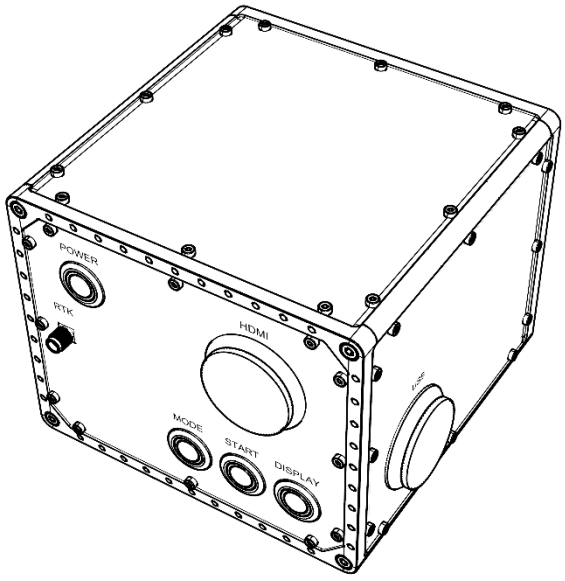
Spectral DEVICES INC.

SPECIFICATION

Multisensor Drone Camera system for Agriculture



MSDC-2-4-AGRI
Version 05
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Specifications subject to change

Table of Contents

Background information 3
Trademarks 3
Sales and Support 3
1. Description 4
2. Key Features 5
3. Specifications 6
4. Drawings 7
5. Package Contents 8
6. Applications in Agriculture 8
7. Software 11
Features 11
8. Image Post-processing 14

Background information

Trademarks

Spectral Devices Inc., MSDC, MSC2, MSDC-2-4, MSDC-2-4-AGRI

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1. Description

The multisensor drone camera system (MSDC-2-4) is a turnkey multispectral imaging solution for easy integration with many drones enabling capture of geotagged aerial images for further analysis in data mapping software.

Each MSDC-2-4 (Fig.1a) includes up to 4 cameras with C-mount lenses optimized for customer specified field of view and ground resolution. All camera optical axis are aligned during the manufacturing process to ensure seamless image co-registration between cameras.

A built-in vision computer provides a high degree of control over the cameras, ensuring synchronized camera operation and image recording. System configuration is performed using simple text-based configuration files. Depending on the setup of the system, these settings can be modified by editing the files directly on a USB drive or an SD card before initiating the flight.

The MSDC-2-4 is equipped with a built-in GPS operating at 10 Hz and RTK base station enabling centimeter-level positional accuracy (Fig.1b). The system also incorporates a solar sensor (Fig.1b) with 19-channel spectrometer in UV-SWIR range, IMU providing 3-DOF sensor orientation and directional sensor for sun angle estimation.

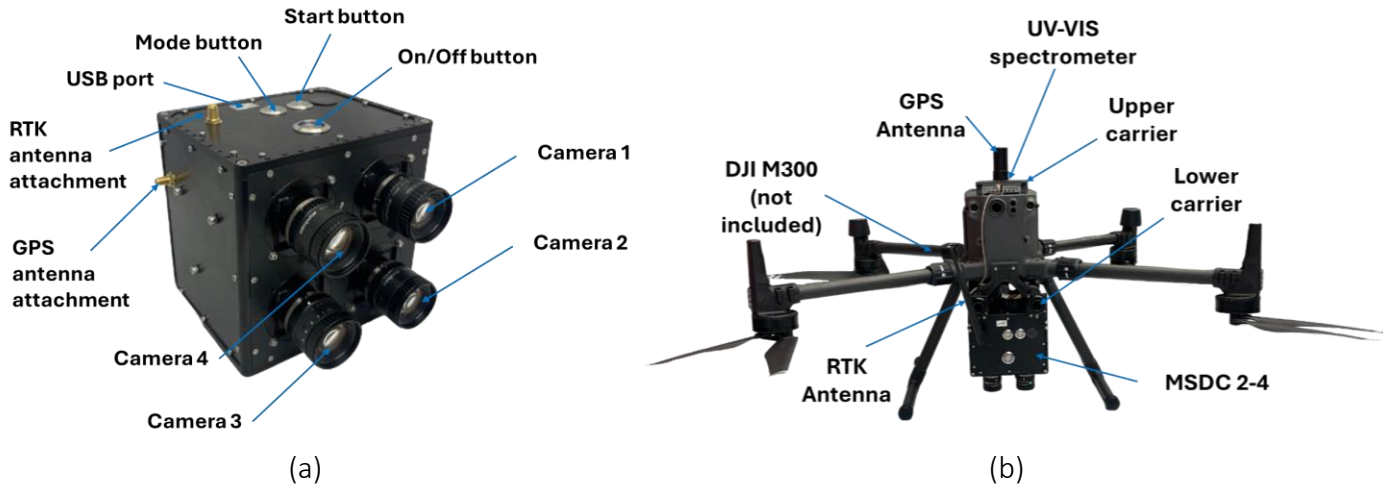


Figure 1. *(a) MSDC 2-4 system. Note: position of switches and access ports is dependent on internal camera configuration. (b) MSDC-2-4 system mounted on a DJI M300 drone.*

Operation of the system is simplified to only three pushbuttons – power, start, mode. The power button turns the system on or off. Start button starts and stops image acquisition and initiates computer shutdown. The Mode button cycles the system between image acquisition and computer shutdown mode.

Acquired images are saved on the USB drive or SD card (dependent on system configuration) and can be inspected using a PC and image post-processing software called msInspector. The software enables flight image and data (gps, solar) review and subsequent tagging with geo-location and radiometric correction data.

Although the system is designed to work with the DJI M300 RTK drone, integration on other drone models is possible if sufficient payload capacity (2 kg) and power (9-36V) is available.

The MSDC-2-4-AGRI drone camera system, designed specifically for the agricultural sector, represents a significant leap in remote sensing technology. This state-of-the-art system features a unique assembly of four sophisticated cameras, making it a formidable tool for precision agriculture and land management. The AGRI model is designed to allow users to perform spectral analysis on a variety of key metrics to assess the plant health and hydration status.

2. Key Features

- Diverse Camera Array
  - 5 MP narrow band NIR camera
  - 5 MP narrow band Red Edge camera
  - 1.3 MP SWIR camera
  - 5 MP narrow band Color camera
- Seamless Integration and User-Friendly Design
  - Compatible with a wide range of drones capable of carrying a payload of 1.7 kg and supplying 9 - 36V DC power
  - Designed with user-friendliness in mind, ensuring ease of use even for those new to drone technology
- Built-in Vision Computer
  - Real-time HDMI output of multispectral images
  - Sustained frame rates of up to 1 FPS with simultaneous recording to USB drive or SD card
  - Over 4 h of sustained frame recording at 1 FPS with a 512 GB USB drive (12-bit mode)
- Built-in GPS
  - High performance GPS with 10 Hz update rate
    Includes RTK base station for centimeter-level accuracy and 20 km range
- Solar sensor
  - 19 channel spectrometer
  - Built-in IMU for orientation
  - Built-in directional sensor
- Enables comprehensive analysis of crop health, soil conditions, and more
  - NDVI, GNDVI, EVI, MSAVI, etc.
  - NDWI, MSI, NDMI
  - NBI
- Advanced Post-Processing Software
  - The system comes equipped with sophisticated image post-processing software
  - Provides the radiometric correction data and adds it to the image metadata
  - Geotagging for precise location mapping
  - Support provided for orthomosaic map generation

3. Specifications

Table 1. *List of cameras in the MSDC-2-4-AGRI system*

CAMERA	TYPE	#BANDS	RESOLUTION/BAND	BANDS	BANDWIDTH (FWHM)
NIR	Area scan	1	2448 x 2048	800 nm	50 nm
SWIR	Area scan	1	1280 x 1024	1500 nm	50 nm
RED EDGE	Area scan	1	2448 x 2048	725 nm	25 nm
COLOR	Area scan	3	2448 x 2048	445 nm, 532 nm, 645 nm	35 nm, 25 nm, 60 nm

Table 2. *Specifications of the MSDC-2-4-AGRI system*

Lens compatibility	All Spectral Devices C-mount lenses
Thermal control	Passive conduction of camera heat to enclosure
Water-resistant	Yes (IP54)
Dust-resistant	Yes (IP54)
Connector access	USB, SD card, HDMI, power cable, two SMA connectors for GPS antenna and RTK antennas
External construction	Aluminum with Stainless-steel hardware
Surface finish	Black anodization with laser etching
Dimensions	136 mm x 136 mm x 110 mm (150 mm with lenses)
Weight	1.70 kg with lenses. 1.38 kg without lenses
Power input	9 - 36 V DC directly from the drone
Image Geolocation	GPS/GNSS @ 10Hz
Frame rate	up to 1 FPS with simultaneous recording to USB drive or SD card

4. Drawings

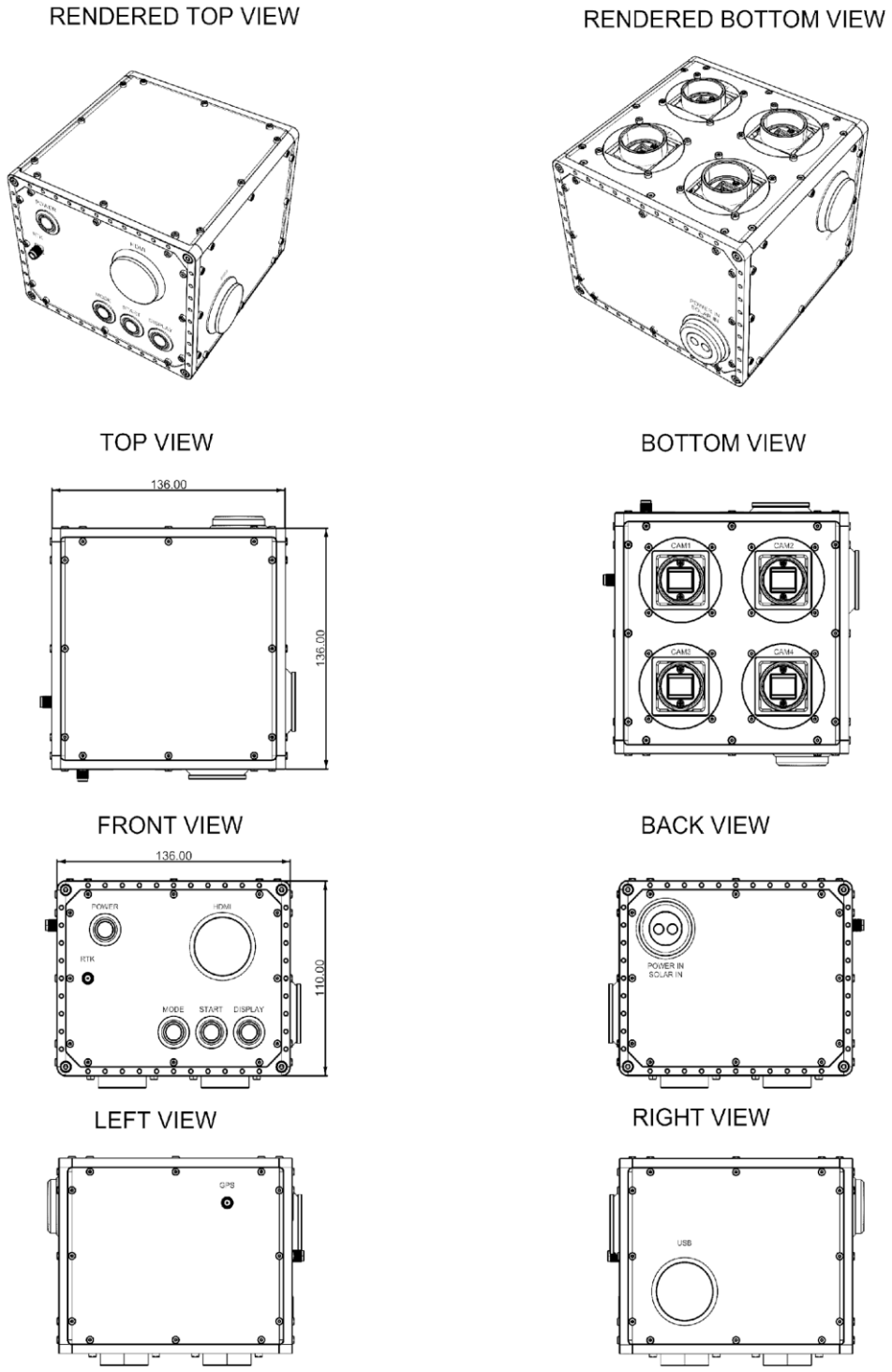


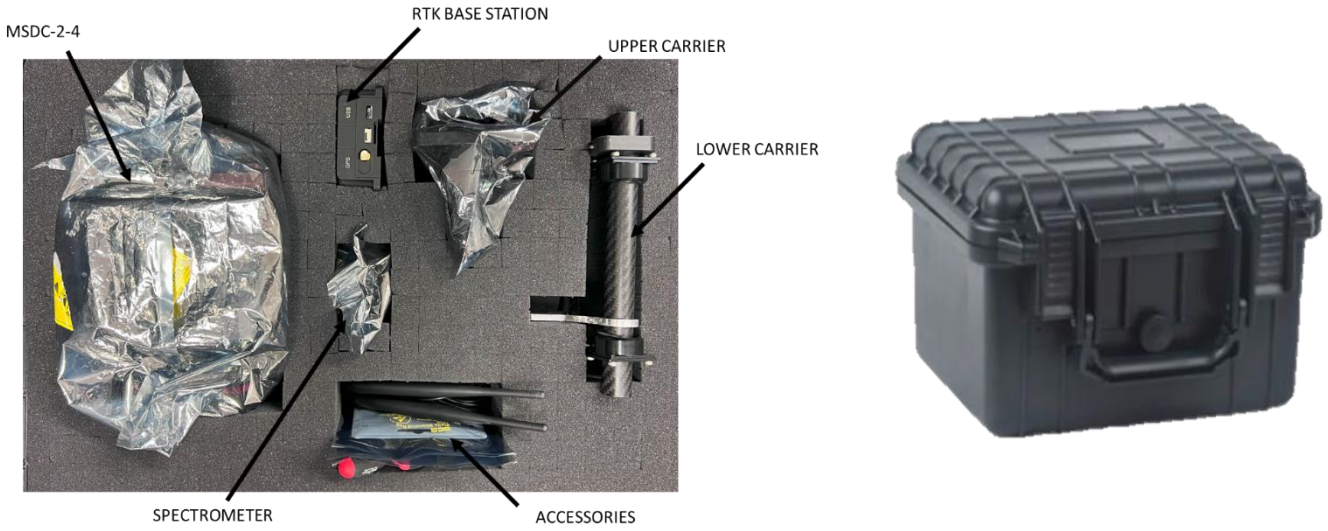
Figure 2. *MSDC-2-4 system drawings.*

5. Package Contents

Package contents are listed in Table 3 and shown in Fig.3a. All items are supplied in a waterproof equipment case (Fig.3b).

Table 3. *MSDC-2-4-AGRI package contents*

MSDC-2-4-AGRI	As shown in Fig.1a.
Lower carrier	Attaches MSDC-2-4 to the drone
Upper carrier	Attaches solar sensor, GPS antenna to the drone and accommodates power regulator board to connect payload to the drone
Two GPS Antennas	Attaches to MSDC-2-4 and RTK base station
RTK antenna	Attaches to RTK base station
RTK base station	Improves GPS accuracy
Two 256 GB SD cards	Used for image saving during flights
SD card adapter	For connection to most PC SD card slots
Solar sensor	Attaches to the upper carrier and connects to the MSDC-2-4 via USB3.0
Power cable	Connects MSDC-2-4 to the power regulator board in the upper carrier
Hex keys	Necessary keys for MSDC-2-4 attachment to the drone
Protective lens covers	Protects lenses when not in use



(a) (b)

Figure 3. *(a) MSDC-2-4 system package and its contents, (b) waterproof equipment case.*

6. Applications in Agriculture

The system can be used to perform a variety of spectral analysis relevant to agriculture. Assessment of chlorophyll content of the plants, which is an indicator of greenness, density, crop vigor and yield potential can be estimated with metrics such as NDVI, GNDVI, EVI, and MSAVI. The hydration status can be estimated using NDWI, MSI and NDMI. Unlike conventional agriculture cameras the SWIR camera allows for NDMI estimation which is a more accurate metric for determination of vegetation water content and monitoring

irrigation status. Additionally, the SWIR camera allows for burn assessment index (NBI) estimation, which can be valuable for mapping burned areas and monitoring post-fire recovery. Table 4 provides example metrics that can be used for MSDC-2-4-AGRI image analysis.

Table 4. *Metrics for Agricultural Multispectral analysis. Note that the list is not limited to the metrics listed.*

METRIC	FULL NAME	BANDS	EQUATION	INTERPRETATION
Crop Health Monitoring		Utilize the RGB, NIR and Red Edge cameras to assess plant health, detect diseases early, and optimize crop yields.		
NDVI	Normalized Difference Vegetation Index	NIR, Red	NDVI = (NIR - Red) / (NIR + Red)	Ranges from -1 to +1. A higher NDVI indicates greater plant health, reflected by the higher chlorophyll content in the vegetation. This is crucial for assessing crop vitality and identifying areas needing attention. NDVI results can be affected by the soil moisture levels and are not accurate for large changes in vegetation density. More advanced metrics (NDRE, EVI, MSAVI) can be used instead depending on the factors affecting the result.
GNDVI	Green Normalized Difference Vegetation Index	NIR, Green	NDRE = (NIR - Green) / (NIR + Green)	Ranges from -1 to +1. A higher GNDVI indicates greater plant health, reflecting more dense and "green" vegetation. This is crucial for assessing crop vitality and identifying areas needing attention. The index can estimate water and nitrogen uptake in the crop canopy. It is more stable than NDVI and performs better for crops with dense canopies or in more advanced stages of growth.
NDRE	Normalized Difference Red Edge Index	NIR, Red Edge	NDRE = (NIR - RedEdge) / (NIR + RedEdge)	Range from -1 to +1. A higher NDRE indicates greater plant health, reflecting denser and greener vegetation. This is crucial for assessing crop vitality and identifying areas needing attention. This metric performs better in crops at late stages of growth.

EVI	Enhanced Vegetation Index	NIR, Red, Blue	EVI =G*((NIR - Red) / (NIR + C_1*Red - C_2*Blue + L)), where C_1 and C_2 are coefficients for atmospheric resistance, L - value to adjust for canopy background	Range from -1 to +1. Higher EVI values generally indicate healthier and more vigorous vegetation, while negative values may indicate non-vegetated surfaces or water bodies. This metric corrects for atmospheric conditions and canopy background noise. Compared to previously listed metrics it is more sensitive in areas with dense vegetation and to canopy structural variations such as leaf size and canopy type.
MSAVI2	Modified Soil Adjusted Vegetation Index	NIR, Red	MSAVI2 =(2*NIR+1-SQRT((2NIR+1)-8(NIR - Red))	Ranges from -1 to +1. Higher MSAVI values generally indicate healthier and more vigorous vegetation, while negative values may indicate non-vegetated surfaces or soil. Used when a lot of soil is present, in early crop development stages.
Soil and Moisture Analysis		Employ the SWIR and NIR camera for detailed soil moisture mapping and irrigation planning.		
MSI	Moisture Stress Index	NIR, SWIR	MSI = (SWIR / NIR)	Higher MSI values indicate higher water stress in plants. This index is instrumental in irrigation planning and drought assessment.
NDMI	Normalized Difference Moisture Index	NIR, SWIR	NDMI = (NIR - SWIR) / (NIR + SWIR)	Ranges from -1 to +1. NDMI helps in monitoring water content in vegetation. Values close to +1 indicate high moisture content, while lower values suggest dry conditions, aiding in water management strategies.
Burn Analysis		Employ the SWIR and NIR camera for burned and healthy are mapping		
NBR	Normalized Burn Ratio	NIR, SWIR	NBR = (NIR-SWIR)/(NIR+SWIR)	Ranges from -1 to +1. Burned areas typically have lower NBR values (more negative) than unburned or healthy vegetation, as the reflectance in the SWIR band increases due to the loss of vegetation cover and water content in burned areas.

				Valuable for assessing the impact of wildfires, mapping burned areas, and monitoring post-fire recovery.

7. Software

With every MSDC-2-4, Spectral Devices provides msInspector, a Windows-based application featuring a graphical user interface (GUI). The software makes inspection and geotagging of images collected with the MSDC series multispectral drone cameras from Spectral Devices Inc quick and easy.

The software onboard the MSDC-2-4 performs real-time preprocessing of images from each camera. For example, multispectral images are demosaiced and saved in TIFF format onto the removable USB drive or Sd card. While single band cameras, such as the SWIR and Red Edge are saved directly to the drive. Images are saved into a hierarchical folder system ensuring no data is overwritten between flights.

msInspector uses configuration, calibration, and correction files specific to each MSDC-2-4 camera. The calibration and correction files are supplied by Spectral Devices. msInspector provides a series of batch operations allowing the user to load images, solar sensor data, and GPS data. At each step, data can be visualized. Lastly, the GPS and solar data can be written into the image metadata.

Features

1. Simple, easy to use tabbed GUI.
2. Data visualization (images, GPS and solar sensor data)
3. Geotags large numbers of images in a single operation.
4. Tags solar sensor data to the images for radiometric calibration.
5. Exports geotagged images in multiple formats to the desired folder.
6. Provides tags required by 3rd party mapping software.

In the msInspector Camera tab the user can review all the collected images and apply non-uniformity corrections to the images (Fig.4).

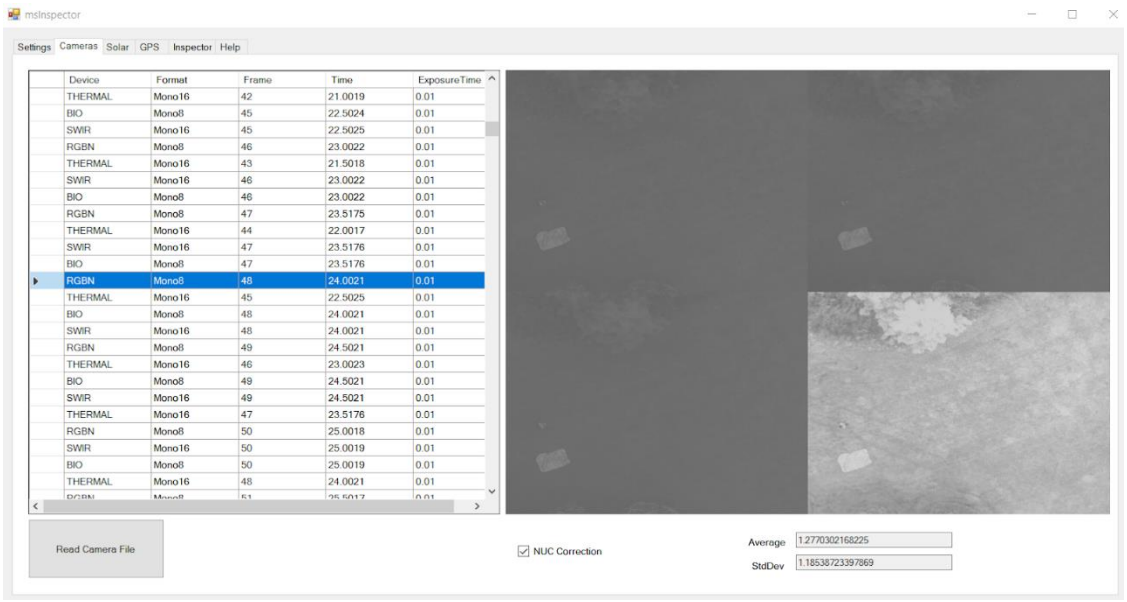


Figure 4. *Camera tab in the msInspector.*

Solar tab (Fig.5) in the msInspector allows user to review data collected by the solar sensor during the flight. Data includes the spectrometer reading across the VIS-NIR spectrum, sensor orientation (yaw, pitch, roll), and solar direction relative to the sensor.

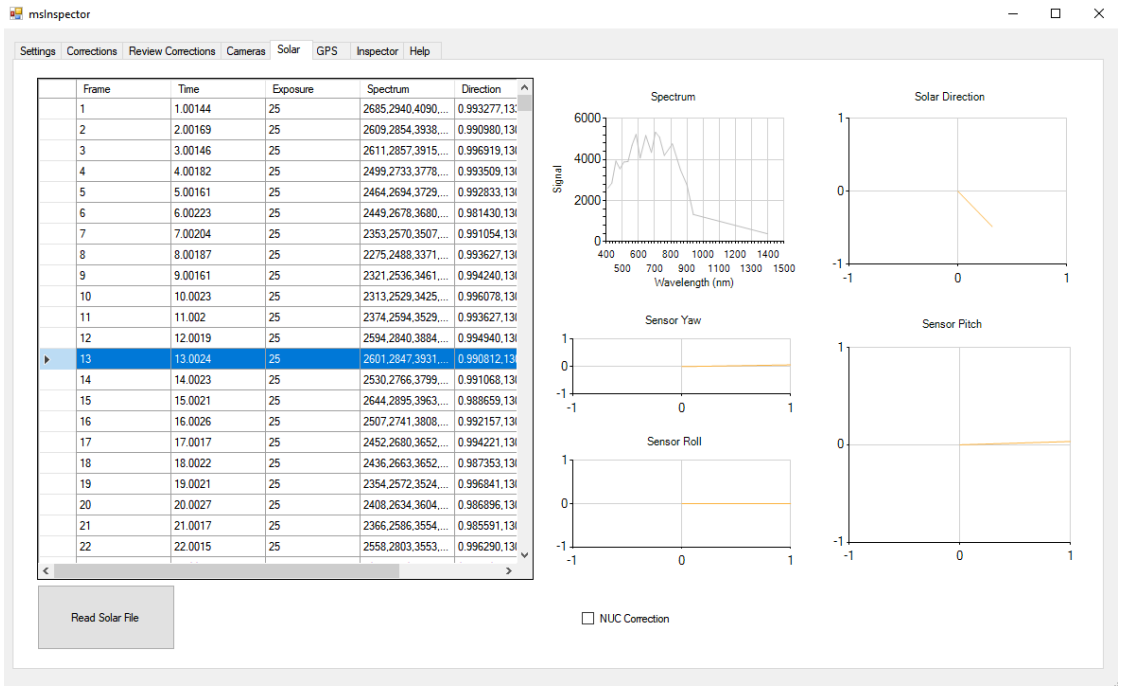


Figure 5. *Solar tab in the msInspector.*

GPS tab (Fig.6) in the msInspector allows the user to review GPS data collected by the GPS sensor (longitude, latitude, and altitude) during the flight. A map is displayed showing the location of the flight along with the flight path.

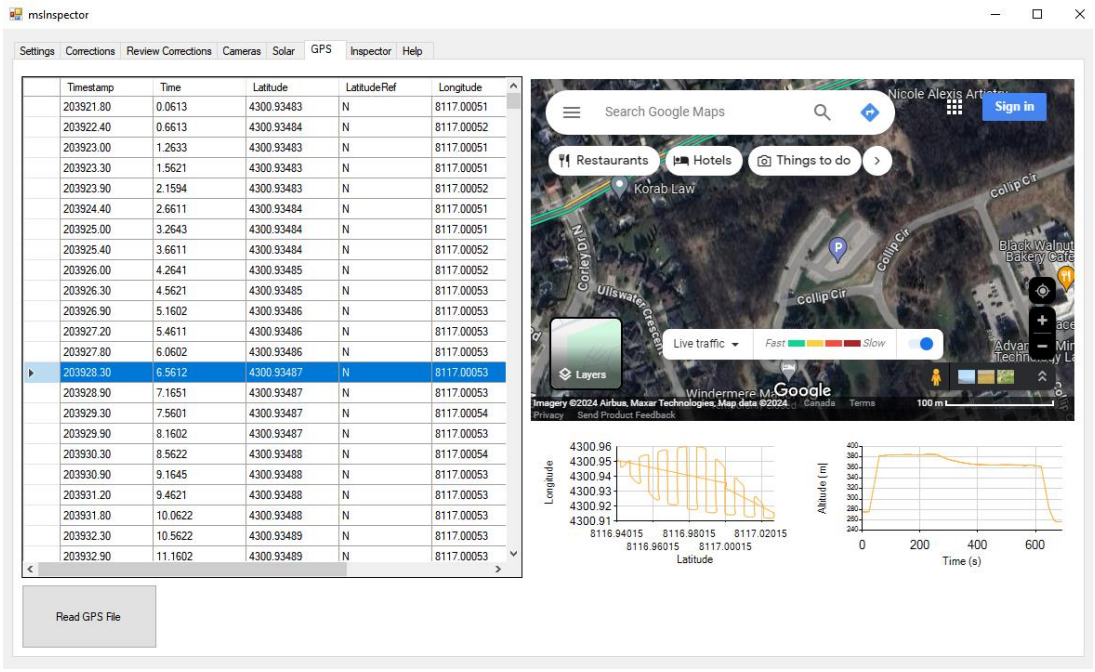


Figure 6. *GPS tab in the msInspector.*

The Inspector tab (Fig.7) in the msInspector allows the user to review all the data together. This data is used for image metadata generation. From this tab, geotagged images are exported with all the necessary metadata for image post-processing using software such as WebODM or Pix4DFields.

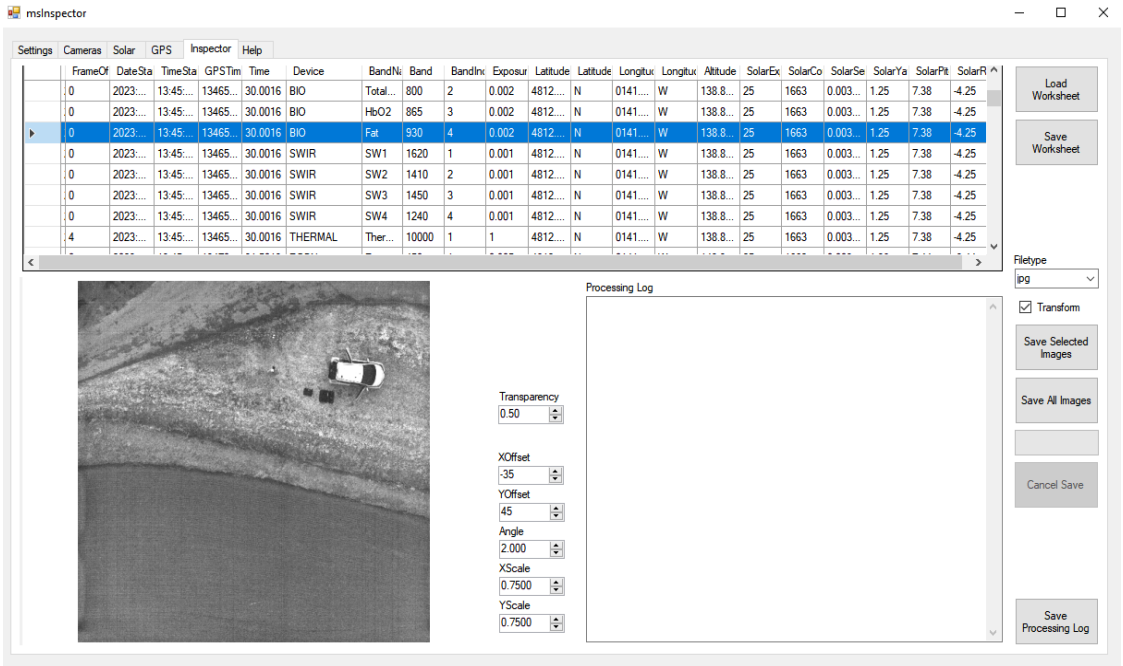


Figure 7. *GPS tab in the msInspector.*

8. Image Post-processing

Images exported from the msInspector are ready for 3D model reconstruction and orthomosaic map generation using open-source software WebODM by Open Drone Maps or subscription software Pix4D.

Spectral Devices Inc. provides tutorials and guides for image post-processing.