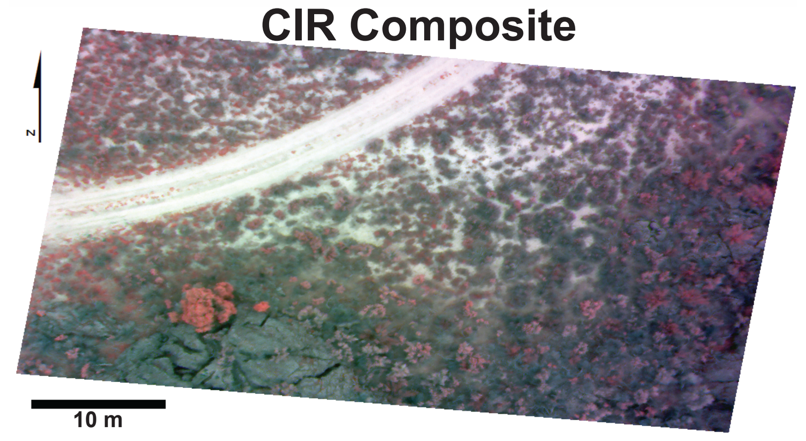
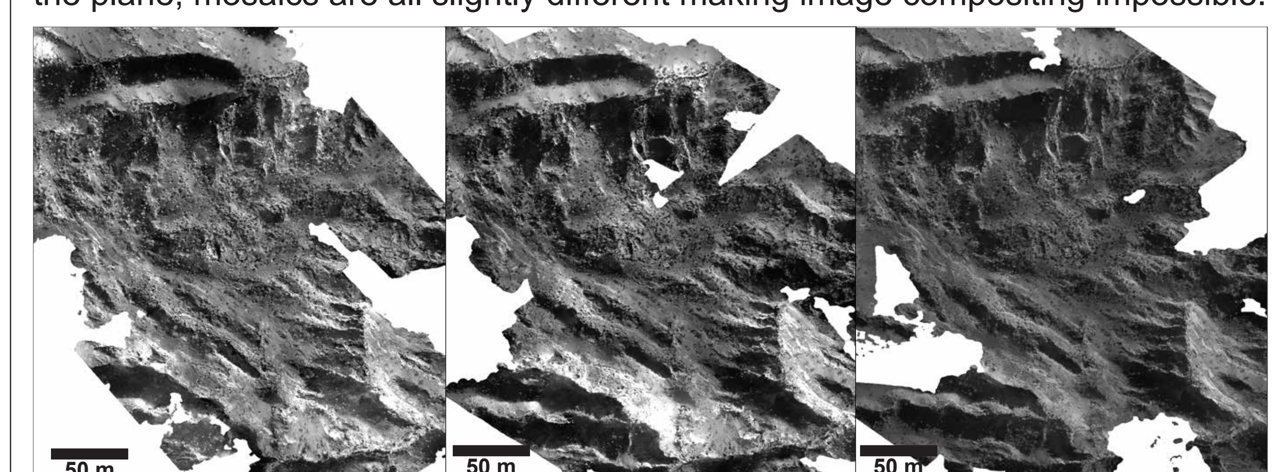


Image composites indicate that, in theory, the SpectroscoPi is capable of delivering expected results:

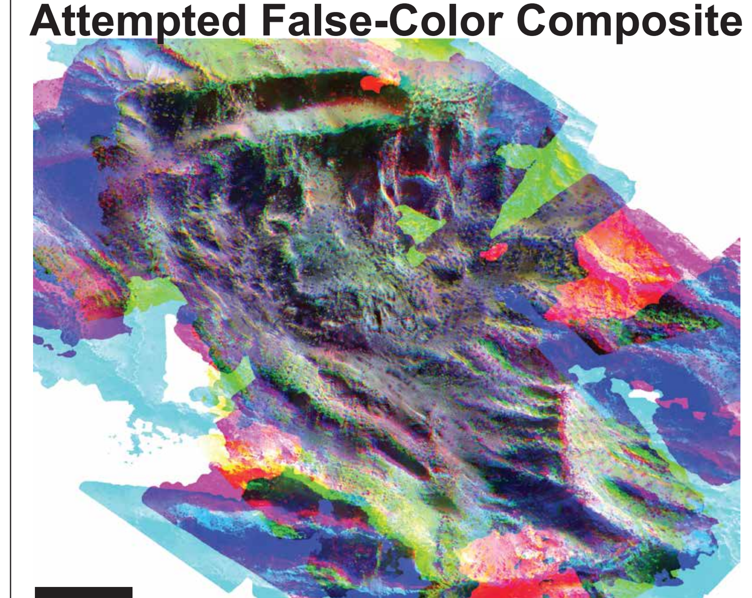
- The RGB composite appears similar to a standard image, albeit with some edge distortion.
- The CIR composite shows bright red color for healthy vegetation, as expected.

Example 2: Imagery from Spirit of MarahUTE

The SpectroscoPi was flown aboard the Spirit of MarahUTE to collect multispectral imagery of a site in southern Nevada to document coloration patterns resultant from fluid flow-driven iron cycling during early(?) diagenesis. Orthomosaics for each color band were produced in Agisoft Photoscan and composited in ArcMap. Due to camera cycling time (~10 sec) combined with forward motion of the plane, mosaics are all slightly different making image compositing impossible.



Attempted False-Color Composite



This false-color composite image derived from the blue, red, and near-infrared (NIR) images above, shows the major alignment errors introduced from capturing images at different angles through the flight as well as differences in resultant orthomosaics following processing in Agisoft Photoscan. For example, in some orthomosaics targets used for georeferencing were completely lost t0hrough the photogrammetry, leaving far too many discrepancies to be useful for compositing.