# Leica TerrainMapper

## Airborne LiDAR Mapping System Product Specifications

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## Overview

Leica TerrainMapper is a compact laser-based system designed for the acquisition of high-density topographic and return signal intensity data from a variety of airborne platforms, at flying heights up to 5500 m AGL. The data is computed using digitised return signal waveforms from which range and return signal intensity measurements are derived in real time and recorded in-flight along with position and attitude measurements from an airborne GNSS/inertial sub-system. The TerrainMapper falls into the category of airborne instrumentation known as LiDAR (LIght Detection And Ranging). This document establishes the minimum requirements for the Leica TerrainMapper, referred to as "the system" herein.

## Basic Design

**Operating Principle:** By measuring the location (latitude, longitude and altitude) and attitude (roll, pitch and heading) of the system, the distance to ground and scan angle (with respect to the base of the scanner housing), a ground position for the impact point of each reflected laser pulse can be determined. Return signal waveforms are analysed in real time, return signal timing derived and stored. The peak signal intensity attribute allows the creation of georeferenced images in addition to providing the intensity characteristic for each point in the point cloud. Finally, complete waveforms for each received return pulse can also be stored at sub-sampled rates.

**What is included:** The system is a turn-key airborne LiDAR mapping system and includes all required airborne equipment and software needed for mission planning, system operation, post-flight processing and output data generation. The system includes the needed modules of the Leica HxMap post-processing software suite necessary to produce latitude / longitude / elevation / intensity point cloud output. Additional modules are available for processing of data from the optional medium-format camera.

**Available Variants:** The system is available in two variants, TerrainMapper-L and TerrainMapper-LN. TerrainMapper-L provides the LiDAR scanner and a webcam for in-flight monitoring of the terrain below and for recording of webcam images to assist in post-flight analysis. TerrainMapper-LN provides a CH82 nadir camera in place of the webcam used in TerrainMapper-L. The CH82 camera allows collection of high-resolution daytime images with 4-band output (RGBN). For both TerrainMapper-L and TerrainMapper-LN, both image and LiDAR data are stored on a single storage media.

**Standard Components:** The system consists of the following physical assemblies:

- TerrainMapper-L or TerrainMapper-LN Pod
- CCxx Camera Controller
- OC60 Operator Interface
- IS40 Stand for OC60
- PD60 Pilot Interface
- Leica PAV100 stabilised platform for TerrainMapper Pod
- 185 mm and 50 mm height adapters, as needed for setting optimum pod height
- Vibration-isolated platform for Camera Controller
- GNSS + GLONASS antenna
- Interconnecting cables

## TerrainMapper Pod

The Pod Assembly contains the Scanner Assembly and either webcam or medium-format camera head.

The scanner produces controlled movement of the transceiver aim point by a Risley prism refractive scanner. The aim point of the laser output (relative to the scanner housing) is determined by a high accuracy optical angle encoder that measures the rotary position of the scanner's two scan wedges. The scanner is protected by a rigid optical window at the bottom of the TerrainMapper Pod.

The following major components form the Scanner Assembly:

**Laser:** The laser produces output laser pulses using a diode-pumped transmitter. It also contains an optical trigger output and fiber-linked beam expansion / collimating optics.

**Laser Output Periscope:** An optical periscope brings the laser output to the centre of the scan wedge assembly.

Fig. 1: Bridge and Ravine, St. Gallen, CH, acquired from 1000 m AGL at 130 knots & 20° FOV; 50 points/$m^2$

**Receiver:** The receiver collects optical trigger output and detects laser pulses reflected by terrain below the aircraft.

**Scanner Mechanisation**: A high-performance servo-controlled motor assembly is used to rotate the scanner's two scan wedges.

**Scan Wedge Assembly:** A dual-wedge Risley prism scanner is used allowing user-selected fields of view from 20 - 40 degrees at altitudes to 5500 m AGL.

Other components in the TerrainMapper Pod include the following:

**Scan Motor Controller:** A servo motor controller is provided that allows scanning at rates as high as 9000 RPM (150 Hz scan rate, or 300 scans per second).

**Digital Camera (webcam):** For TerrainMapper-L, an XGA-resolution (1280 x 960 pixel) digital camera is included in the scanner. This integrated camera allows a real-time view of the terrain below the aircraft, as well as providing recorded images at fixed intervals. The images can also be displayed post-flight using the associated Leica HxMap processing software.

For TerrainMapper-LN, the CH82 Camera Head is mounted in place of the webcam. A choice of 50 mm or 80 mm lenses is offered.

## Leica PAV100 Stabilised Platform

The Leica PAV100 provides stabilisation of the TerrainMapper Pod to ensure that the sensor remains pointed in the nadir direction.

## CCxx Camera Controller and Mounting Plate Assembly

The Camera Controller contains assemblies responsible for system control, position and orientation measurement and raw data recording. The following major functions are provided by the Camera Controller:

**NovAtel SPAN GNSS/IMU Sub-system:** This sub-system provides and records master timing and aircraft position / attitude information using a GNSS receiver, a high-accuracy IMU (mounted inside the TerrainMapper Pod) and an integral processor. The NovAtel SPAN sub-system records raw GNSS/IMU data via the data logging function provided inside the Camera Controller.

**Data Logging:** This portion of the Camera Controller stores output from the LiDAR Scanner, SPAN and webcam / medium-format camera, including GNSS timing and position, unprocessed IMU data, pulse timing, return signal waveform attributes, synchronisation data and scanner position information, and raw images for later processing. The data is stored on a removable solid state disc (SSD) in the MM30 removable drives. Four MM30 drives are supplied with the system allowing rotation of storage media from the field back to the processing centre.

**Data Storage:** All flight data are stored on the MM30 removable drives.

**Interface Plate:** A vibration-isolated interface plate is provided to allow Camera Controller mounting to aircraft.

## OC60 and PD60 User Interface Hardware

The OC60 and PD60 provide airborne-qualified, outdoor-readable display platforms for operator interface and flight navigation software, respectively. The operator interface software provides a graphical user interface for system set-up, operation, monitoring and flight navigation.

**OC60 Operation Controller:** Primary input to the operator interface software is via the OC60's large touch-screen display. The OC60 display unit is installed via a VESA-standard mounting hole pattern. This mounting surface allows mounting on user-provided brackets, or on the optional IS40 pedestal or PHT50 holder.

**PD60 Pilot Display:** The primary navigation display for the system is the PD60. The compact display with "hot keys" allows ready switching between available navigation views. A VESA-standard mounting hole pattern is provided, allowing mounting on user-provided brackets.

Fig. 2: Leica TerrainMapper mounted in Leica PAV100 Gyro-Stabilised Sensor Mount

## Workflow Software

The workflow package addresses all project phases from planning through processed data delivery. The following software is included with the system:

**Leica MissionPro Flight Planning and Evaluation Software:** Calculates optimal flight line layout and embeds layout and optimised system settings in a flight plan database file for transfer to system.

**AeroPlan:** This proprietary mission planning template is a subset of Leica MissionPro Flight Planning and Evaluation Software and is provided to aid users in determining proper system set-up and flight line spacing.

**Leica FlightPro Sensor Control and Flight Management Software:** Accepts flight plan database files from MissionPro and provides aided navigation for pilot and automatic or manual system operation for the system operator.

**NovAtel Inertial Explorer GNSS/IMU Processing Software**: Combines GNSS base station data with NovAtel SPAN airborne GNSS data to provide a DGNSS or PPP aircraft position solution; combines the DGNSS solution with raw IMU data from the TerrainMapper Pod to provide smoothed position and orientation data. Post processed output features a "tightly-coupled" solution, allowing steep bank angles during turns.

# Technical Specifications

**Critical Item Definition:** The system consists of all hardware and software necessary to meet the specifications herein. All assemblies are designed for rugged environments sustained on unpressurised light aircraft. As such, the system is capable of operation while being subjected to variations in temperature, humidity and altitude experienced in-flight. In addition, surfaces of the system exposed during flight are capable of operation during exposure to precipitation and blowing dust.

**Physical Requirements:** The system is within the following envelope dimensions, as shown in the TerrainMapper Installation Information, document 872383. The standard configuration for the Camera Controller is a rackless assembly on a vibration-isolated interface plate assembly.

| TERRAINMAPPER POD ASSEMBLY DIMENSIONS (-L, -LN): | |
|---|---|
| Length | 16.06" (408 mm) |
| Width | 16.06" (408 mm) |
| Height | 29.41" (747 mm) |
| **MAXIMUM WEIGHT:** | |
| TerrainMapper Pod (-LN, 50mm lens, with CNUS5 IMU) | 90.8 lb (41.3 kg) |

# Mounting

**TerrainMapper Pod:** The TerrainMapper Pod is mounted to the aircraft using the included PAV100 stabilised mount.

**Camera Controller:** The Camera Controller is normally mounted using the included 783453 vibration isolated interface plate assembly. If mounting in a user-supplied vibration-isolated platform is desired, the Camera Controller can be mounted using features for this purpose supplied on the bottom of the Camera Controller.

**Operator Interface:** The Operator Interface is designed for mounting to sturdy horizontal or vertical surfaces using the VESA-standard mountings provided for attachment to user-supplied brackets, to the optional IS40 mounting pedestal or to the optional PHT50 holder. Mounting for this assembly should be provided by the user in an appropriate fashion to minimise strain on the high-density electrical connectors used for interface between the Camera Controller and the OC60 Operation Controller, and to minimise movement of the assembly or cables when exposed to atmospheric turbulence during flight.

**Pilot Display:** The Pilot Display is designed for mounting to sturdy horizontal or vertical surfaces using the VESA-standard mountings provided for attachment to user-supplied brackets. Mounting for this assembly should be provided by the user in an appropriate fashion to minimise strain on the high-density electrical connectors used for interface between the Camera Controller and the PD60 Operation Controller, and to minimise movement of the assembly or cables when exposed to atmospheric turbulence during flight.

Fig. 3: Leica TerrainMapper showing camera head Leica RCD30 CH82

## Performance Requirements

**Flying Height:** The maximum recommended flying height for the system is approximately 5500 m AGL. Figure 4 describes the maximum pulse rate for target detection as a function of flying height. Recommended minimum range is 300 m.

**Field of View (FOV):** System FOV is adjustable over the range of 20 - 40 degrees, in 1-degree increments. Contact Leica Geosystems for inquiries regarding maximum unvignetted FOV for installation in specific aircraft.

**Scan Pattern:** The system provides 3 scan patterns, all in a plane nominally parallel to the base of the pod, nominally centred about nadir:

- Conical (circular) scan: with data collection on both forward-looking and aft-looking directions
- Quasi-sinusoidal scan: with data collection on both left-bound and right-bound scans
- "Flower" scan: with continuous data collection

**Scan Rate:** Maximum scan rate of 150 Hz can be achieved regardless of FOV for conical and sinusoidal scan patterns. For "flower" scan pattern, the total duration of one "flower" scan depends on the settings used for the two scan wedges. The scan rate (cycle rate in Hz) is user-selectable from 1500 - 9000 RPM (25 - 150 Hz) in 1 RPM increments via the graphical user interface. A minimum scan rate of 3600 RPM must be used for FOVs less than 40 degrees.

**Roll Stabilisation:** Automatic stabilisation is provided by the PAV100 stabilised mount, in roll, pitch and heading directions. Refer to PAV100 literature for specifications.

**Illuminated Footprint:** Output beam divergence is 0.25 mr nominal, measured at the $1/e^2$ point. For reference, this is equivalent to approximately 0.15 mr measured at the 1/e point.

**Pulse Rate:** The maximum achievable pulse rate of the system is related to the maximum flying height to be encountered. Figure 4 summarises maximum pulse rates at various flying heights, assuming a 40-degree FOV. The range of pulse rate values is from 200,000 Hz - 2,000,000 Hz in 100-Hz increments.

**Multiple Pulses in Air:** The system is equipped with a gateless Multiple Pulses in Air (MPiA) feature, which allows increased maximum pulse rates over that offered by gated MPiA systems when any significant terrain relief is encountered. Up to 35 simultaneous MPiA zones can be accommodated per flight line. Maximum achievable pulse rates are shown in figure 1 and apply so long as no more than 35 MPiA zones are encountered within the flight line. Processing software must automatically determine the proper zone for any return pulse. There is no loss of point density in the transition area between adjacent MPiA zones.

**Target Detection Rate:** The system is capable of detecting 90% of targets having at least 10% diffuse reflectivity and fully intercepting the laser footprint. Return reflection for targets with less than 10% diffuse reflectivity may not produce adequate signal strength and may result in "drop-outs". The ability to measure range associated with a given return is dependent on the surface having adequate reflectivity and intercepting a sufficient portion of the laser footprint. Targets intercepting less than the full laser footprint will require proportionally higher reflectivity for successful detection.

**Multiple Target Detection:** The system is capable of detecting up to 15 returns for each outbound laser pulse, provided each reflecting surface results in adequate signal strength for detection.

**Minimum Vertical Separation:** The minimum vertical separation (range separation) that can be detected on a given outbound laser pulse is 0.5 m.

**Multi-Return Intensity:** Systems are shipped with a multiple-return intensity measurement feature. With this feature, the sizes of the reflected returns at various elevations are measured in addition to the distances to each reflecting surface measured by the range waveform digitiser. A 14-bit scale is used to digitise return signal intensity from the detection channel. A 16-bit scale is used upon output of intensity data from Leica HxMap, after compensating for variations in slant range. The ability to digitise the signal strength is dependent on the surface having adequate reflectivity and intercepting a sufficient portion of the laser footprint. Targets intercepting less than the full laser footprint will require proportionally higher reflectivity for successful detection.

**Accuracy:** The system produces data after post-processing with a lateral placement accuracy of 5 – 59 cm and vertical placement accuracy of 9 - 25 cm (one standard deviation) from full-field-filling targets of 10% diffuse reflectivity or greater with atmospheric visibility of 23.5 km or better for flying heights up to 5500 m AGL and nominal FOV of 40 degrees. Accuracy estimates for various flying heights above terrain are shown below and can be provided in detail by using the AeroPlan mission planning template. Estimates below are made assuming a 40-degree FOV, CNUS5 IMU and a nominal 4 cm GNSS error and target SNR of 13.4 (6.7 minimum). Note that the accuracy estimates below and provided by AeroPlan are conservative, and typical vertical accuracy of < 5 cm is achieved at a nominal flying height of 1000 m AGL.

**Side Lobes:** The laser output beam does not have any side lobes outside the main beam.

**Input Voltage:** See “Environmental Requirements”.

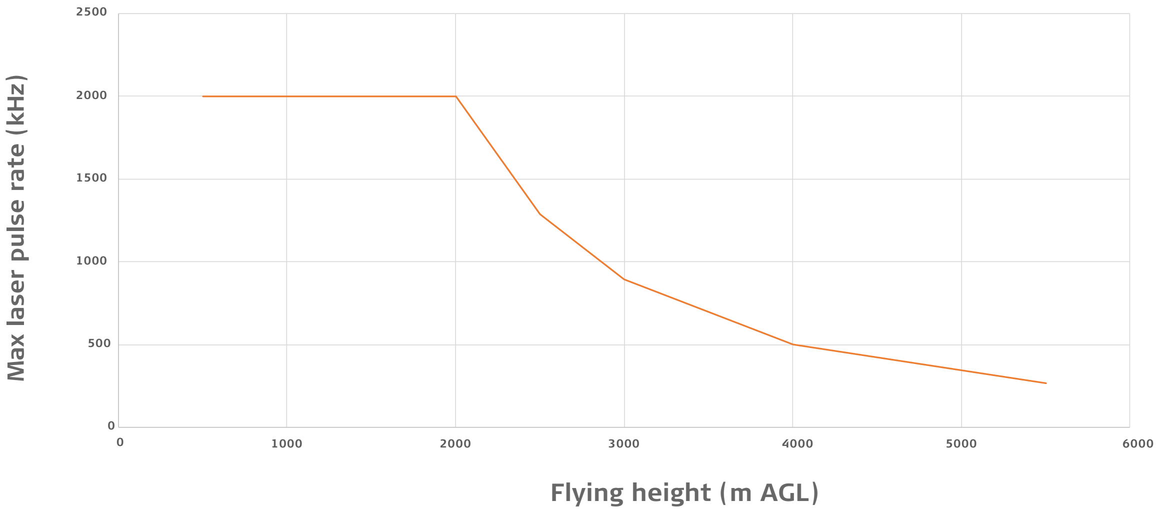


Fig. 4: Performance envelope for specified detection limit. Note: higher accuracy obtained at lower pulse rates for any given flight height.

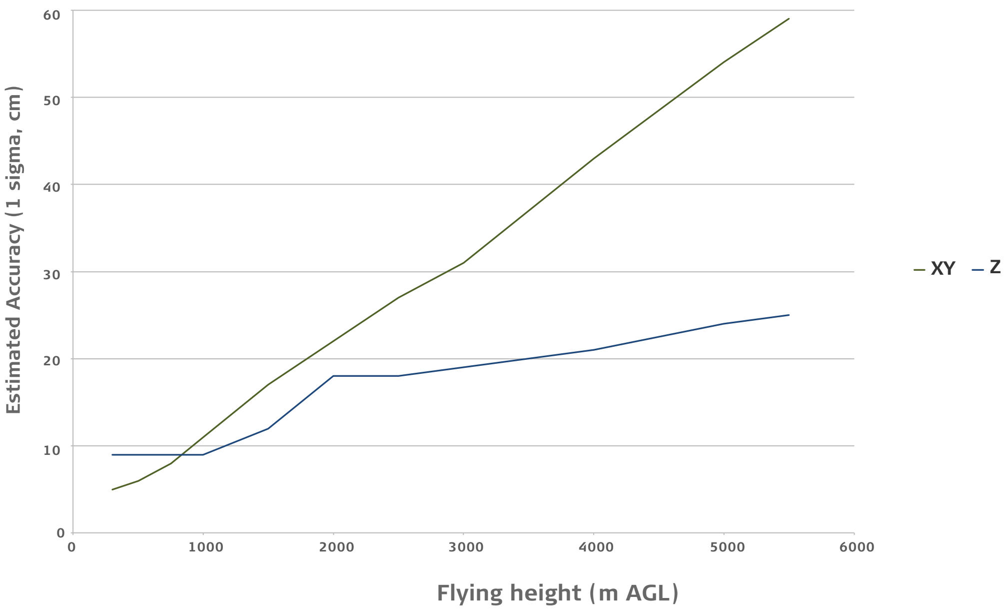


Fig. 5: Estimated accuracy (system level, including GNSS/IMU error).

**Input Power:** The system is designed to minimise damage due to out-of-range supply voltage. Maximum average power draw is 700 Watts including the PAV100. Peak Power draw is 1000 Watts.

**Reverse Polarity Protection:** The system is designed to sustain accidental exposure to reverse polarity applied to the main power input. The system will not operate under such a condition.

**Laser Output Control:** The system provides control over laser output over an approximate 100:1 range in 1% increments.

**Beam Uniformity:** The laser beam quality shall exhibit an $M^2$ value better than 1.3.

**Warm-Up Time:** The system is ready for use within 6 minutes of application of primary power, assuming start-up at 0 °C or higher temperature.

**Duty Cycle:** The system is capable of continuous operation at maximum pulse rate. Recording capacity is defined below.

## Design Requirements

**Laser Output Shutter:** The system has an integrated shutter allowing full output or complete obscuration of the output laser beam. The assembly is remotely actuated using the graphical user interface software. The assembly provides status signals sufficient to allow confirmation of assembly position (closed or open).

**Emission Indicator:** A CDRH-compliant laser emission indicator is provided on the Pod. When the Pod is installed in the aircraft, the emission indicator is readily visible.

**Warning Buzzer:** A CDRH-compliant warning buzzer is incorporated into the Pod.

**OS Installation:** Non-mechanical drive

**OS Protection:** Protected from improper shutdown via EWF or equivalent on Windows 7 (OC60, CC33) or Windows 10 (CC43)

**Data Storage:** Removable SSD (MM30), 2400GB standard

**Recording Capacity:** The system has a nominal recording capacity of › 5 hours on a pair of MM30/2400GB Mass Memory when operating at maximum pulse rate and assuming an average of 2 returns per outbound pulse. Capacity is proportionally longer at lower pulse rates or fewer returns per outbound pulse. Capacity is lower when using waveform recording mode and also depends on waveform rates. Data drives can be swapped in-flight, after system shut-down, re-start and in-air GNSS/IMU initialisation.

**Post-Processing Software:** Software is provided which processes raw data collected in the air and on the DGNSS base station and produces an output data set in WGS84 coordinates. Industry standard LAS 1.4 format is used for output of the post-processed data. Post-processing software is designed to run under all Microsoft Windows 64-bit operating systems Window 10 and higher.

Fig. 6: Close-up of the Leica TerrainMapper

# Workflow Software Requirements

Workflow software is designed to meet the following requirements:

**Unified Software Package:** The software provided for processing raw data from the system with the supplied trajectory data must produce all data products without the need to exit and/or export data to additional software packages. All processing must be from a single unified User Interface.

**Point Cloud Generation:** The software must be capable of the following functions:

- Ingest of raw data from MM30 media
- Creation of point cloud
- Creation of gray-scale intensity image output (i.e., x/y/intensity images in *.tif format)
- Radiometric corrections of intensity data for variations in slant range and visibility
- Colorisation of point cloud (-LN variant)
- Calibration of LiDAR sensor
- Generation of intra-line QC data including quality of elevation matching in 4 programmable error bands (typically <4 cm, 4 - 7 cm, 7 - 10 cm and > 10 cm) including both tabular data and graphical format (ortho view color coded by error level, for quick visual interpretation)
- Line-to-line registration of LiDAR data strips
- Generation of line-to-line QC data including quality of elevation matching in 4 programmable error bands (typically < 4 cm, 4 - 7 cm, 7 - 10 cm and > 10 cm) including both tabular data and graphical format (ortho view color coded by error level, for quick visual interpretation)

**Point Cloud Viewing:** The software must provide a point cloud viewer accessible from the workflow software menu with the following functions:

- Point cloud viewing in ortho or perspective views
- Display of data, color coded by elevation, intensity or both (simultaneous)
- Section tool to allow viewing a limited "slice" of the point cloud with user-defined section thickness. The section tool must not be restricted as to section orientation about a vertical axis
- Measurement tool to allow measurement between locations (slant distance, elevation change, lateral distance) within a section

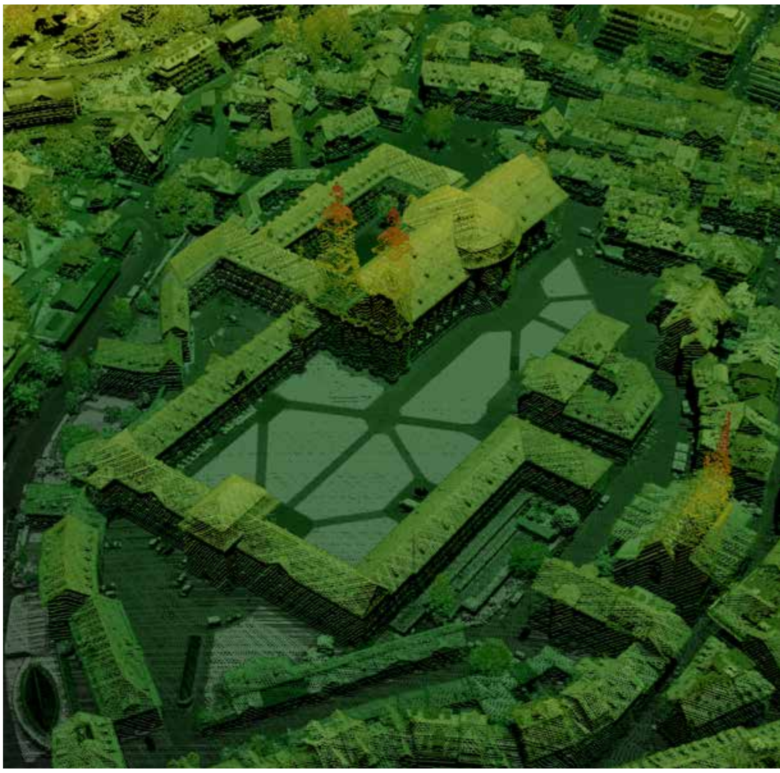

Fig. 7: Cathedral, St. Gallen, CH, acquired from 1000 m AGL at 130 knots & 40° FOV; 25 points/m²

**Point Cloud Formatting:** Output in LAS 1.4 format, including point cloud color (if -LN variant used):

- **Projection Engine:** Point cloud data can be output in user-selectable projection, datum and geoid. At a minimum, UTM and US State Plane systems must be supported. User-required custom projections or geoid corrections are possible by providing mathematical definitions for custom projections. All coordinate conversions are compatible with CORPSCON.

**Image Generation:** The software must be capable of the following functions:

- Ingest raw image data from MM30 media
- Create developed images (de-Bayering)
- Apply radiometric and geometric calibrations
- Georeference images
- Create ortho images
- Perform image calibration (IMU boresight)

**Distributed Processing:** The software must provide the ability to delegate processing to multiple processing computer nodes using the HT Condor environment to increase processing speed. The standard deliverable must provide licencing for at least two operator interface nodes and four processing nodes. Software must be scalable to increase the number of processing nodes via additional licences.

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