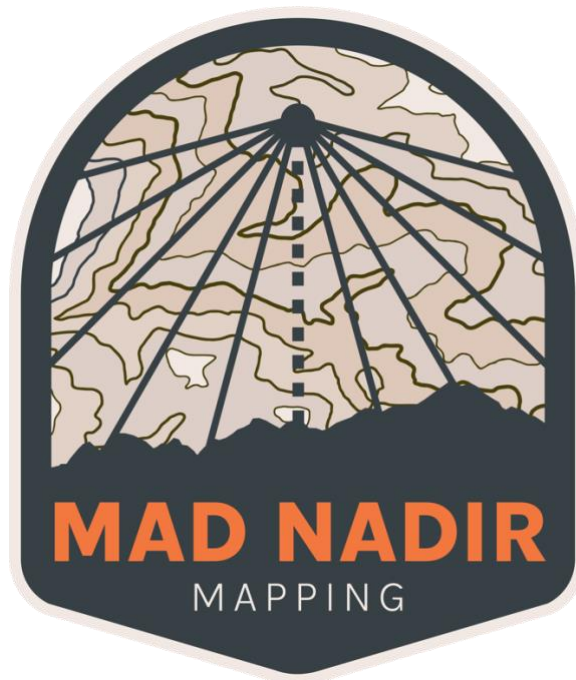


# Mad Nadir Mapping Lidar System (MNMLS)

## Mad Nadir Mapping Lidar Processor (MNMLP)



## User Manual

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Version 2.0

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# 1. Introduction

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This User Manual provides the information needed for a drone lidar operator to understand and properly utilize both the Mad Nadir Mapping Lidar System (MNMLS) and the included Mad Nadir Mapping Lidar Processor (MNMLP) software. Note that this User Manual is a living document and the iteration provided to you in the USB flash drive at purchase is specifically written for your hardware, firmware, and software versions. Mad Nadir Mapping will let customers know of any updates to the MNMLS firmware, the MNMLP software, and the subsequent User Manual changes made to reflect those updates. Mad Nadir Mapping *strongly* suggests the user read through and understand this document in its entirety prior to using the MNMLS and MNMLP products. Many questions will likely be answered by reading through this User Manual.

What's included with your purchase:

- 1x Hard Case
- 1x MNMLS Unit
- 1x MNMLP Software
- 1x USB3 Flash Drive
  - Contains the user manual and the MNMLP installer
- 1x Multi-frequency Helical GNSS Antenna
- 1x GNSS Antenna Mounting Kit

## 1.1 Mad Nadir Mapping Lidar System (MNMLS) Overview

The Mad Nadir Mapping Lidar System (MNMLS) is an all-inclusive and turn-key UAV lidar system that is ready to acquire actionable data right out of the box. The system is both lightweight (~730 grams), affordable, and contains a tactical grade inertial measurement unit (IMU) coupled with a multi-frequency GNSS receiver. Combined, these two components make up the highly accurate inertial navigation system (INS). MNMLS uses a multi-return lidar scanner capable of recording single, double, and triple returns. Each MNMLS unit includes a GNSS antenna and mounting kit along with a perpetual license to the Mad Nadir Mapping Lidar Processor (MNMLP) software (including the BayesMap StripAlign tool). The MNMLS allows for push-button data logging and also contains a web-app interface for system checks, IMU calibration, data logging, etc. The MNMLS comes standard with a skyport mount (power only), but can be mounted on any UAV (VTOL, fixed-wing, multi-rotor) with a custom mount. All MNMLS units are designed and assembled in the USA. More details about the MNMLP software can be found in [Section 2](#).

### System Specifications:

- Overall Weight: 730 grams + 90 grams (GNSS antenna/mount)
- Input Voltage Range: 12 - 15 V
- Several Mount Options
- Push Button Data Logging
- Simple Web App Data Interface (2.4 or 5.0 GHz wifi)

- LED Status Light
- External USB3 Data Logging
- UAV GNSS Antenna and Mount
- Designed and Assembled in the USA

### INS/IMU Specifications

- Tactical Grade IMU (US Company)
- 0.04° Roll/Pitch (RMSE)
- 0.13° Heading (RMSE)
- Gyroscope: 1.5°/hr Bias Instability
- Accelerometer: 19 µg Bias Instability
- Multi-band GNSS
  - GPS L1C/A L2C, GLO L1OF L2OF, GAL E1B/C E5b, BDS B1I B2I, QZSS L1C/A L2C
- 0.01 m + 1 ppm CEP

### Laser Specifications

- Lidar Returns: Single (first), Single (strongest), Double, and Triple
- FOV: 70.4° (horizontal) x 4.5° (vertical)
- Beam Divergence: 0.28° (vertical) x 0.03° (horizontal)
- PRF: 240,000 PPS (single), 480,000 PPS (double), and 720,000 PPS (triple)

## **1.2 Mad Nadir Mapping Lidar Processor (MNMLP) Overview**

Each MNMLS purchase includes a perpetual processing license for the Mad Nadir Mapping Lidar Processor (MNMLP) software. The MNMLP software is easy to use and includes an interactive lever arm/boresight tool, contains a BayesMap StripAlign function, utilizes PPK trajectory processing, allows for field-based processing, does not require an active internet connection (except when using StripAlign), contains no hidden post-processing steps, employs multi-core processing techniques, consumes low amounts of RAM, requires zero license fees, and includes free software updates. The MNMLP software seamlessly ingests the raw MNMLS data and outputs a georeferenced compressed .las file (.laz) that can be brought in to any lidar post-processing software. The installer file for the MNMLP software is within the included USB3 flash drive. It is suggested to make a copy of the USB3 contents as you will use the flash drive for data logging. More details about the MNMLP software can be found in [Section 3](#).

### Software Specifications

- Zero License Fees
- Simple Workflow with Industry Standard Outputs (.laz)
- Compatible with Windows 10/11
- Multi-Core Processing with Very Low RAM Usage
- Lever Arm and Boresight Correction Tool
- StripAlign Function Powered by BayesMap
- No Internet Access Required (\*except StripAlign)

- No Hidden Post-Processing Steps
- PPK Trajectory Processing (requires base station)
- Perpetual Software License Included (\*including BayesMap StripAlign)
- Software Upgrades Included (\*not including BayesMap StripAlign)

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## 2. Mad Nadir Mapping Lidar System (MNMLS)

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### 2.1 MNMLS Components

The Mad Nadir Mapping Lidar System (MNMLS) is an all-inclusive UAV lidar mapping system. The MNMLS receives its power from the skyport mount on the top of the case. Remember to attach the MNMLS to the drone prior to turning the drone's power on. When the system first receives power, you will hear the MNMLS fan cycle on as well as the laser head spin up for several seconds. The laser head will then enter power saving mode until the user starts the data logging process. The main MNMLS components include the 1) System Status LED, 2) Pushbutton, 3) GNSS Antenna and Mount, 4) USB3 Flash Drive, and the 5) MNMLS Web App. Each of these five main components is described below along with a section for MNMLS Best Practices and Mission Planning.

#### 2.1.1 System Status LED

The System Status LED provides the user with meaningful system information.

- When power is first applied to the system the LED will remain solid for ~15 seconds during the bootup phase. Note that during this bootup phase the MNMLS fan will power on (located on the opposite side of the case) and the laser head will audibly spin-up, and then go into a power saving mode
- After the bootup phase is complete, the system will then wait for a GNSS signal lock and the LED will display a “waiting for lock” mode. This mode is indicated by 4 fast blinks followed by 1 second of LED off. This series of LED blinks is repeated until the GNSS signal is acquired. If the GNSS antenna is not connected, or the GNSS antenna is connected but does not have a good sky view, then the GNSS signal will not lock and the System Status LED will stay in this mode. Data logging cannot start until a GNSS signal lock is acquired
- Once a GNSS signal lock is acquired the system will enter into a “waiting for logging” mode. The LED will remain solid in this mode and the user can start the appropriate logging procedures. Note that once the system has received an initial GNSS signal lock, the system will remain in this mode and the LED will remain solid (unless data logging is active) -- even if the GNSS antenna is unconnected or the system is moved to a location with a poor sky view. In this case, the LED will appear to the user that it has a GNSS signal lock, but in reality, it does not. Under these scenarios data logging will not be possible until the proper GNSS signal returns
- When data logging has been initiated by the user (via the Push Button or Web App) the system will enter into an “initial data logging” mode. In this mode, the LED will blink very rapidly for around 30 seconds. During this time the laser head will audibly spin-up as it comes out of its power saving setting. This “initial data logging” mode will continue until either A) the system enters into the “active logging” mode (LED blinks at 1 Hz) or B) the system was not able to properly begin logging and re-enters the “waiting for logging” mode (solid LED)
- If the system was not able to properly initiate data logging, the LED will return to solid and the system will revert to the “waiting for logging” mode

- If the system was able to properly initiate data logging, the system mode will change to “active logging” and the LED will blink at 1 Hz. Do not proceed with your UAV mission until the “active logging” mode has been attained and the LED blinks at 1 Hz
- After the system receives a safe shutdown command (from the Pushbutton or the Web App), the LED will turn off. This indicates that the system has been safely shutdown and that the user may remove power from the MNMLS and/or detach the MNMLS from the UAV. Always safely shutdown the MNMLS prior to removing power or detaching the system

## 2.1.2 Pushbutton

The Pushbutton provides a means for the user to interact with the MNMLS without the need to use the MNMLS Web App. The Pushbutton allows for the following actions.

- Start Logging

Hold down the Pushbutton for 3 - 4 seconds to initiate the start logging sequence. For this sequence to begin the system must be in the “waiting for logging” mode and the System Status LED should be solid. Once the sequence has begun the system will enter into the “initial data logging” mode and the System Status LED will blink very rapidly. During this time the laser head will audibly spin-up as it comes out of its power saving setting and the system components will begin their logging and data checks. This “initial data logging” mode will continue until either A) the system enters into the “active logging” mode (LED blinks at 1 Hz) or B) the system was not able to properly begin logging and re-enters the “waiting for logging” mode (solid LED).

- The default lidar return type for the Pushbutton Start Logging method is “Double Return”
- A text file named “\_buttonStartConfig.txt” should be placed on the USB drive in order to adjust the return type for a mission started with the Pushbutton
- The sole contents of this text file should be a 0, 1, 2, or a 3. Here, a 0 denotes the “Single - First Return” type, a 1 denotes the “Single - Strongest Return” type, a 2 denotes the “Double Return” type, and a 3 denotes the “Triple Return” type
- This change is not persistent and the default return method for a Pushbutton data start will always be “Double Return”
- The system will always check the USB3 drive for the “\_buttonStartConfig.txt” if the Pushbutton start method is used

- Stop Logging

Hold down the Pushbutton for 3 - 4 seconds to initiate the stop logging sequence. For this sequence to begin the system must be in the “active logging” mode and the System Status LED should be blinking at 1 Hz. That is to say, if the system is not actively logging and the Pushbutton is held for 3 - 4 seconds then the system will initiate the start logging sequence instead. When the stop logging sequence is sent, the system will switch from the “active logging” mode back to the “waiting for logging” mode and the System Status LED will switch from blinking at 1 Hz back to a solid LED. During this time you will hear the laser head spin down and re-enter power saving mode. Note that the USB drive will be safely ejected after the stop logging Pushbutton command completes. To avoid data corruption, please wait several seconds after the lidar re-enters power saving mode and

the system switches back to the “waiting for logging” mode prior to removing the USB drive.

- **Shutdown**

Hold down the Pushbutton for 8 - 9 seconds (or until the System Status LED turns off i.e., around 12 - 13 seconds) to initiate the safe shutdown sequence. Always safely shutdown the MNMLS prior to removing power or detaching the MNMLS from the UAV. The user may opt to use the safe shutdown sequence instead of the stop logging sequence to safely stop the data logging process. That is to say, if the system is in the “active logging” mode (System Status LED is blinking at 1 Hz) and the user holds down the button to issue the Shutdown sequence (8 - 9 seconds), the system will first begin the stop logging sequence prior to entering the safe shutdown sequence. The system is safely shutdown when the System Status LED light turns completely off. Do not remove power from the system until the LED is off and a few seconds have passed.

### 2.1.3 GNSS Antenna & Mount

- The MNMLS includes a multifrequency GNSS helical antenna and arm mounting system
- The user can supply their own GNSS antenna and mount as long as the cable has an SMA connection and records the appropriate GNSS frequencies as listed in the INS/IMU Specifications sub-section in [Section 1.1](#)
- Make sure the GNSS antenna has a clear view of the sky and the GNSS antenna cable is properly plugged into the SMA port labeled “GNSS” above the Pushbutton on the MNMLS
- Make sure the excess GNSS cabling is safely secured prior to each flight
- The user should make note of the “x”, “y”, and “z” lever arm offsets for each mission as they will be required for accurate georeferencing using the MNMLP software. The “x” axis is aligned with the yaw/heading of the MNMLS/drone. The “y” offset is perpendicular to the yaw/heading of the MNMLS/drone. The “z” axis is in the down direction. The terms “Left”, “Right”, “Front”, and “Back” are relative to the normal direction of travel/heading of the drone. So, if the user is standing behind the drone looking towards its normal forward direction, “Left” is to the left, “Right” is to the right, “Front” is towards the forward direction, and “Back” is towards the reverse direction. The offsets should be measured from the GNSS L1/L2 antenna phase center to the bottom middle of the Avia laser head (i.e., the origin of the lidar reference frame). The antenna reference point (ARP) is located at the bottom of the supplied GNSS helical antenna. The L1 phase center is 30.8 mm above the ARP and the L2 phase center is 32.6 mm above the ARP. The lidar frame’s origin is 32.4 mm along the “x” axis and 30.6 mm along the “y” axis. The “x” axis in this sense is the front/back axis when looking directly down at the MNMLS as it would be mounted on the drone. The “y” axis in this sense is the left/right axis when looking directly down at the MNMLS as it would be mounted on the drone. See the schematics below in Figure 1
  - A positive “x” offset occurs when the lidar is in FRONT of the GNSS antenna
  - A positive “y” offset occurs when the lidar is to the RIGHT of the GNSS antenna
  - A positive “z” offset occurs when the lidar is BELOW the GNSS antenna
- The MNMLP software includes an interactive lever arm and boresight tool. This tool can be used to individually adjust the lever arm offsets (and boresight misalignment angles) “on the fly” and fine-tune them until the user is satisfied with the output point cloud

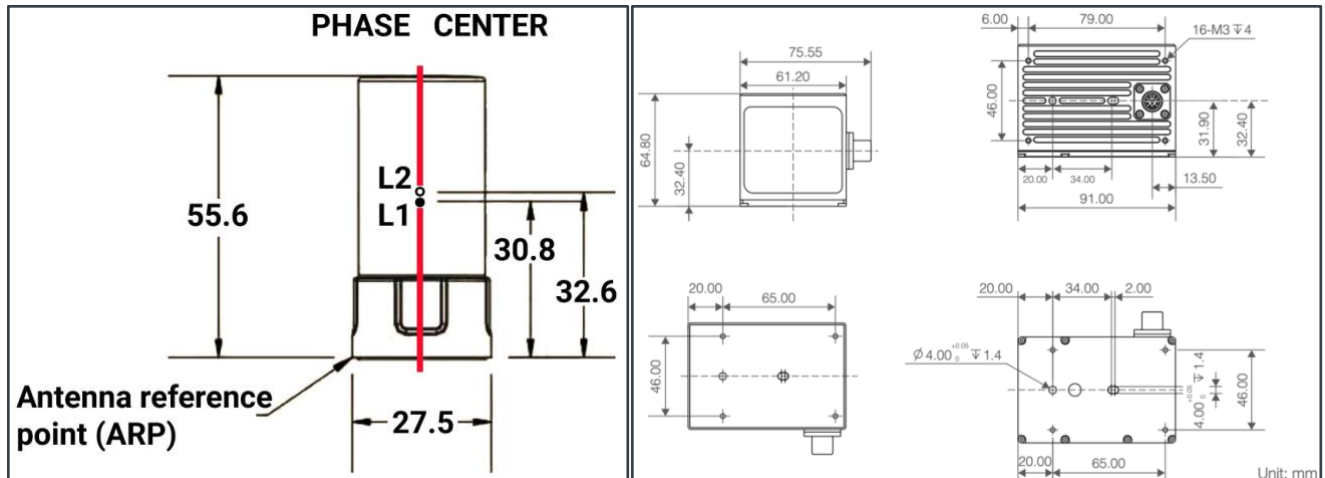


Figure 1: Antenna reference point (ARP) and phase center of the GNSS antenna (left) and origin of the lidar reference frame (right). The lidar frame's origin is where the two dashed lines cross in the top-left schematic of the image on the right

## 2.1.4 USB3 Drive

- The MNMLS includes a USB 3.1 Samsung Fit Plus 128 GB flash drive
- The system will only work with the supplied Samsung USB 3 flash drive. The model of this drive is MUF-128AB/AM. It is suggested to keep a few of them on hand
- The system will not properly log data if there is not a Samsung Fit Plus USB 3.1 drive attached
- It is the user's responsibility to make sure there is enough capacity on the flash drive prior to each mission. The storage capacity can be checked using the MNMLS Web App. If the flash drive runs out of space during the mission you will very likely lose your data
- A new USB drive should be formatted as ExFAT before first use. You can use the MNMLS Web App to wipe and reformat the drive. The supplied drive is already properly formatted for your convenience
- The drive will be properly ejected/unmounted if using the Pushbutton stop logging or shutdown procedures. Otherwise, you must use the MNMLS Web App to safely eject/unmount the drive. Never remove the drive unless it is properly ejected/unmounted. Otherwise you may corrupt the data
- Note that only one USB drive should be plugged into the MNMLS at a time

## 2.1.5 MNMLS Web App

The system includes an easy-to-use Web App that allows the user to interact with the MNMLS. In order to use the Web App the user must first connect to the MNMLS wifi access point. Note that the MNMLS hotspot may take several seconds to display after power is initially applied to the system. The Web App can be used on a desktop, laptop, tablet, or a phone.

- SSID: MNMLS\_xxxxxxx
- Password: "MNMLSMNMLS"

Once connected to the MNMLS wifi the user must navigate to the browser of their choice and enter the following IP address and port number to load the MNMLS Web App. Note that the Web App may not be available for the first 30 - 60 seconds or so after power is initially applied to the MNMLS. Just refresh the page until the Web App loads.

- 192.168.69.1:6969

Mad Nadir Mapping may occasionally supply the user with a firmware update file. Instructions will be provided to the user with this file. However, the general MNMLS firmware update process is described below

- The user will put the firmware file in an otherwise empty USB drive and then physically connect the USB drive to the MNMLS
- The user will connect to the Web App and select the “ATTACH USB DRIVE” button. Anytime a USB drive is mounted to the MNMLS the system will automatically check for a firmware update file
- If the system finds a firmware update file it will automatically begin the update procedure
- The firmware update file be removed if the update was successful

The MNMLS Web App is broken down into different sections: 1) Logging Commands Section, 2) System Commands Section, 3) Logging Status Section, and the 4) USB Status Section. These four sections are denoted by the red numbers in Figure 2. The Web App sections are individually described in the sub-sections below along with the individual buttons and actions available to the user within each section.

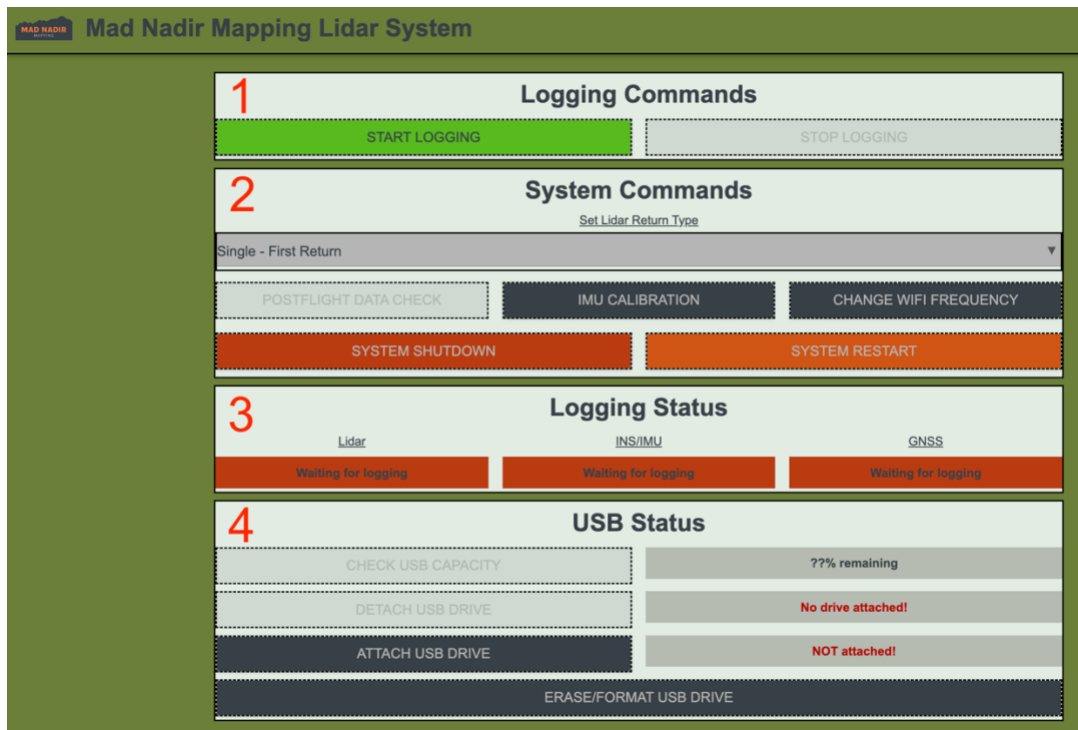


Figure 2: Main window of the MNMLS Web App. The individual GUI sections are labeled in red numbers

### 2.1.5.1 Logging Commands Section

This portion of the Web App allows the user to start or stop the logging procedure.

- “START LOGGING” Button: This button allows the user to begin logging
  - Before selecting this button the user should make sure to select the appropriate return type using the “Set Lidar Return Type” dropdown under the “System Commands” Section
  - The provided USB drive must be attached/mounted prior to selecting this button. The system will alert the user to this fact if a drive is not already mounted
  - Once this button is selected the user is greeted with a window that allows them to “Enter a unique name for this flight”. The user should input a meaningful name for the mission. Note that a system timestamp (UTC) will be appended and will become the full name of the folder on the USB drive where the data for this mission is logged. Select “OK” when the name is entered and to begin logging
  - The logging commands will then be sent to the system and the “Logging Status” Section will populate (see below) according to the sub-system data checks
  - Once the “Logging Status” checks are all green, the user may begin their mission
  - Note that the “START LOGGING” button will be greyed out when data is actively logging
  - Note that if the user wishes to use the Web App when the UAV returns “home” from a mission then they must reconnect to the MNMLS Web App
- “STOP LOGGING” Button: This button allows the user to stop the logging process
  - Once this button is selected the user will be prompted with a window asking them if they are sure they want to stop logging. If so, select “YES” and the stop logging procedure will begin. If not, select “NO” and the system will continue logging
  - The “STOP LOGGING” button will be greyed out unless data is actively logging

### 2.1.5.2 System Commands Section

This portion of the Web App allows the user to interact with the MNMLS via various system commands and settings.

- “Set Lidar Return Type” Dropdown: This dropdown allows the user to select the return type for the mission
  - The available options are: “Single - First Return”, “Single - Strongest Return”, “Double Return”, and “Triple Return”
  - Note that the user must set the return type for the mission prior to selecting the “START LOGGING” button
  - The return mode option that is currently selected in the dropdown menu when the user clicks the “START LOGGING” button is the return mode that will be used during the mission
  - Changing the mode via this dropdown has no effect on the default return mode used with the Pushbutton data logging method. See [Section 2.1.2](#)

- “POSTFLIGHT DATA CHECK” Button: This button provides the user a quick initial field data check of a completed mission
  - The USB drive must be mounted or this button will be greyed out
  - Once this button is clicked the user is greeted with a dropdown menu allowing them to select the mission they wish to pass into the postflight data check tool
  - After selecting the mission please wait for the three sub-system (Lidar, INS/IMU, & GNSS) data inspection commands to complete. The longer the mission, the longer this step will take
  - Once the inspections are complete a form will display showing the user different data checks for each of the three sub-systems (Lidar, INS/IMU, & GNSS). The user can navigate between the different sub-systems using the buttons at the bottom of the form
    - “Lidar Data”
      - Make sure the “Data Type” (i.e., lidar return type) for the mission is what was desired
      - Check to make sure the “Length of Log” makes sense for the mission and that it is comparable to the “Length of Log” fields in the “GNSS Data” and “IMU Data” tabs. They should all be similar
      - Note the “Time of First/Last Data Point” and make sure that it is comparable to the same field in the “GNSS Data” and “IMU Data” tabs. They should all be similar
      - The “System Status” should be at or close to 100% “Normal”
      - The “PPS Status” should be at or close to 100% “PPS Ok”
      - The “Timestamp Type” should be at or close to 100% “GPS”
    - “GNSS Data”
      - Check to make sure the “Length of Log” makes sense for the mission and that it is comparable to the “Length of Log” fields in the “Lidar Data” and “IMU Data” tabs. They should all be similar
      - Note the “Time of First/Last Data Point” and make sure that it is comparable to the same field in the “Lidar Data” and “IMU Data” tabs. They should all be similar
      - Check that the “Approx. # of GNSS Sats” contains a meaningful number. E.g., > 8
    - “IMU Data”
      - Check to make sure the “Length of Log” makes sense for the mission and that it is comparable to the “Length of Log” fields in the “Lidar Data” and “GNSS Data” tabs. They should all be similar
      - Note the “Time of First/Last Data Point” and make sure that it is comparable to the same field in the “Lidar Data” and “GNSS Data” tabs. They should all be similar

- Check to make sure the “Valid Timestamps” field is at or near 100%
    - Check to make sure the “Valid Attitude” field is at or near 100%
  - After the data inspections are complete the user may hit the “DONE” button to return to the main GUI window
- “IMU CALIBRATION” Button: This button allows the user to do a ground calibration of the magnetometer in the IMU. This should not need to be utilized frequently as the system runs a constant magnetometer calibration in the background during use. **The current suggestion is to calibrate (multi-axis) the magnetometer when using the MNMLS on a new UAV.** Note that the system does not rely heavily on the magnetometer during normal MNMLS operation
  - Once the user selects this button they will be prompted with a window telling them to rotate the MNMLS (More likely, the drone with the MNMLS attached) 360 degrees around the yaw/heading axis. This is to excite the IMU to test if an IMU calibration is suggested. The user may select “CANCEL” to go back to the MNMLS Web App main GUI window. Select “OK” when the MNMLS has been rotated 360 degrees around the yaw/heading axis
  - The calibration test will then begin to check the IMU to see if a magnetometer recalibration is suggested. The system will either recommend or not recommend a magnetometer recalibration. The user may choose “YES” to recalibrate or “NO” to return to the MNMLS Web App GUI window regardless of the recommendation
  - If the user selects “YES” they will be prompted with a drop-down window to select the magnetometer calibration method. The available options are “Multi-Axis Calibration” and “Single-Axis Calibration”. We recommend a “Multi-Axis Calibration” for best results. However, if it is not possible to rotate the system 360 degrees along at least two axes (e.g., for large UAVs), then the user may select the “Single-Axis Calibration” method. Again, the MNMLS does not rely heavily on the magnetometer during normal operation. The user may select “CANCEL” to go back to the MNMLS Web App main GUI window. Select “OK” once the desired calibration method is selected from the drop-down
    - “Multi-Axis Calibration” Method: The user must rotate the MNMLS along the yaw/heading axis and at least one other axis (roll or pitch) until the calibration is 100% complete
    - “Single-Axis Calibration” Method: The user must rotate the MNMLS along the yaw/heading axis until the calibration is 100% complete. Any data collected from motion around other axes will be utilized but is not required
  - Once the calibration procedure progress reaches 100% the window will let the user know the calibration was successful. Select the “OK” button. The calibration settings will then be saved to the on-board IMU and the user will return to the main GUI window
- “CHANGE WIFI FREQUENCY” Button: This button allows the user to adjust the frequency of the MNMLS wifi access point. The access point can be switched between 2.4 GHz and 5 GHz

- Once the button is selected the user is greeted with a dropdown allowing them to select their desired wifi frequency. Once the desired frequency is selected, push the “OK” button
- If the wifi frequency is already set to the selected frequency the user will be notified of this via a pop-up. Select “OK” and the user will return to the main MNMLS Web App GUI window
- Otherwise, a pop-up will notify the user that the system will now adjust the wifi frequency and to wait for the MNMLS access point to reappear and then reconnect to the MNMLS wifi
- Note that in order to complete the access point frequency change the user will be briefly booted off the MNMLS wifi network. Please wait for the system to adjust the frequency and then re-connect to the MNMLS wifi network
- “SYSTEM SHUTDOWN” Button: Allows for a proper shutdown of the MNMLS
  - Remember to safely shutdown the MNMLS prior to cutting power to the drone or detaching the system from the drone
  - Once this button is selected the user will be prompted with a window asking them if they are sure they want to shutdown the system. If so, select “YES” and the shutdown procedure will begin. If not, select “NO”
- “SYSTEM RESTART” Button: Allows for a safe rebooting method for the MNMLS
  - Once this button is selected the user will be prompted with a window asking them if they are sure they want to restart the system. If so, select “YES” and the restart procedure will begin. If not, select “NO”

### 2.1.5.3 Logging Status Section

This portion of the Web App allows the user to see the logging status of the three main sub-systems that make up the MNMLS. The text and color information beneath the “Lidar”, “INS/IMU”, and the “GNSS” headers display to the user the status for each of those three MNMLS sub-systems. These values will only be updated if the user pushes the “START LOGGING” button in the MNMLS Web App

- RED = Waiting for logging to begin
- YELLOW = Logging has started but waiting for status checks to pass
- GREEN = Proper logging has commenced and the system is ready for takeoff

### 2.1.5.4 USB Status Section

This portion of the Web App allows the user to interact with the USB drive.

- “CHECK USB CAPACITY” Button: This button checks the available storage capacity of the mounted USB drive
  - The available storage capacity of the USB drive is listed to the right of this button
  - This button will be greyed out if a drive is not mounted
- “DETACH USB DRIVE” Button: This button safely ejects/unmounts the attached/mounted USB drive

- Always eject/unmount the flash drive prior to physically removing the USB drive from the MNMLS. The user can also wait until the system is properly shutdown prior to physically removing the drive
- This button will be greyed out if a drive is not mounted to the MNMLS
- “ATTACH USB DRIVE” Button: This button safely mounts the connected USB drive
  - Only one USB drive should be connected/plugged in to the MNMLS at a time
- “ERASE/FORMAT USB DRIVE” Button: This button erases and reformats the attached USB drive
  - Note that if data is present on the drive, it will be erased

## 2.2 Standard MNMLS Data Outputs

The following files and folders should be present in the project folder after each successful MNMLS data acquisition.

- “IMU” folder containing numerous IMU, INS, and GPS logs (the number of these files is dependent on the length of the mission)
- “logs” binary file containing various system logs. These logs may be requested by Mad Nadir Mapping to provide appropriate support on any issues that may arise during MNMLS operation
- “rawGNSS” binary file containing the raw GNSS data logged during the mission
- “rawLidar.mnm” binary file containing the raw lidar data logged during the mission

## 2.3 MNMLS Best Practices

- The MNMLS receives its power from the skyport mount on the top of the case
- Attach the MNMLS to the drone prior to turning the drone’s power on
- Data is logged to the USB drive. If there is no drive present, then the system cannot record data
- Use the supplied (or equivalent) Samsung Fit Plus USB drive only
- Try to remove flight data from the USB before the USB storage fills up. Data will not properly log if the USB drive fills up mid-flight. You can use the Web App to check the storage capacity of the drive and to erase the drive (if necessary)
- Remember to always properly eject/unmount the drive if you are going to remove it. The drive can be properly ejected/unmounted using the Web App. If the Pushbutton method is used to stop data logging, then the USB will be automatically (and safely) ejected/unmounted
- Make sure the lidar system’s GNSS antenna has a clear sky view. The system cannot begin data logging until a GNSS signal lock is achieved
- Note that the MNMLS does not require specific IMU calibration maneuvers or dynamics. The MNMLS Web App does include a magnetometer recalibration tool. This does not need to be used frequently as the internal IMU constantly calculates and updates the magnetometer calibration values in the background during normal operation. Further, the MNMLS does not rely heavily on the magnetometer data for yaw/heading measurements

## 2.4 Mission Planning

- The FOV for the laser scanner is 70.4 degrees horizontal and 4.5 degrees vertical

- Make sure your GNSS base station (not included) has begun logging prior to starting your mission
- A good starting place is to run missions at 20-30% sidelap to make sure there are no gaps in the data and to make sure there is enough overlapping data for post processing (e.g., strip alignment)
- It is suggested to run terrain following missions in order to keep proper pass overlap
- Note that about 3 - 5 degrees of data from the horizontal FOV can and should be removed as the edges of the horizontal FOV of the laser head are known to be less accurate. The user can use the "Scan Angle Rank" field in the output point cloud file for this
- A good starting altitude for missions is at 50 m AGL (or 50 m above the point/s of interest). Note that increases in altitude will typically decrease the overall system accuracy and the resulting quality of the output point cloud. Missions with larger AGLs may be run, but the output data quality will be reduced according to the angular uncertainty in the attitude measurements. The user should test which altitude works best for them. There is no one-size-fits-all solution
- A good starting mission speed is 5 - 7.5 m/s. This can be adjusted based on point density and/or canopy penetration needs as well as battery/mission requirements. Typically (assuming the same AGL), faster speeds will decrease the output point density and slower speeds increase the output point density. The user should test which flight speed works best for them. There is no one-size-fits-all solution
- The MNMLS does not require specific in-flight IMU calibration procedures. To start the mission the user can take off and head to the first mission waypoint. The dynamics of this action are enough for the system. Further, the IMU inside the MNMLS constantly calculates IMU calibration values in the background during normal operation
- The user may employ battery hot swapping methods during MNMLS operation. No special procedures need to be completed in order for this procedure to be successful. The suggested steps are below:
  - User completes the first part of the mission with the initial battery set
  - The user lands, hot swaps the batteries, and then continues with the new mission
  - It is suggested to keep the time of the hot swap to a minimum as the longer the procedure takes the larger/clunkier the raw sensor data files will be
  - Note that during processing in the MNMLP software the user will simply cut out the data outside of the normal passes
- The user can create a custom camera in their flight planning software of choice using the parameters listed below. This allows the user to plan their missions according to their overlap, speed, and altitude/terrain following requirements
  - Custom "Camera" parameters that can be used for flight planning purposes:
    - Focal Length: 18 mm
    - Image Width: 6000 pixels
    - Image Height: 4000 pixels
    - Sensor Width: 23.5 mm
    - Sensor Height: 15.6 mm
    - Pixel Pitch: 3.9  $\mu$ m

## 3. Mad Nadir Mapping Lidar Processor (MNMLP)

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The Mad Nadir Mapping Lidar Processor (MNMLP) is the georeferencing and processing software included with each MNMLS purchase. The software runs on Windows 10/11 operating systems. The software contains zero hidden post-processing steps. There are no license fees associated with the MNMLP software and upgrades are included. The software does not require an active internet connection in order to function (except when actively using the StripAlign tool). This allows the user to process the data before they leave the field. The MNMLP software employs multi-core processing techniques and consumes low amounts of RAM. The main function of the MNMLP software is to process the raw data inputs from the three MNMLS sub-systems (laser head, IMU/INS, GNSS) into georeferenced point cloud files (i.e., .laz). These output point cloud files can be brought in to any lidar post-processing software. The MNMLP software includes PPK trajectory processing (base station data required), an interactive lever arm/boresight tool, and a robust strip alignment function powered by BayesMap StripAlign. Installation information is described in [Section 3.1](#), the main MNMLP GUI window and tools are described in [Section 3.2](#), and an example processing workflow is described in [Section 3.3](#).

### 3.1 Software Install/Uninstall

The MNMLP software only works on the Windows 10/11 operating system. The MNMLP install file (“MNMLP\_Installer.exe”) is located in the USB3 flash drive that is included with each MNMLS purchase. We recommend immediately making a backup copy of this installer file as the user will soon use the USB3 drive for data logging purposes. Store the backup installer file in a safe place.

To install the MNMLP software:

- Copy the “MNMLP\_Installer.exe” file to the computer
- Double-click the executable file
- Follow the installation prompts
- We recommend installing the software in a directory where the user has read/write permissions. Otherwise, the user may need to run the MNMLP software as an admin
- Installation should take a ~1 - 2 minutes of time

To uninstall the MNMLP software:

- Navigate to the MNMLP install directory
- Double-click the “unins000.exe” file
- Follow the uninstaller prompts to remove the software from your system

### 3.2 Main GUI

In order to run the MNMLP software the user should double-click the MNMLP shortcut icon on the desktop, in the start menu, or double-click the “MNMLP.exe” file in the installation folder. The first time the MNMLP software is run the user will be prompted with a Software License Agreement. In order to utilize the MNMLP software the user must agree to this license agreement (and all licenses found in the MNMLP install directory). Once the MNMLP executable is run the Mad Nadir Mapping logo will briefly

appear and then the main GUI window will open. This GUI window is the main user interface. The main GUI window of the MNMLP software includes five sections: 1) Project Folder Section, 2) Processing Tools Section, 3) PPK Base Station Section, 4) Lever Arm & Boresight Section, 5) Action Section. These five sections are denoted by the red numbers in Figure 3 below. The five MNMLP GUI sections are individually described in the sub-sections below.



Figure 3: Main GUI window of the MNMLP software. The five individual GUI sections are labeled by red numbers

### 3.2.1 Project Folder Section

This section is for the user to select the project folder that is to be processed. A project folder is a specific mission folder that is recorded to the USB3 flash drive attached to the MNMLS. Do not alter the contents of the project folder as the MNMLP looks for certain files in order to check the validity of the data and then to process it. A project folder must be selected or the MNMLP software will not run. Select the project folder by clicking the “Browse” button and then navigating to the project folder and selecting the “Select Folder” button. Once the user selects the project folder the “Project Folder” text box will populate with the full path to the selected folder. See [Section 2.2](#) for the list of files and folders that should be present in the project folder. We recommend the user to copy the project folder off of the USB3 drive and onto a local computer drive and using

the local version for processing in the MNMLP Software. Once a project folder is loaded, the previous processing run's base station coordinates, lever arm values, and boresight angles are automatically populated in the GUI (if applicable).

### 3.2.2 Processing Tools Section

The second section contains checkboxes for the processing tools/methods available within the MNMLP software. The tools include 1) "Preprocess Raw Lidar", 2) "Georeference Lidar", 3) "Boresight Lidar", and 4) "Combine Flights". These four processing tools are described below. Each of the processing tools will display a pop-up progress bar showing that the tool is currently active. Note that the BayesMap StripAlign tool is built into the MNMLP software so there is no specific checkbox for the alignment function. The user will be prompted to align the data during one or two steps in their processing workflow (See the "BayesMap StripAlign" subsection below for more information).

- Preprocess Raw Lidar

This tool allows the user to preprocess the raw lidar data. This step must be done at least one time prior to the "Georeference Lidar" step. Once the preprocessing step is completed, the user will not need to run this step again unless the user has removed the intermediate data. For reference, the intermediate data is in the "Raw" subdirectory within the project folder. Note that the user can select both the "Preprocess Raw Lidar" and "Georeference Lidar" checkboxes during the same data processing run. In this case, the data will be preprocessed prior to the georeferencing step.

The preprocessing step will generate a number of intermediate data files that can be removed once you are done with the georeference and/or boresight steps. The software will prompt the user to remove these intermediate files after the georeferencing or boresight steps have completed. Note that if the intermediate files are removed after the "Georeference Lidar" step then the user will not be able to use the boresight tool unless the "Preprocess Raw Lidar" and "Georeference Lidar" steps are ran again. It is suggested to remove the intermediate data files after the data has been properly boresighted in order to save storage space. The data can always be preprocessed again using the original data in the project folder. The "Preprocess Raw Lidar" step will take advantage of all of the available cores on the processing machine.

- Georeference Lidar

This is the main tool in the MNMLP software and allows the user to georeference the raw MNMLS sub-system data. The output of this tool is a georeferenced laz file in the appropriate UTM coordinate reference system (e.g., EPSG: 32612). There are six fields (along with the "X", "Y", "Z" values) in the output laz file: 1) GPS Time, 2) Intensity, 3) Number of Returns, 4) Point Source ID, 5) Return Number, and 6) Scan Angle Rank. The GPS Time field is in the "Adjusted Standard GPS Time" format. The Point Source ID field provides the pass/strip number for each point. The Scan Angle Rank field provides the horizontal angle for each point. These angles are not roll compensated and can be used to easily filter out the less accurate points along the edge of the scanner's horizontal FOV (see [Section 2.4](#)).

When selecting this tool, the user must also select which xyz method will be used during georeferencing (i.e., INS or PPK). The "INS xyz" and "PPK xyz" checkboxes will become active once the "Georeference Lidar" checkbox is selected. The "INS xyz" method uses

location data directly from the INS. This method is less accurate than the PPK trajectory method but does not require any base GNSS data. It is suggested to only use this method for a quick data check in the field. The “PPK xyz” method computes the trajectory from a robust PPK processing solution. This method is the most accurate between the two. The PPK method requires the use of data from an external GNSS base station (not included). See [Section 3.2.3](#) for more information on these data inputs. Note that the PPK method must be utilized in order to take advantage of the BayesMap StripAlign tool.

Once the user runs the “Georeference Lidar” tool a separate trajectory window will display after the INS xyz data is parsed or the PPK trajectory has been solved. This window plots the mission trajectory and allows the user to select individual passes or portions of the mission for actual processing. If the “INS xyz” method was selected the trajectory points in the plot will be colored by the number of seconds since the mission began. If the “PPK xyz” method was selected the trajectory points in the plot will be colored by the number of seconds since the mission began as well as the PPK solution status (PPK Fix, PPK Float, Single, or DGPS) and the points with a high solution deviation (if they exist). The goal of selecting the individual passes is to remove the data collected during turns in between passes/strips and at the beginning and end of the mission. If passes were previously selected in an earlier data processing run, then these passes are automatically reloaded into the window for your convenience. Directions on how to interact with the trajectory window are below. See Figure 4a for an example trajectory window plot.

- Hover over the “HELP!” text at the bottom of the window for information on how to select the individual lidar passes. This information is also described below
- The buttons on the bottom left of the window allow the user to interact with the plot. These include the 1) “Home” button to zoom to the extent of the plot, the 2) “Undo” and “Redo” view buttons, the 3) “Pan” button to navigate around the plot, and the 4) “Zoom” button to zoom in on certain regions. Note that the “Zoom” and “Pan” buttons must be deselected in order to mark the start/end of a pass
- Double-left-click to mark the start of a pass/strip. A green circle will appear at the selected start location. The user can re-mark the start point as many times as they want
- Double-right-click to mark the end of a pass/strip. A red circle will appear at the selected end location. The user can re-mark the end point as many times as they want
- Select the “Accept Pair” button if happy with the start and end point locations. The symbol for the start and end points will then change to black stars and small black dots will be placed on the points in between the stars (the selected start/end points)
- If you aren’t satisfied with the pass/strip pair/s then select the “Remove Last Pair” button to remove the last accepted start/end point pair
- You may also single-right-click on any of the previously selected passes to remove it
- Repeat this process until all of the passes/strips are properly marked. Then select the “DONE” button to start the remainder of the georeferencing process and the generation of the output point cloud

- The “Auto-Pass” button allows the user to automatically select passes based on different variables/settings. See Figure 4b.
- Note that only the data between each accepted start/end point will be processed into the output laz point cloud file
- Note that a “passPlot.png” file will be created and saved to the project folder. This file provides a static view of the trajectory window as it was when the “DONE” button was pressed
- Note that the BayesMap StripAlign tool will not run without at least one overlapping pass pair

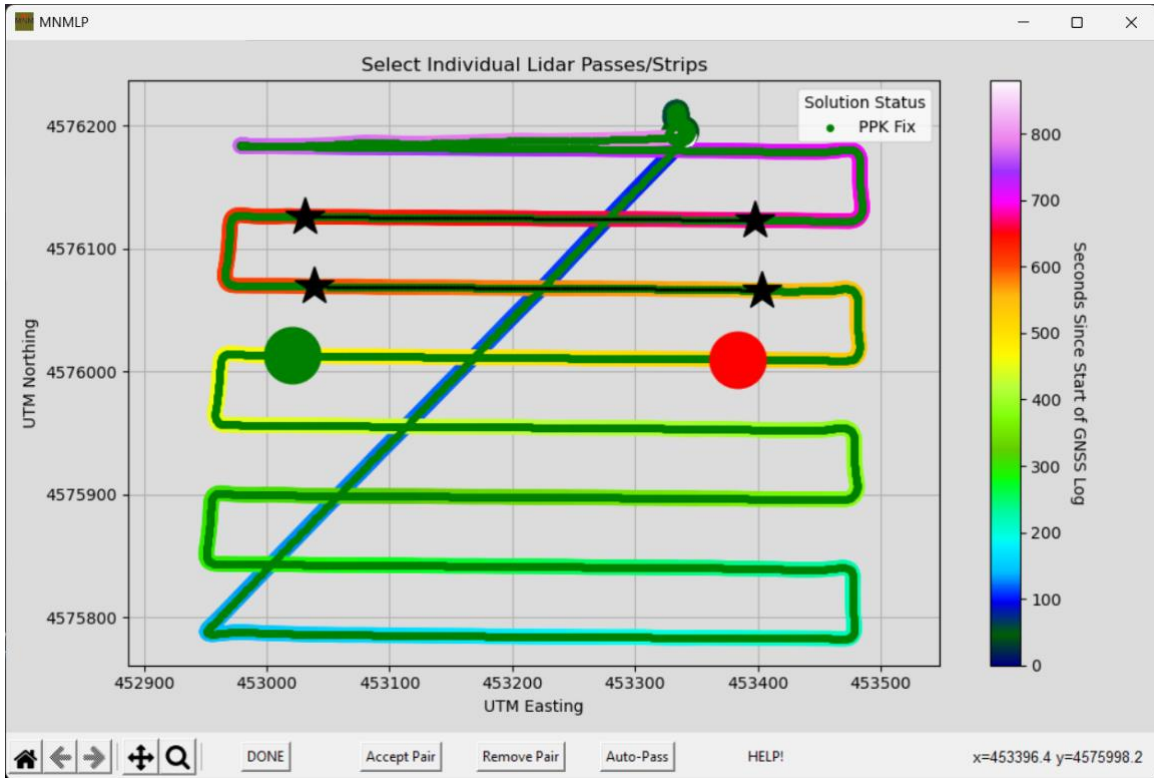


Figure 4a: Example trajectory window plot showing the various buttons and pass markers. Two passes/strips have been selected (two pairs of black stars) and one pass/strip pair has been marked but not yet accepted (green and red circles)

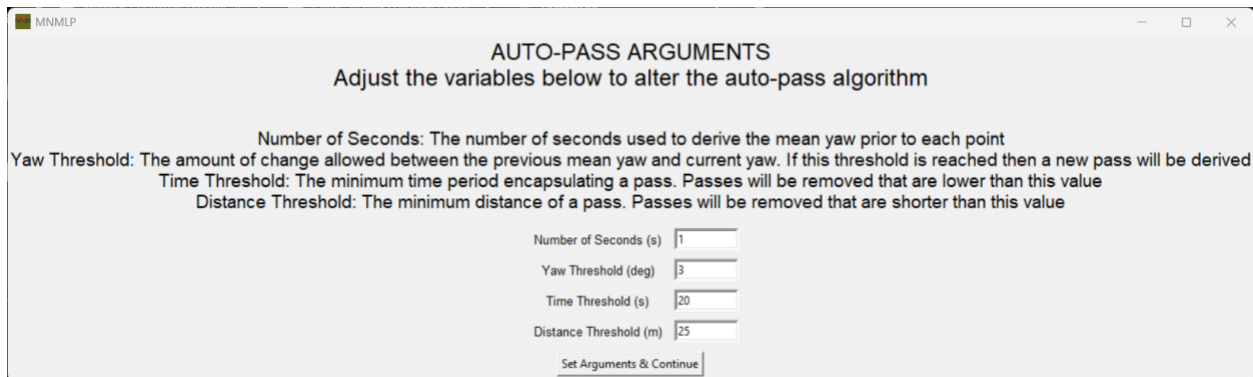


Figure 4b: Auto-pass window showing the different settings used to automatically derive passes

After the pass selection window has closed, the user is prompted with the FOV and RANGE Filter window. These settings allow the user to filter out points based on their horizontal FOV and raw laser range values. The user may also elect to not use any of these filter settings. The filters are enabled by moving the associated sliders to the desired location. Note that the FOV filter is not sent forward to the boresight tool. i.e., Points in the full FOV are passed to the boresight tool. Note that the FOV filter is sent forward to the strip alignment tool. i.e., Points in the filtered FOV are passed to the strip align tool. The example filter window is shown in Figure 4c.

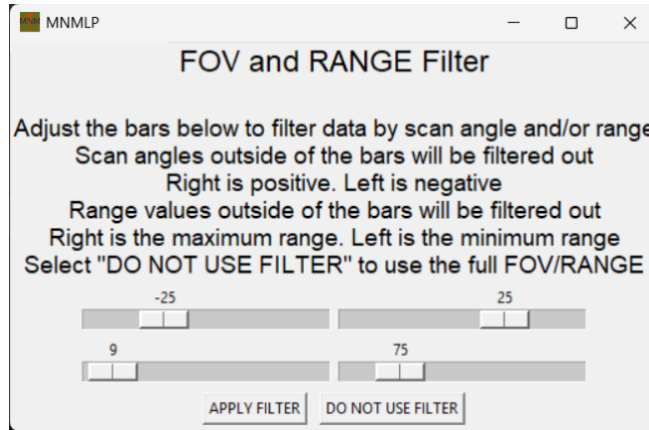


Figure 4c: FOV and RANGE Filter window. The horizontal FOV filter slider is on the top and the RANGE filter slider is on the bottom. As example, the sliders in this screenshot show that the horizontal FOV will be filtered to -25 degrees to +25 degrees and 9 m to 75 m in raw RANGE distances

Once the georeferencing step is complete a point cloud file will be located in the project directory named “output.laz”. A trajectory file is also generated (traj.csv). The columns in this file are: gpsTime, utmEasting, utmNorthing, ellipsoidal height (m), roll (rad), pitch (rad), yaw (rad). At this point, a pop-up window titled “Strip Align Output” will appear and ask the user if they want to strip align the recently created “output.laz” file. Select “YES” to align this georeferenced point cloud or “NO” to continue on. Not that if either “YES” or “NO” is selected the “output.laz” will remain as-is in the Project Folder. Once the alignment is complete or the user selects “NO” to the alignment prompt window, a pop-up window will notify the user that georeferencing is complete and ask if they want to remove the intermediate data. Note that if the user wants to use the lever arm/boresight tool they should not remove the intermediate data at this stage.

- **Boresight Lidar**

This tool allows the user to interactively adjust the three lever arm values and/or the three boresight misalignment angles and then export a new/corrected point cloud file to the project folder. It is suggested to use this tool instead of manually entering the lever arm and boresight angles (Section 3.2.4) unless these values are explicitly known from a previous data run. This is due to the fact that the “Boresight Lidar” tool cannot run if non-zero values are input into the “Lever Arm and Boresight Section” during the initial georeferencing run. Note that the intermediate data files must be present in the project folder in order for this tool to run.

The boresight tool corrects a voxelized version of the previously output georeferenced point cloud in real time as the user manually adjusts the lever arm and/or boresight

misalignment angles. This on-the-fly adjustment of the point cloud allows the user to interactively fine tune the lever arm and boresight angle adjustments until the highest accuracy is reached. The boresight tool allows for data filtering (i.e., voxel size, scan angle), selection of the active point cloud field (i.e., pass/strip number, intensity, elevation, scan angle), GCP plotting, 3D measuring between points, cross-section selection/plotting, and point-based error metrics. Some best practices and notes for using this tool are provided below.

- The scan angle filter does not affect the output laz file. It only filters out the points in the interactive display. This is so the user can adjust the lever arm and/or boresight misalignment angles on filtered data. The user may choose to filter out the points with scan angles near the edge of the horizontal FOV (See [Section 2.4](#)) during post-processing
- This tool voxelizes (e.g., downsamples) the output georeferenced point cloud derived during the “Georeference Lidar” step. Voxelizing larger datasets may take some time (even when using the multiple core voxelizing method). To mitigate this potential issue, the user could georeference a smaller area (where there are known boresightable features) during the initial “Georeference Lidar” step. This is done by selecting smaller passes/strips and/or fewer passes/strips during the pass selection process in the trajectory window plot (See Figure 4a). The voxelization process would then run considerably faster. After the lever arm and boresight values are found from the boresight tool, the user can manually input those values in the “Lever Arm and Boresight” section and re-run the “Georeference Lidar” tool with the appropriate lever arm and boresight correction values
- The boresight misalignment angles may be different across flights. This is due to the fact that misalignment in the output point cloud is not solely attributed to the boresight angles and can come from several other error sources (e.g., IMU drift, oscillations, etc.). It is recommended to run the “Boresight Lidar” tool for each dataset in order to achieve the best results. Some post-processing software can account for these misalignments. So, the user may not need to run this tool if they will utilize an appropriate external post-processing software. The BayesMap StripAlign tool is capable of correcting much of these error sources. The user should experiment on whether or not they can achieve their desired results without running the boresight tool and relying solely on the StripAlign function

Once the “Process Data” button is pressed the user will be prompted with a pop-window allowing them to 1) Select between two different voxelizer processing methods, and 2) Upload a GCP file that will be plotted in the interactive boresight viewer. The window is shown below in Figure 5.

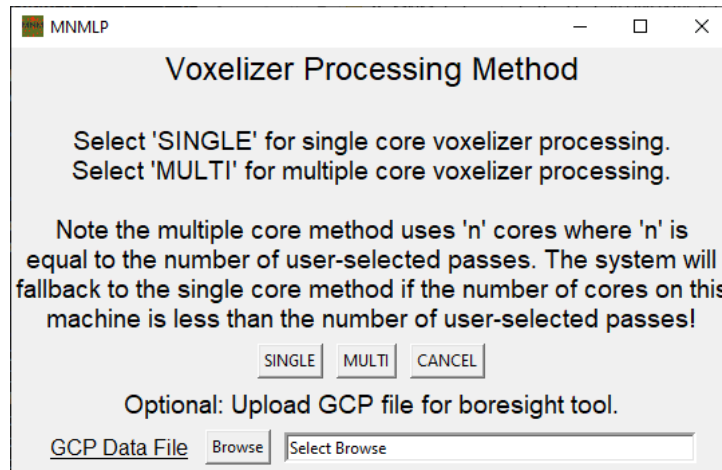


Figure 5: Voxelizer processing method and GCP upload window. This is the first user prompt shown during the boresight lidar tool workflow

- The two available processing methods are “SINGLE” and “MULTI”. The user should select “SINGLE” to use a single core method for data voxelizing. The user should select “MULTI” to use a multi-core method for data voxelizing. Note that if the point cloud contains only a single pass/strip and the multi-core method is selected, then the tool will revert to the single core method. It is suggested to select the multi-core method for datasets with more than one pass/strip
- The user may optionally input a GCP text file for plotting alongside the voxelized point cloud data in the interactive boresight viewer. The GCP text file must have the following characteristics in order to be plotted by the interactive data viewer: 1) The GCP coordinates must be in a WGS 84/UTM CRS (e.g., EPSG: 32612), 2) The file must be a csv and contain only four columns with no header row, 3) The columns should contain the a) GCP Name, b) Easting (m), c) Northing (m), and d) Elevation (m). Make sure to select the GCP text file prior to selecting the “SINGLE” or “MULTI” voxelizer processing method. The GCPs will be plotted as white spheres on the interactive boresight viewer once it loads. Example contents of a GCP csv file are below

```
gcp1,454233.353,4573714.182,2219.453
gcp2,454168.409,4573719.673,2220.699
gcp3,454163.694,4573809.433,2221.906
base,454256.969,4573696.078,2220.894
```

Once the “SINGLE” or “MULTI” voxelizer processing method button is pressed the user will be prompted with a pop-window allowing them to select the specific voxelizer strength to use during processing. The window is shown below in Figure 6.

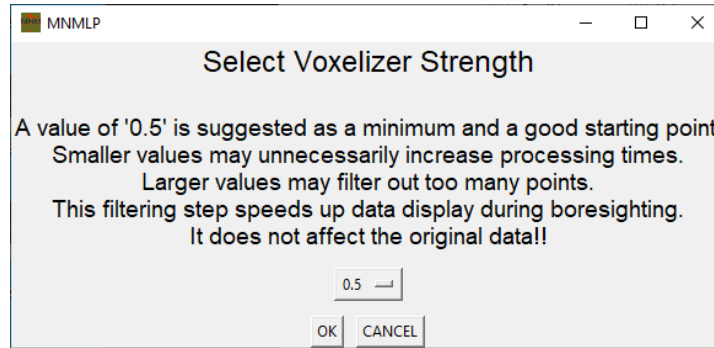


Figure 6: Voxelizer strength selection window. This is the second user prompt shown during the boresight lidar tool workflow

- The user should click the drop-down option menu to choose the specific voxelizer strength. The available strength options are 0.01, 0.05, 0.1, 0.25, 0.5, 0.75, and 1.0. The units are in meters. The smaller the voxelizer strength the longer the voxelization process will take
- Once the strength is selected the user should press the “OK” button to begin the voxelization process. The “Voxelizing Lidar Data for Manual Boresighting Tool” progress window will then appear
- If the user feels too much time has passed before the voxelization step has completed they may close the “Voxelizing Lidar Data for Manual Boresighting Tool” progress window (by hitting the “x” button) and the voxelization process will be safely canceled. At this point, the user can reduce the voxelizer strength and/or re-run the “Georeference Lidar” tool while selecting a smaller portion of the study area

Once the data has been voxelized the text in the active progress bar will change from “Voxelizing Lidar Data for Manual Boresighting Tool” to “Boresighting GUI is Open...” and the interactive boresight plotting window will then open. An example of the interactive plotting window as it opens is shown in Figure 7 below. The specific sliders and buttons available to the user in the initial plotting window are: 1) “Scalar Field” Slider, 2) “Point Size” Slider, 3) “Scan Angle Filter” Slider, 4) “Voxel Filter” Slider, 5) “Enable Boresight Sliders” Button, and 6) “Apply Boresight & Save LAZ” Button. These are described in more detail below.

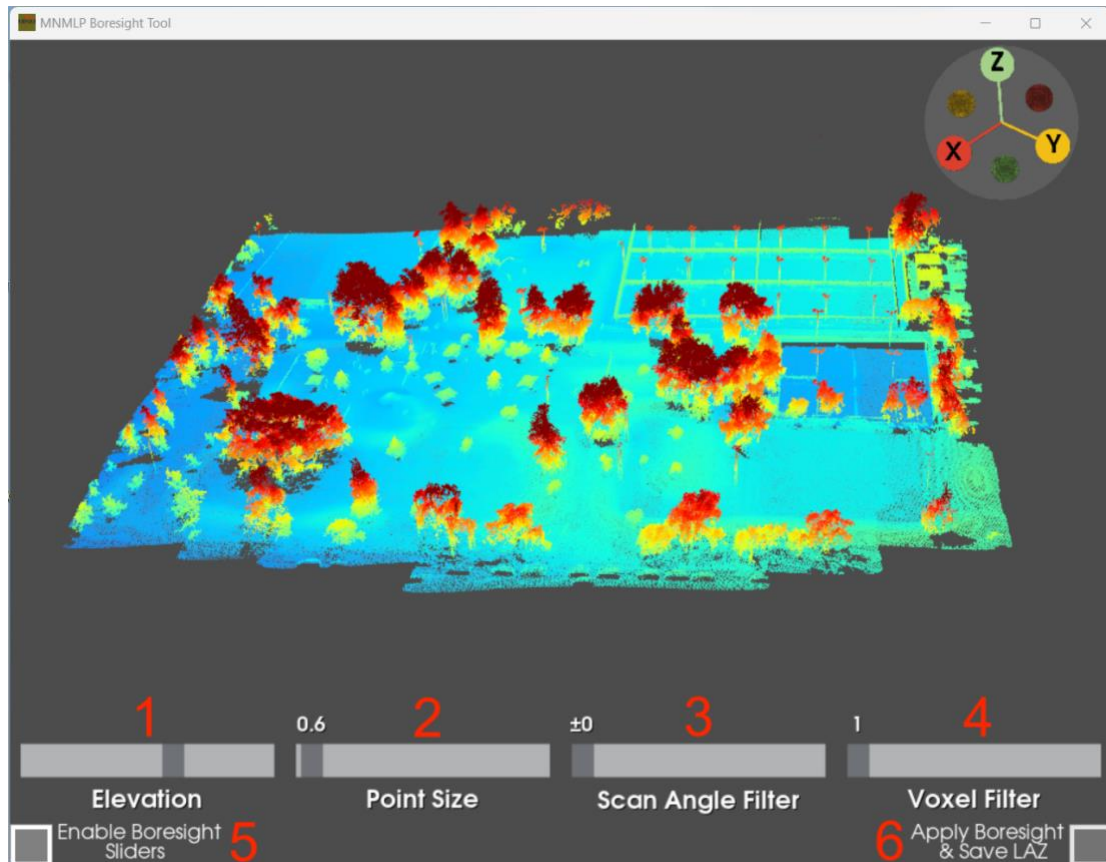


Figure 7: Main interactive plotting window as it initially opens. The buttons and sliders initially available to the user when the interactive window opens are noted by the red numbers

- The (1) “Scalar Field” slider allows the user to color the point cloud by the selected scalar field. The options are a) Pass Number, b) Intensity, c) Elevation, and d) Scan Angle
- The (2) “Point Size” slider adjusts the point size of the point cloud within the interactive plotting window
- The (3) “Scan Angle Filter” slider filters out points within a given scan angle range. For example, a value of 5 will filter out points with a scan angle of  $5^\circ$  from either (left/right) edge of the horizontal FOV. Recall the horizontal FOV is  $70.4^\circ$ . So, this value of 5 will filter out points where the scan angle is  $\geq 30.2^\circ$  and  $\leq -30.2^\circ$ , where  $0^\circ$  is nadir (not roll compensated). This effectively reduces the horizontal FOV by  $5^\circ$  on either side (by  $10^\circ$  in total). Recall that about 3 - 5 degrees of data from the horizontal FOV of the laser head can and should be removed as the edges of the horizontal FOV of the laser head are known to be less accurate. This filter does not influence the output boresighted laz file when the user selects the “Apply Boresight & Save LAZ” button. The output laz file will contain points from the entire FOV. This filter is meant to allow the user to visualize the point cloud and make adjustments to the lever arm and boresight values without the lower-quality edge FOV points
- The (4) “Voxel Filter” slider filters out points based on the number of original points within the voxel as calculated during the initial voxelization process. For

example, a value of 3 will filter out all points whose voxels contained  $\leq 3$  points from the full (un-voxelized) dataset. This filter does not influence the output boresighted laz file when the user selects the “Apply Boresight & Save LAZ” button

- The (5) “Enable Boresight Sliders” button will enable the three different lever arm and the three different boresight slider bars. These slider bars can be adjusted and the displayed point cloud will be recalculated/updated in real time. Note that if the real-time adjustments are delayed or are taking too long then the user should either a) Reduce the voxel size during the initial voxelization step or b) Reduce the area that was initially georeferenced. Figure 8 displays the interactive window after the “Enable Boresight Sliders” button has been toggled. The six newly visible slider bars allow the user to adjust the 1) “X” lever arm values, 2) “Y” lever arm values, 3) “Z” lever arm values, 4) Roll boresight misalignment angle, 5) Pitch boresight misalignment angle, and the 6) Yaw boresight misalignment angle

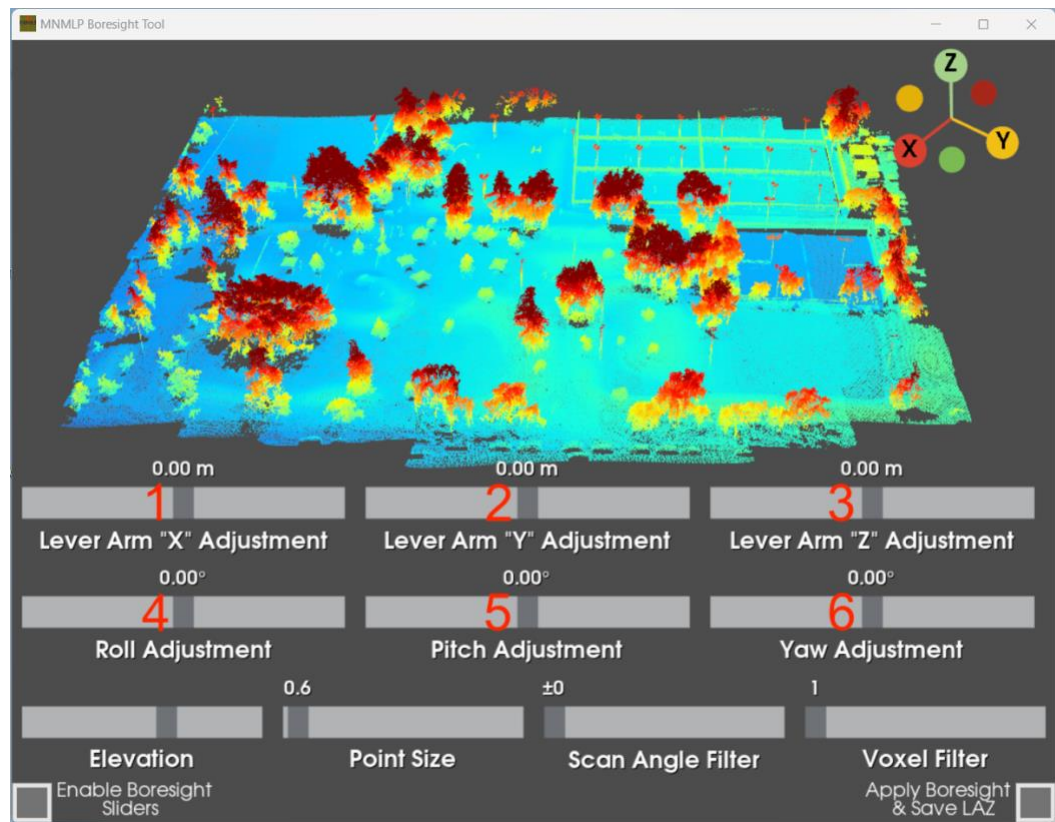


Figure 8: Interactive plotting window after the “Enable Boresight Sliders” button has been toggled. The adjustment sliders are labeled by the red numbers

- The (6) “Apply Boresight & Save LAZ” button will apply the selected lever arm and boresight values to the full point cloud and generate a new laz file. The output point cloud file will be named “outputBoresighted.laz” and will be saved to the project folder. After selecting this button the active progress bar will change from “Boresighting GUI is Open...” to “Saving Boresighted LAZ File”. Once the corrected laz file is created, a pop-up window titled “Strip Align Output” will appear and ask the user if they want to strip align the recently created

“outputBoresighted.laz” file. Select “YES” to align this point cloud or “NO” to continue on. Not that if either “YES” or “NO” is selected the “outputBoresighted.laz” will remain as-is in the Project Folder. Once the alignment is complete or the user selects “NO” to the alignment prompt window the interactive plotting window will close and the user will return to the main menu

There are a number of keyboard/mouse click shortcuts that can be used with the interactive plotting window. These are described below:

- “q” will close the interactive plotting window. Note that this is the same as pressing “x” at the top right of the window. An output boresighted laz file is not created after the “q” key is pressed
- “f” will focus on the point where the mouse cursor is located and will set the axis of rotation for the plot at that point. If there are distance measurement points visible on the plot the “f” key will also clear them
- “r” will reset the plot view and zoom to the extent of the loaded point cloud
- “Right-click” will mark the first or last measurement at the current point location of the mouse cursor. This allows the user to derive distances between any two points in the plot. A white line vector will be drawn between the two points and the “X” distance, “Y” distance, “Z” distance, and total distance values (in meters) will be displayed. If two points are already marked, a third right-click will clear the two-point distance measurement from the window
- “x” will create a cross-section from the white line vector derived from the active two-point distance (placed by the “Right-click” method described above). The plot then enters the “cross-section mode” and will display the points along the marked two-point distance line. If there is not a two-point distance measurement present then pressing the “x” key will have no effect. Pressing this key will also 1) Clear the cross-section view if the plot is currently in the “cross-section mode” and 2) Clear the pass-to-pass distance measurement if the plot is currently in the “cross-section distance mode” (see below for this mode)
- “d” will move the plot from the “cross-section mode” and into the “cross-section distance mode”. The “d” key will only have an effect if the plot is in the “cross-section mode” when pressed. This mode calculates the distance to the closest point from each pass for every point in the cross-section. The software will then derive the mean distance for each point. The points are then colored by their mean distances except for when the mean distance value is >0.25 m (grey points). The overall mean point-to-point distance (meters) for the entire cross-section (along with the standard deviation) will be shown on the top-left of the interactive plotting window. Figure 9 displays the interactive window when the plot is in the “cross-section distance mode” and the “Enable Boresight Sliders” button has been toggled. The overall mean distance value for the cross-section is located at (1), the color ramp for the individual mean distance points within the cross-section is located at (2), and the example colorized points within the cross-section are located at (3). If the plot is already in the “cross-section distance mode” and the “d” key is pressed, the plot will revert to the “cross-section mode” and the point-to-point distance measurements will be removed. The “cross-section mode” and the “cross-section distance mode” can be utilized to make slider bar adjustments to the lever arm and boresight values while getting

meaningful metrics about the alignment of the passes and how those slider adjustments affect the pass alignment. When making major adjustments to the lever arm or boresight values while in the “cross-section distance mode”, it is recommended to select the “d” key in order to revert to the “cross-section mode” and then re-selecting the “d” key to return to the “cross-section distance mode”. This is suggested in order to re-derive points in the cross-section (as the points will have changed location due to the lever arm/boresight adjustments) and to re-calculate the distance metrics. Note that smaller initial voxel sizes and/or longer cross-sections will increase the calculation time of the distance measurements. It is suggested to choose a meaningful area to adjust the lever arm/boresight sliders before entering the “cross-section distance mode” by using the “Right-click” method described above to carefully select a cross-section to derive the point-to-point distance metrics

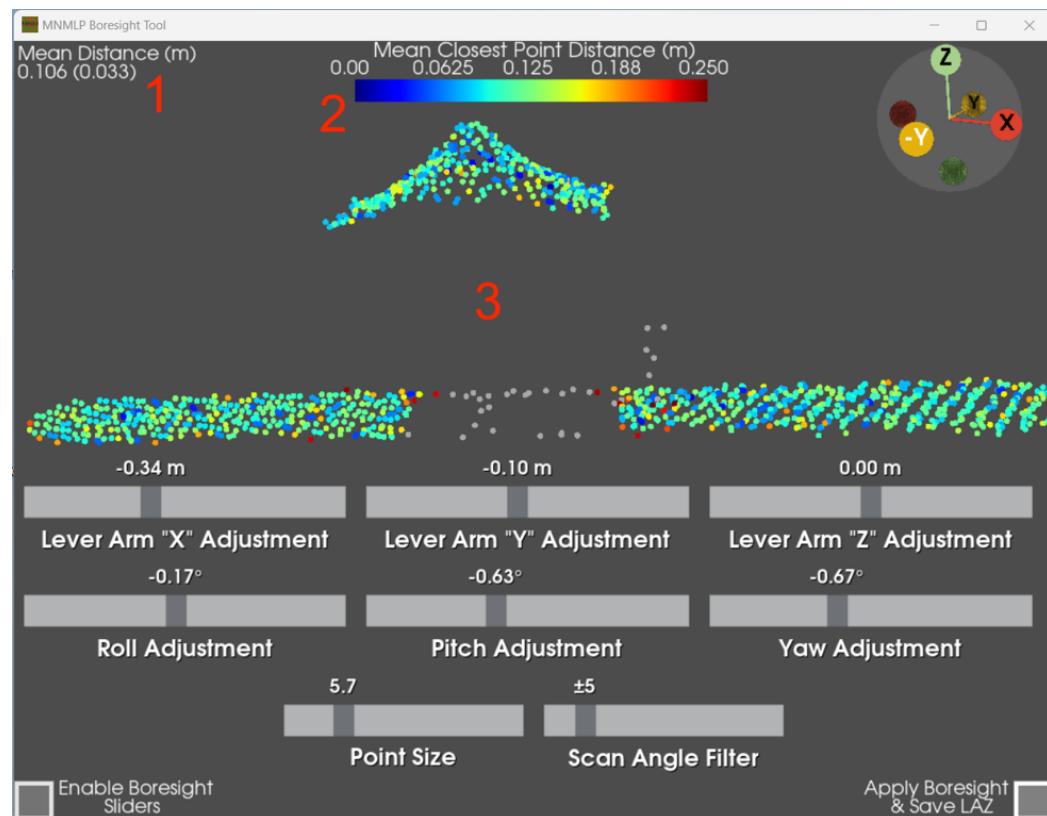


Figure 9: Interactive plotting window during the “cross-section distance mode” and when the “Enable Boresight Sliders” button has been toggled. The “cross-section distance mode” objects are labeled by red numbers

- “c” will 1) Clear the two-point distance measurement if it is present, 2) Clear the cross-section view if the plot is currently in the “cross-section mode”, and/or 3) Clear the pass-to-pass distance measurement if the plot is currently in the “cross-section distance mode”
- Combine Flights

This tool allows the user to align and/or combine “output.laz” or “outputBoresighted.laz” files from multiple missions/flights into one single aligned and/or merged output point cloud file. Note that the input laz files must be in the same CRS or the tool will not run.

The selection order of the input files does not matter. The aligned and/or merged output file will be created in the chosen project directory and will be named “outputAlignedMerged.laz” or “mergedOut.laz”. Note that you cannot run the lever arm/boresight tool on the “outputAlignedMerged.laz” or “mergedOut.laz” files. So, if necessary, the user should use the boresighted data as inputs.

- BayesMap StripAlign

This built-in tool allows the user to align the output point clouds using the robust StripAlign function from BayesMap. There must be at least one overlapping pass pair for this tool to run. Otherwise, the tool will stop and the user will be prompted with a warning window noting that the tool could not run. Note that the point cloud must be derived using the “PPK xyz” method in order to utilize the StripAlign tool. The user will be prompted to align their point cloud at one or two places during processing (depending on their workflow). Point 1: After the strips/passes are selected and the initial output georeferenced point cloud is derived. Point 2: When using the boresight tool after the user has selected the “Apply Boresight & Save LAZ” button and the output lever arm’ed/boresighted point cloud is derived. Note that the logs from the most-recent StripAlign data run will be present in the “StripAlignLogs” subdirectory within the Project Folder.

### 3.2.3 PPK Base Station Section

This section will remain inactive/greyed out until the user selects the “Georeference Lidar” tool and the “PPK xyz” method. Base station GNSS data is required to calculate the trajectory when utilizing the “PPK xyz” method. The “PPK xyz” method computes the trajectory from a robust PPK processing solution. This section allows the user to point the MNMLP software to the base station GNSS data and provides the selection method for how to derive the base station coordinates. Each of which is required for the MNMLP software to use the PPK trajectory processing method. For reference, the software will place the base station coordinates used for PPK trajectory processing in a “.baseCoords” file within the project folder. This text file contains the latitude, longitude, and ellipsoidal height (WGS84) values along with their associated standard deviations (for the SPP Method only).

- Input Base GNSS Data

Select the “Browse” button and then navigate to the directory where the raw .ubx or RINEX obs/nav data from the associated base station. Note that the base GNSS data does not need to be located in the project folder. The MNMLP software will only accept the following as base GNSS data inputs: 1) A single, raw binary ubx file (\*ubx, \*UBX), or 2) A pair of RINEX observation and navigation files (\*obs, \*o, \*nav, \*n, \*p). Both the observation and navigation file must be selected if using RINEX data. Note that RINEX version 3.03 is recommended.

- Manual Base Coords

This checkbox tells the MNMLP software to use the base station coordinates that are manually input into the “Latitude (dd)”, Longitude (dd), and “Height (m)” fields within the “Base Coords (WGS84)” section below. These base station coordinates are used during PPK trajectory processing. The coordinates must be in WGS84.

- Rinex Base Coords

This checkbox tells the MNMLP software to use the base station coordinates within the RINEX header. The software assumes the RINEX coordinates are in EPSG: 4978. It will then convert these coordinates to WGS84 (i.e., EPSG: 4326). These converted base station coordinates are used during PPK trajectory processing.

- SPP Base Coords

This checkbox tells the MNMLP software to process the base station GNSS data using a Single Point Positioning (SPP) method in order to derive the base station coordinates. These SPP base station coordinates are used during PPK trajectory processing.

- Base Coords (WGS84)

This user input section is only active when the “Manual Base Coords” button is selected. The user must manually input the latitude, longitude, and ellipsoid height of the base station in the appropriate “Latitude”, “Longitude”, and “Height” input boxes. Note that latitude and longitude should be in decimal degrees and the height value should be ellipsoidal height in meters. Each of which should be in WGS84. These coordinates are used during PPK trajectory processing.

### 3.2.4 Lever Arm and Boresight Section

This section will remain inactive/greyed out until the user selects the “Georeference Lidar” tool. This section contains user input text boxes for the xyz lever arm offsets and the boresight misalignment angles. These values are optional and the “Georeference Tool” will still run if these fields are at their default zero value. It is suggested to leave these fields set to their default zero value unless these values are known with certainty. This is because the “Boresight Lidar” tool cannot run if these values were set during georeferencing. It is best practice to use the “Boresight Lidar” tool after georeferencing to interactively adjust the lever arm and angular misalignment values. So, leave these as the default zero values if you plan on running the boresight tool. See the “Boresight Lidar” sub-section within [Section 3.2.2](#) for more information on deriving these values with the built-in boresighting tool.

- Lever Arm (GNSS to Lidar)

This sub-section contains three input boxes for the “x” (front/back), “y” (left/right), and “z” (up/down) offsets between the GNSS L1/L2 antenna phase center and the origin of the lidar reference frame. These measurements are in meters. The “x” axis is aligned with the yaw/heading of the MNMLS/drone. The “y” offset is perpendicular to the yaw/heading of the MNMLS/drone. The “z” axis is in the down direction. The terms “Left”, “Right”, “Front”, and “Back” are relative to the normal direction of travel/heading of the drone. So, if the user is standing behind the drone looking towards its normal forward direction, “Left” is to the left, “Right” is to the right, “Front” is towards the forward direction, and “Back” is towards the reverse direction. Hovering the mouse over the text provides the user with information on the sign of these measurements according to where the lidar scanner is relative to the GNSS antenna. This information is also below. The lever arm values can be meaningfully derived by careful measurement when the system is mounted/attached to the drone. See [Section 2.1.3](#) for more information.

- A positive “x” offset occurs when the lidar is in FRONT of the GNSS antenna
- A positive “y” offset occurs when the lidar is to the RIGHT of the GNSS antenna
- A positive “z” offset occurs when the lidar is BELOW the GNSS antenna

- Lidar Boresight Angles

This sub-section contains three input boxes for the roll, pitch, and yaw boresight angles. These are the misalignment angles between the lidar frame of reference and the IMU/INS frame of reference and should be provided in degrees. The best method to derive these angles is to leave the values at their default zero values during the georeferencing step and then subsequently running the “Boresight Lidar” tool to interactively adjust the three separate angles. Unlike the lever arm offsets, these values cannot be physically measured by the user.

### 3.2.5 Action Section

This section contains the three “action” buttons. These buttons are used after the user has selected the appropriate tools and inputs for the desired data processing run. To run the desired processing steps the user must select the “Check Params” button and then the “Process Data” button. These buttons are described below.

- “Check Params” Button

This button checks the individual MNMLP GUI sections for the proper user inputs. The button also checks to make sure the appropriate data is present in the provided project folder to complete the specific processing task requested by the user. This button must be pressed prior to selecting the “Process Data” button and processing the data.

- “Process Data” Button

This button will be greyed out until the user presses the “Check Params” button and the user inputs and associated data files have passed their checks. The user may then press the “Process Data” button once it is active. As soon as it is pushed the following will happen: 1) All buttons and user inputs (except the “Exit” button) of the MNMLP GUI window will deactivate, 2) The main MNMLP GUI window will minimize, 3) The user-selected processing tasks will begin, and 4) The associated progress bar window will be shown. The main window will reappear when the requested processing task has completed. Note that a “guiLog” file will be placed in the project folder once the user presses the “Process Data” button. This text file contains information about the user inputs used for this data run.

- “Exit” Button

This button allows the user to exit and close the MNMLP software. Note that the user can exit the software anytime by pushing either the “x” at the top-right of the main MNMLP GUI window or by using the “Exit” button.

## 3.3 Example Processing Workflow

- 1) Copy mission data from the supplied USB3 drive to the processing computer
- 2) Start the MNMLP software
- 3) Browse to the mission data folder and select it as the project folder
- 4) Select the “Preprocess Raw Lidar” and the “Georeference Lidar” checkboxes
- 5) Select the “PPK xyz” checkbox
- 6) Select the “Manual Base Coords” check box and manually input the known base coordinates or select the “SPP Base Coords” checkbox to calculate the base coordinates using single-point positioning
- 7) Press the “Check Params” button followed by the “Process Data” button

- 8) Wait until the trajectory window pops up and select the start and end point of each lidar pass/strip
- 9) Select the “DONE” button
- 10) Adjust the appropriate FOV and RANGE filter settings and select the “APPLY FILTER” button
- 11) Wait until the georeferencing phase is complete
- 12) Say “YES” to the “Strip Align Output” window in order to run the georeferenced point cloud through the BayesMap Strip Align tool (\*this is unnecessary if the user will run the lever arm’ed/boresighted point cloud through the StripAlign tool\*)
- 13) Wait until the georeferencing or StripAlign phase is complete and the main GUI reappears
- 14) Do not remove the intermediate data when prompted if planning to use the boresight tool
- 15) Select the “Boresight Lidar” checkbox
- 16) Press the “Check Params” button followed by the “Process Data” button
- 17) Browse to the location of the GCP csv file (if applicable)
- 18) Select the “MULTI” button for multi-core voxelization
- 19) Select a voxel strength of 0.5 and hit the “OK” button
  - a. If voxelization time and data density is reasonable continue with lever arm/boresight adjustment
  - b. If not, exit the boresight tool by closing the interactive boresight window or closing the “Voxelizing Lidar Data for Manual Boresighting Tool” progress bar to return to the main GUI window
  - c. Adjust either voxelization strength and/or re-georeference the data, but this time only process a meaningful area to do the lever arm/boresighting (e.g., linear features like roofs, hard surfaces, etc.)
  - d. Re-run the boresight tool
- 20) Create a cross-section using the “Right-click” method
- 21) Change the scaler field to “Passes”
- 22) Adjust the lever arm and boresight angles
- 23) Derive the point-to-point distances
- 24) Adjust the lever arm and boresight angles
- 25) Recalculate the point-to-point distances
- 26) Continue adjusting the lever arm and boresight angles
- 27) Re-derive the point-to-point distances
- 28) Continue adjusting the lever arm and boresight angles
- 29) Create a new cross-section of a different area using the “Right-click” method
- 30) Repeat steps 18 – 26 until satisfied with the results
- 31) Select the “Apply Boresight & Save LAZ” button to save the adjusted point cloud to the project folder
- 32) Say “YES” to the “Strip Align Output” window in order to run the lever arm’ed/boresighted laz file through the BayesMap Strip Align tool
- 33) If the full dataset was not georeferenced in order to reduce voxelization strength and interactive lever arm/boresight adjustment time – then enter the lever arm and boresight values into the main GUI and then re-run the “Georeference Lidar” tool
- 34) Exit the software and remove the intermediate data when prompted

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## 4. Troubleshooting & Support

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This section contains answers or fixes to common questions or issues that may arise when using the MNMLS hardware and/or the MNMLP software and provides contact information for Mad Nadir Mapping Support.

### 4.1 Common Questions or Issues

*Q: Why does the “System Status” LED never stop blinking after power-on?*

A: The system needs a clear sky view in order to receive proper GNSS signals. Make sure the GNSS antenna has an unobstructed view of the sky. Sometimes a GNSS lock could take several minutes depending on the conditions.

*Q: It’s my first flight and my data looks weird. Why?*

A: Make sure to do a multi-axis magnetometer calibration anytime the system is placed on a new UAS. Especially when first receiving the MNMLS unit.

Q:

A:

Q:

A:

Q:

A:

### 4.2 Mad Nadir Mapping Support

Make sure to read through the entirety of this User Manual (RTFM) prior to contacting support. If any questions remain, then don’t hesitate to reach out to [info@MadNadirMapping.com](mailto:info@MadNadirMapping.com) with any questions that are not answered from the material within this User Manual.