**Headwall & geo-konzept Webinar Questions & Answers**

*Detection of Vegetation Encroachment on Infrastructure using UAV Hyperspectral Imaging & LiDAR*

Date & Time

Wednesday, 4 December 2019, 10am US Eastern / 3pm GMT (UTC)

Synopsis

Vegetation management (VM) is an important and costly part of utility and infrastructure operations. Shrubs, invasive species, and unhealthy or overgrown trees can imperil power lines, towers, roads, and block or damage bridges as a result of weather events.

Compared with manned aircraft, lightweight unmanned aerial vehicles (UAVs) with hyperspectral imaging (HSI) & light detection and ranging (LiDAR) payloads are less expensive to operate, can produce images and data of higher spatial resolution, and can economically provide more up-to-date information about vegetation growth rates and speciation.

See the results of a series of low-altitude UAV flights over railways (courtesy Deutsche Bahn rail) with adjacent vegetation. The HSI & LiDAR payload enabled spectral classification and height measurements of the vegetation, as well as measurements of proximity to man-made structures. We also show early work with data fusion of spectrally classified images and 3D terrain with extremely precise positioning that could greatly aid vegetation clearing operations.

- Brief introduction to the new Center for Hyperspectral Remote Sensing Europe by Headwall & geo-konzept
- Flight experience and data analysis with examples of novel data fusion
- Questions from attendees via online Questions window

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Questions & Answers

How about the point cloud difference from different flights of LiDAR or how to impove the accuracy of airstrip matching? Or what benefit does the LiDAR point cloud have for hyperspectral orthorectification?

> If you are referring to flying multiple times over an area and capturing LiDAR data, each set of data (points of narrowband NIR laser light reflected off surfaces measured by the LiDAR sensor) are captured with Global Positioning System (GPS) data and Inertial Measurement Unit (IMU) data onboard the drone's payload. So when data from multiple flights are combined, the resulting 'point cloud' of data is accurate to within the accuracy of the GPS/IMU, which is typically better than +/5cm.
>
> See slide 14 of the presentation. In order to perform orthorectification properly, you need an accurate Digital Elevation Model (DEM). What LiDAR gives us is an accurate DEM. If we know the relative heights of the points in the scene, then we can accurately 'paint' them without distortion because we know what the magnification of each pixel is. In this case, the LiDAR is a huge help. The data over the railroad would not have looked as good if we had used a commercially available DEM (with potentially much coarser spatial resolution and less accurate x-y and z geo-positioning).

How about the match difference from Hyperspectral and LiDAR?

> We are not exactly sure what this question is asking. However, both data sets are orthorectified, so there are GPS locations for every point in the point cloud, as well as for every pixel in the hyperspectral image.

What is the accuracy of IMU angles for correcting angle Euler movment for LiDAR and for hyperspectral ?

> We are not exactly sure what this question is asking, however: The IMU/GPS used for these data was run through a Post Processing Kinematics (PPK) program to improve the data quality. The accuracy of the IMU data from the PPK is +/- 0.025° in Roll and Pitch, and 0.08° in Yaw or Heading.

What is the swath at this altitude (50 meters)? What was the lens focal length?

> The lens focal length was 17 mm. The flight was approximately 68m above the roadway, and 78m above the railroad. This gave a swath width of about 20m. There were two flight paths, with a programmed overlap of 40%.

How many flights did you make for covering such surface?

> For this particular project, we just needed to make one flight of about 5 minutes in duration. It was not close to the total flight time available from one battery charge for the UAV. See slide 19.

What is the weight of the payload?

> As a point of reference the drone itself with batteries is about 9.5 kg. The payload with the hyperspectral sensor (Headwall Nano-Hyperspec VNIR model), high-performance GPS/IMU & LiDAR is about 1.55 kg.

If we have a LiDAR with Nano to create DEM then do we need to have still GPS with Nano?

> Yes. The hyperspectral payload includes the sensor itself and a standard or high-performance GPS/IMU unit. The raw LiDAR data is processed with the GPS/IMU data in order to create the point cloud. It is not possible to create the point cloud, and therefore the DEM, without the GPS/IMU data. Once the DEM is created, the GPS/IMU data is used with the raw hyperspectral data to create the orthorectified hyperspectral image.

How to handle if there is signal saturation in few pixels in the scene?

In general, spectra from saturated pixels will not be reliable. If only a few pixels are saturated, then the spectral analysis can be performed on the whole scene, and the saturated pixels will not be classified. In the future, we plan on adding functionality to track saturated pixels through the conversion to radiance and then reflectance, to ensure that those pixels can be easily excluded from analysis.

Is there any possibility to record ambient light conditions and compute absolute reflectance values from the hyperspectral imager so that those values can be compared at the same site over different lighting conditions such as different times of the year, or different cloud conditions?

Our normal procedure is to place a calibrated tarp with three different reflective panels (56%, 30% and 11% reflectance) in the path of the flight, so that it is imaged along with the scene. The raw data are converted to radiance, using factory calibration data, and then an average radiance spectrum from the tarp is recorded. Since we have the absolute reflectance curves for the tarp panels from the manufacturer, we can then scale the average radiance for the tarp panel, and use it to compute the reflectance of the entire flight.

So, while we are not directly recording the downwelling irradiance, the measurement of the calibrated tarp does compensate for most of the variations in lighting conditions.

What is the Ground Sampling Distance (GSD) of hyperspectral imagery?

It varies according to the parameters of the particular mission. But in this case for the railroad flight the GSD was 3.5 cm (at a 78M distance above the railroad tracks themselves).

Whats the precision of the IMU you are using in your LiDAR and hyperspectral device?

I was referring to the Inertial unit not the GPS.

The IMU/GPS used for these data was run through a Post Processing Kinematics (PPK) program to improve the data quality. The accuracy of the IMU data from the PPK is +/- 0.025° in Roll and Pitch, and 0.08° in Yaw or Heading.

Some trees [in Panama] have yellow or redish leaves, how that works for the encroachment determination?

Determining encroachment is not a problem. We're not 100% positive about how well the various vegetation indices will work for plants that have other pigments other than chlorophyll. We might have to see this on an individual basis. We believe that you will see differences in spectra from a tree with yellow leaves, for example, as it becomes sick—there should be some spectral features that we can key in on.

What type of software do you use to process these images?

When looking at or editing the LiDAR point clouds or creating the DEM, we use the freely available software called CloudCompare (e.g. slide 33). The LiDAR point cloud files are actually created using Headwall's LiDAR Tools (e.g. slide 15). Making the orthorectified image using the raw data, GPS data, and the DEM is performed by Headwall's SpectralView program. Spectral classification is also performed using SpectralView. Fusing the (classified) hyperspectral images and the DEMs to create 3D terrain models was done in the open-source program QGIS.

Is it better to fly faster or slower?

The optimal flight speed depends on the intensity of the illumination and the altitude of the flight. In general, we want to travel forward by one projected pixel per frame period. The higher the altitude, the larger the projected pixel will be on the ground. The frame period is determined by the integration time, which we set to get a high signal level without saturation, while looking at a white tile on the ground. Lower light levels will mean longer integration times, and thus slower flight speed. The DJI Matrice 600 Pro UAV that we use cannot do programmed flight at any speed below 1 m/s, so if our calculations indicate that our altitude and frame time will require a speed of less than 1 m/s, we can increase our altitude, which will always result in faster flight speeds for the same frame period.

In general, we fly between 1 and 10 m/s.

What's the ideal flying distance from ground?

In the USA, the maximum altitude we can fly is 120m. Practically, we have found that at altitudes below 10m, the downdraft from the propellers disturbs objects on the ground. The lower the altitude, the higher the spatial resolution, and the less area that can be covered.

We generally fly between 20 and 60 meters above ground level.

The range of the LiDAR unit is 100m, and we have found that we can get good LiDAR data for flights at altitudes up to 80m.

For someone who don't believe in technology, how can you convice him on the accuracy of these images compare to satellite?

That is an interesting question since technology is what makes applications like this possible. I presume that you mean the technology of using unmanned aerial vehicles instead of manned aircraft or satellite data. As we mentioned during the presentation, one advantage is that the relatively low altitude of a UAV enables higher spatial resolution (centimeters) versus the relatively high altitude of a manned aircraft or satellite (meters or tens of meters). You can also more easily schedule flights of a UAV to monitor areas over time. So there is also a convenience factor to consider.

Hi everybody, is it possible to use RTK (Real-Time Kinematics) coordinates? Did you use it on this flight?

We use Post-Processing Kinematics (PPK) instead of RTK. According to the GPS manufacturers we have spoken with, both give similar results with the PPK being slightly better. We have elected to use PPK, so we don't need an RTK base station. Headwall has a short White Paper on RTK-vs-PPK that is a good primer on the subject.

At which altitude and with which speed did you fly [over the railroad]?

See slide 19. The altitude above ground was about 70 meters, and the flight speed was about 4.5 meters-per-second. The total mission flight time over the target was about 5 minutes (excluding initialization). On a related note, when we set up our flights, we measure the ambient light and set the exposure time so we get a strong but not saturated signal and set the flight speed with the focal length of the imager and the altitude, so that the UAV is traveling forward by one projected pixel every frame time, so we get complete coverage of the area (there are built-in and publicaly available Headwall calculators for this purpose). In general if it is dark, we fly slower and if we are flying at a higher altitude, we can fly faster.

Hi. My company, wants to buy a LiDAR like this one. What is the price of this sensor? We want a LiDAR for drone

Headwall sells direct in the US and some countries, and through authorized resellers in other countries such as those in Europe and Asia. Knowing your location, we are happy to have the appropriate company contact you.

In this specific application I don't see any advantage using hyperspectral. LiDAR should be enough, right?

The LiDAR is certainly important in determining the relative distances between objects, but the spectral data allows the image to be classified into different materials and species. This could be important, if certain species of plants were known to be particular problems.

The more important advantage of the hyperspectral data is the ability to use spectral analysis to calculate vegetation health indices, which would allow the identification of unhealthy trees in the imagery. You are correct in this case that the trees all seemed quite healthy, and so there ws not a clear advantage from using the hyperspectral analysis.

How does the hyperspectral data enable encroachment detection? Isn't it more a LIDAR ability than a hyperspectral ability?

Indeed the LiDAR point cloud allows detection of immediate encroachment. However, there may be trees whose health (determined by hyperspectral imaging) might lead to falling into a place that blocks or impedes travel or damages a bridge, tower, or building. The ability to detect and then decide to take action could ultimately save more than the cost of the treatment or removal of the tree.

If we don't have LiDAR for DEM, can we correct the distortion?

Yes. Headwall's orthorectification software can take in DEMs in a variety of formats, from multiple sources. The higher the resolution of the DEM (up to a point), the lower the distortion of the orthorectified image. The data presented here were orthorectified with a DEM having 50cm pixel spacing.The US Space Shuttle undertook a number of RADAR topography missions (SRTM). Those generated digital elevation models for almost the entire world at a resolution of about 30 meters. This data is freely available, and can be used for orthorectification. They will in general be good for land that does not change drastically over small areas. See slide 31. The SRTM data would do well on the railroad part but not on the trees. In general those DEMs are built without vegetation, whereas when we do hyperspectral imaging we're more interested in the things sticking up out of the earth.

Is the classification software free for use if buy a nano camera?

Yes, Headwall provides two 'seats' of our software with the purchase of our sensor payloads and with our 'turnkey' platforms. Additional 'seats' are available at nominal pricing. Your local representative or reseller can provide you with a sales quote.

How do you relate each Hyperespectral pixel with each LiDAR point?

There are thousands if not millions more LiDAR points (in point clouds) than there are hyperspectral pixels. So what we do in our LiDAR Tools program (see slide 15) is fuse the DEM with the hyperspectral image. This means that for each pixel in the hyperspectral image we have the latitude and longitude coordinates plus the elevation from the DEM. We have looked into associating points in the point cloud with pixels from the hyperspectral image but the point clouds are already large data structures (tens of gigabytes). If we were to add, say, 300 spectral bands to each of those points, then that 10-GB file becomes 3-TB! So we have not yet implemented associating a spectrum with every point in the point cloud.

What is realistic scale (linear km) achievable for a project with aerial, UAS?

For the parameters of the flight over the railroad, our flight planning software calculates that we could have covered a total of about 9.7 hectares in the maximum 15 minute flight time. At higher altitudes, the area coverage can be up to about 16 hectares per flight. Always, flights at lower altitudes will have higher spatial resolution and lower total area coverage.

Can one open the Headwall hyperspectral data using other programs (other than the Headwall proprietary software)?

Yes. We save our hyperspectral data cubes in an ENVI-compatible format. L3Harris Geospatial Solutions is the proprieter of ENVI, a commercial program to open and analyze hyperspectral data. The ENVI file format is not proprietary, though. There is a text header and a flat binary file. So users of ENVI can open and utilize data from Headwall systems. Users of the free HyperCube program by the US Army Corps of Engineers can also open Headwall data. Headwall has also written code in Matlab and Python to open and analyze our data (contact us for more information). There are no restrictions by Headwall on looking at the data captured using our systems.

Is there a need to correct for atmospheric moisture when using Hyperspectral data?

Our standard procedure is to fly over a calibrated reflectance tarp as part of the flight. The raw data are all converted to radiance using a factory calibration, and then an average radiance spectrum of one of the tarp panels is calculated. This is used, along with the manufacturer's measured spectrum of the tarp panel, to convert the radiance data to reflectance. This process implicitly corrects for any atmospheric absorptions, and so no atmospheric modeling is required.

What are the typical hardware costs (UAV + hyperspectral camera) for systems like this?

Headwall sells a wide variety of payloads and full 'turnkey' systems that range in price from 5-digits to 6-digits in US dollars. Our technical sales representatives or resellers can work with you toi determine the best configuration and pricing.

Based on the obtained hyperspec image and the software, how can we write our own program to process the data for classification and segmentation?

Headwall stores hyperspectral data in ENVI format. There are freely available libraries for MATLAB and for Python that can be used to write software to open and anlyze hyperspectral images. Spectral Python, in particular, has several different spectral analysis algorithms built into it.

All the data presented here was classified and segmented using Headwall's SpectralView software.

Is it also possible to detect dead trees or wood (trees without leaves but maybe very dangerous to fall into the rail)?

See slide 37. There were some dead trees in this area with the power lines. They were not specifically (spectrally) classified in this case. So it looks like they are misclassified. But in general the bark of a tree will have a very different spectrum than a leaf, and it should be possible to pick those out as dead trees.

Do you know, is it possible to detect different tree-family-groups (not species)? Many thanks! Very interesting and impressive!

It is certainly possible to differentiate between species of trees, as we showed in the presentation. Headwall does have agricultural customers who use our imagers to identify different cultivars within the same species (such as tomatoes). In general, the classification process works well if there are multiple well-identified exemplars of each type to be differentiated.

If you are asking if it is possible to group trees into, for example, Pines, Oaks, or Maples, we have not done this, but it should work.

What is the a.g.l. elevation for these survey flights?

For this particular flight, an altitude above ground of 70 meters was used. You can use other altitudes with tradeoffs being spatial resolution versus the area being scanned. Of course, local areas may have altitude restrictions.

What is total flight time? What's the battery size (mAh) for the UAS system?

This particular 'turnkey' system with the DJI Matrice 600 Pro UAV, Nano-Hyperspec sensor, LiDAR, and high-performance GPS/IMU can fly about 15 to 20 minutes with each set of batteries. This can vary by the winds, temperature, and humidity. Headwall recommends returning to land before the battery charge level falls below about 20%. The batteries (6 per set) have a rating of 4500 mAh each. Headwall typically includes 3 complete sets of batteries and two chargers to maximize the flight times during each mission.

Comparing LiDAR-based DEM and with Photogrammtry-(aerial photo)-based DEM, which method provide higher quality of orthrectified hyperspectral product?

LiDAR DEMs are in general more accurate than photogrammetry based DEMs. The higher accuracy DEM will give a higher quality orthorectified data product.

How is radiometric correction done with panels?

Radiometric correction is done using the Headwall SpectralView software, and a radiometric calibration performed at the factory and stored as a set of calibration files.

Our normal procedure is to place a calibrated tarp with three different reflective panels (56%, 30% and 11% reflectance) in the path of the flight, so that it is imaged along with the scene. The raw data are converted to radiance, using factory calibration data, and then an average radiance spectrum from the tarp is recorded. Since we have the absolute reflectance curves for the tarp panels from the manufacturer, we can then scale the average radiance for the tarp panel, and use it to compute the reflectance of the entire flight.

What is the weight of camera and gimbal? And whats is the FOV

CORRECTED ANSWER: Headwall's Nano-Hyperspec sensor and the powered gimbal (no LiDAR) weigh under 3 kg. The sensor with lens is under 1 kg, and the powered gimbal is a little over 2 kg for a total of about 2.8 kg. The data presented here were taken with a 17mm focal length lens, which gives a sensor field of view of 15 degrees. At the altitude of these flights (70m), this corresponds to a swath width on the ground of about 19m.

Why was the MCARI chosen instead of others such as NDVI, OSAVI etc for the classification? 2. Should it be fairly easy to obtain any Vegetation Index from hyperspectral data?

Using hyperspectral data, it is very easy to obtain the 7-8 indices that we support in Headwall's AgView program. For this project, MCARI was chosen because it showed the most contrast for a visual presentation. But in AgView you different indices to choose from. Regarding calculating more (arbitrary indices), separate programs can be written. This is not currently built into our software.

However, the AgView software has been written to allow easy addition of new indices. For a non-recurring engineering fee, Headwall can add essentially any spectral index to the AgView software for user customization.

Could you replace this workaround (hyperspectral imaging) with running an automated virtual clearance analysis over the rails, based only on geometry of point cloud?

I do not know what "automated virtual clearance" is, but certainly all sorts of analysis can be done on the point cloud. However, absent the hyperspectral data, identification of tree species or plant health will not be possible from the point cloud alone.

Did you use other classification algorithm except Spectral Angle Mapper ?

The headwall software includes a classification module that is based on a modification of the Spectral Angle Mapping technique.

Headwall is currently evaluating other classification algorithms, and if we find any improvements over SAM, we plan to incorporate those classifications as well.

Can an index like MCARI be used to differentiate different species of plants and thereby make good guesses at which species are present in a given pixel?

This would probably be better done by spectral classification with reference spectra from exemplars of each species.

Indices like MCARI will show different values for different species with the same level of health, but using only three bands is throwing away a lot of data that could be used for speciation.

Does this mean that I cannot orthorectify my hyperspectral data unless I have LIDAR data also or some other reference data source?

A Digital Elevation Model (DEM) covering the area overflown is necessary for good orthorectification. If the terrain is flat, the orthorectification software will allow the user to do the calculations with a flat DEM at a constant altitude, and with the correct altitude, this will give good results for truly flat terrain.

If the user does not have LiDAR, there are several freely available sources of DEM data, including the Space Shuttle Radar Topograpy Missions (SRTM), which cover most of the globe at approximately 30m horizontal resolution

What is your band resolution?

The band resolution for the Nano-Hyperspec is 2.2 nm

What camera are you using?

We used a Headwall Nano-Hyperspec sensor. It is a VNIR (400-1000nm) sensor capable of capturing 270 spectral bands at 12-bit bit depth and 640 spatial bands at a time. Built into the sensor itself are 480GB of solid-state storage and a microprocessort for capture up to 350 Hz. A variety of lenses can be used with it.

Can you do unsupervised classification?

All the hyperspectral data produced by the Headwall systems is stored in ENVI format. Therefore, it should be possible to open up the data in any hyperspectral analysis software, and apply whatever analysis the software supports.

At present, the classification method that is programmed into the Headwall software is a modified Spectral Angle Mapping algorithm. This is what was shown in the presentation, where the classification was done by generating reference spectra from parts of the scene.

Other unsupervised methods, such as Principle Component Analysis are possible in third-party software.

What are the ambient light contraints for the hyperspectral imager (sun angle and cloud conditions)? What were the conditions at the time for the datasets shown in this presentation?

It was evenly overcast (cloudy). It was necessary to fly relatively slowly (<5m/s). The speed is a direct function of the integration time: less light means the need to integrate longer to get a good image and fly slower. Ideal conditions would be bright and sunny with no clouds, but the next-most desired condition would be evenly overcast. Partially cloudy with intermittent interruptions of clouds over the target area are not desired, since images captured over even a short time could contain different lighting conditions. Solar angle does make a difference. We recommend flying between 10am and 2pm. Shadows don't have as good a spectra as areas that are directly lit.

Have there been any forestry-use demos around your center?

Not yet.

How about the accuracy of your GNSS solution of MGIS?

We are not sure what MGIS is or how it would relate to the work we do. The GPS used in this work was Headwall's enhanced GPS, which used Post Processing Kinematics. The Accuracy of the PPK data is approximately ± 5 cm in all directions, and ±0.025° in Roll and Pitch and ±0.08° in Yaw.

Could you show us the tools of fuse radar and hyperspectral tools from headwall?

The fusion of the LiDAR DEM and the hyperspectral data is done in the Headwall LiDAR Tools program. This program has three tabs, which allow calculation of the point cloud from the raw LiDAR and GPS/IMU data, calculation of a DEM from the point cloud, and fusion of the DEM and hyperspectral data.

We can provide an example of a fused data cube on request.

About Headwall

Headwall is a leading designer and manufacturer of complete spectral instrumentation solutions for remote sensing, advanced machine vision, and government/defense markets. With a worldwide base of end-user and OEM customers, Headwall enjoys a market leadership position through the design and manufacture of spectral solutions that are customized for application-specific performance. The Company has three European locations in Belgium, Germany, and Italy. European headquarters operations at Headwall BVBA are located near Brussels, Belgium. For more information, visit www.headwallphotonics.com.

About geo-konzept

Since 1992 geo-konzept GmbH stands for reliable and robust GPS and GIS technologies for agriculture and forestry. The company is one of the market leaders in the field of high-precision and GPS-supported agriculture. Particular emphasis is placed on steering, sensor and management systems. Further business fields are laser-supported and high-precision 2D and 3D measurements, e.g. for architects or blasting companies. Mobile GIS and remote sensing (aerial photography and analysis) also play an important role in the company. Services as well as our own hardware and software development complete the picture of geo-konzept as a company for environmental planning systems. For more information, visit geo-konzept.de.

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