MoonPanoramaMaker for the Automatic Exposure of High-Resolution Panoramas of the Moon

User Guide (Version 0.9.3, October 30, 2016)

Rolf Hempel

Table of Contents

1. Introduction

MoonPanoramaMaker automates the process of taking high-resolution panoramas of the Moon. Since the USB cameras employed cover a very small field of view, multiple views must be combined to produce a complete panorama. MoonPanoramaMaker covers the current Moon phase with an optimal grid of single views and automatically steers the telescope mount and camera during their exposure.

With the introduction of digital image technology the photography of the Moon has taken a great leap forward. The so-called "Lucky Imaging" technique today allows amateur astronomers to record surface details which in the old days of analog photography were out of reach even to professional astronomers with access to the best earth-bound telescopes. For high-resolution work today the camera of choice is a video module which connects to the USB interface of a portable computer. With such a camera one can take many images in a short time and store them without compression artefacts in a video file. On the negative side, however, the image sensors are quite small and exhibit relatively low pixel counts.

The natural domain of these cameras is, therefore, the photography of selected surface features at high spatial resolution. For a panorama of the whole Moon, many of those views – hereafter referred to as "tiles" – must be stitched together. While good software products are readily available for the automatic combination of even large numbers of tiles into a panorama, taking the video files is still left to the skillful hands of the observer. For every tile this involves steering the telescope to the location of the tile center and triggering the video acquisition using some video capturing software.

As long as the camera field of view is not much smaller than the diameter of the Moon, taking the video files manually is no problem. The situation is different, however, if the whole Moon panorama is composed of more than 100 tiles. This can happen easily if a telescope with an aperture of 10" or more is used for diffraction-limited imaging. In such a situation it is nearly impossible to steer the telescope manually such that the tiles form a uniform coverage of the Moon, with similar overlaps between tiles and no holes in between. This is where MoonPanoramaMaker comes into play. The program computes an optimal coverage of the current Moon phase with tiles, and then controls the telescope and camera during video acquisition.

MoonPanoramaMaker supports two workflow variants: In semi-automatic mode, the program steers the telescope to the next tile location but leaves the camera control to the observer. This may make sense if the observer wants to use his or her own video control software, or if the camera is not connected to the computer. The observer acknowledges the end of each exposure, and MoonPanoramaMaker moves the telescope to the next tile. In fully automatic mode MoonPanoramaMaker controls both the telescope and camera, by triggering the external camera control software FireCapture.

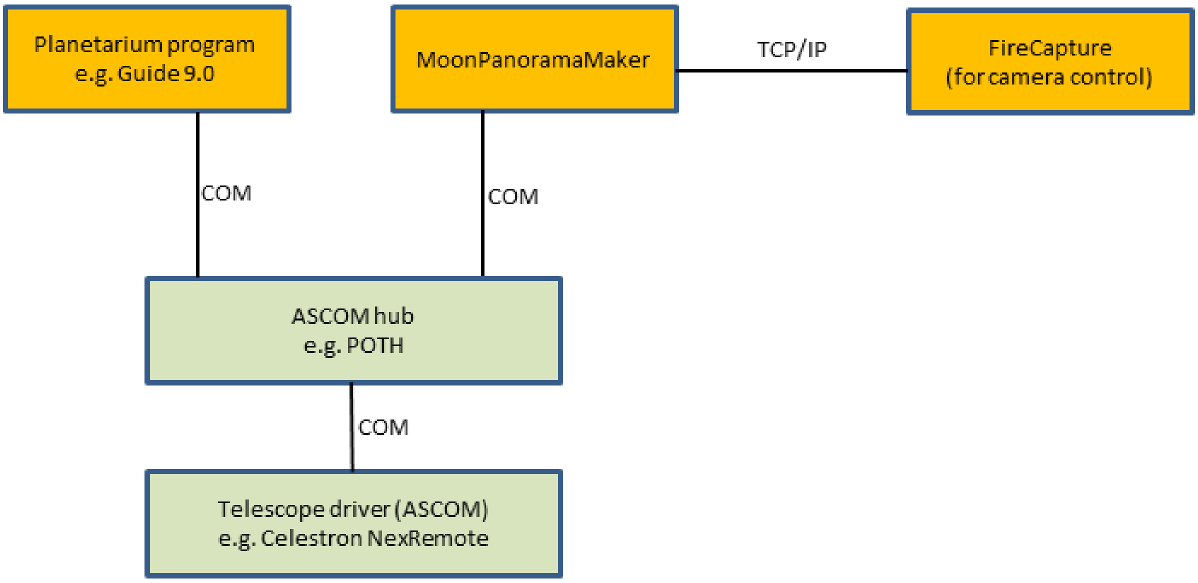
2. System Requirements and Software Installation

MoonPanoramaMaker communicates with the telescope mount via the ASCOM interface. Since it is based on Microsoft's "Common Object Model", MoonPanoramaMaker can be used on Windows systems only. The whole software was tested on an Acer laptop computer (type "Acer Aspire V5-573G", Intel Core i5-4200U, 8 GBytes RAM) running Windows 7 Professional. MoonPanoramaMaker has much lower requirements on RAM size and CPU speed than the camera control software FireCapture. Since MoonPanoramaMaker is active mostly when FireCapture is not taking videos, it increases the peak load only very slightly.

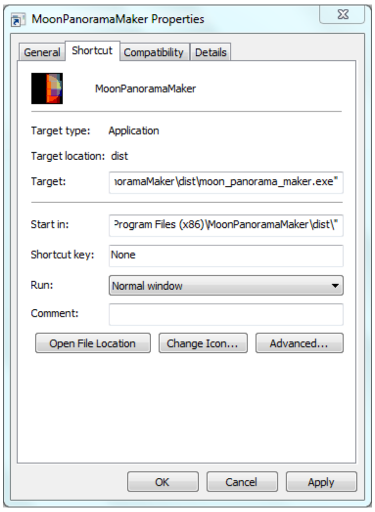
The ASCOM software can be downloaded from the website http://ascom-standards.org/. The tests were performed using the "ASCOM Platform 6.1SP1". Additionally, an ASCOM driver for the telescope mount is required. ASCOM drivers for many popular mountings can be found on the ASCOM web page http://ascom-standards.org/Downloads/ScopeDrivers.htm.

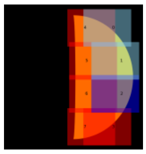
MoonPanoramaMaker assumes that the telescope is mounted equatorially. It operates it by using a minimal set of ASCOM instructions only, and therefore in principle should work with almost any driver. It assumes, however, that the driver in a GoTo operation always approaches the target position from the same side in the declination coordinate, i.e. either from the North or from the South. Otherwise backlash in the declination gear could greatly reduce the pointing accuracy.

In order to allow other application programs, e.g. a planetarium program, to access the ASCOM interface of the telescope mount alongside MoonPanoramaMaker, the program assumes that an ASCOM hub is placed between the mount driver and the application programs. The ASCOM platform provides the hub named POTH ("Plain Old Telescope Handset"). It is fully sufficient for this purpose. The following figure gives an overview of the software units involved and their interactions.



The MoonPanoramaMaker software itself is distributed as a single file: the Windows installer "MoonPanoramaMaker_0.9.3.exe". When the installer is started, a wizard guides the user through the installation process. Apart from the program start entries, MoonPanoramaMaker does not write any parameters into the Windows Registry and can be installed at any file system location. An uninstaller is provided with the software. It removes all installed files, with the exception of "MoonPanoramaMaker.ini" and "MoonPanoramaMaker.log" in the user's home directory. Those two files have to be deleted manually.





Properties dialog of the program starter: Configuring the starter icon has to be done manually (see text below).

The installation wizard offers to place a program starter on the desktop. It is recommended to replace its standard icon with the MoonPanoramaMaker icon, which can be found under the filename "MoonPanoramaMaker.ico" in the installation folder.

During program execution in fully automatic mode MoonPanoramaMaker communicates with the camera control software FireCapture (http://www.firecapture.de/index.html), developed by the German amateur astronomer Torsten Edelmann. The software is freely available at the website given above. In order to make both programs communicate with each other, the folder "MoonPanoramaMaker" (it only contains the single file "MoonPanoramaMaker.jar") must be copied from MoonPanoramaMaker's installation directory into FireCapture's "plugins/x64" directory.

MoonPanoramaMaker 0.9.3 is consistent with FireCapture's plugin interface version "1.1" which was introduced with the FireCapture version "v2.5Beta09.x64". It will not work with older FireCapture versions. Therefore, it is strongly recommended to download the most recent FireCapture version using the button "Download FireCapture v2.5 BETA (64-bit)".

3. *Program Execution*

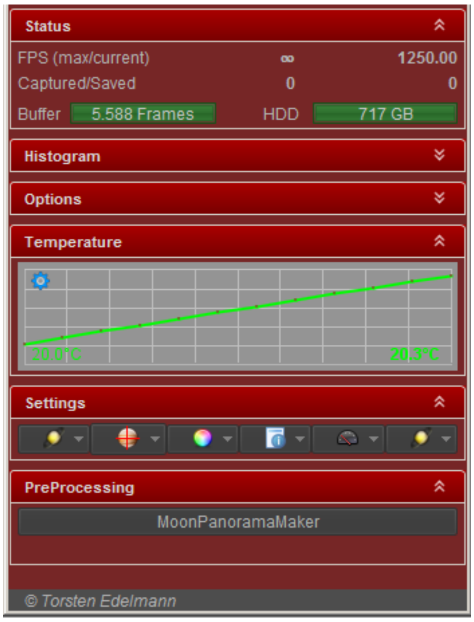
MoonPanoramaMaker communicates with the user via a graphical user interface (GUI). To ease its use in an outdoor environment, almost all functions can be invoked by single key strokes and do not require mouse operations.

3.1 Configuration at First Program Launch

When the program is started for the first time, a window opens automatically for the input of individual parameters. The parameters are arranged in groups relating, for example, to the geographic location, the telescope used and the workflow control. Specific parameters describing some popular USB cameras are predefined. They can be modified, and parameters for other camera models can be added. The model actually used is then selected from the list.

Predefined parameter values give the user an impression of the required formatting. If the mouse pointer hovers over a parameter name, a tooltip appears describing its meaning. A detailed explanation of all parameters can be found in "Appendix A: Parameters at the Configuration Dialog".

When the user acknowledges the complete parameter input by pressing the "OK" button, all parameters are tested for formatting and plausibility. If an error is detected, a popup window appears with the appropriate request for correction. If no more errors are detected, MoonPanoramaMaker writes the configuration file "MoonPanoramaMaker.ini" into the user's home directory. At later program invocations the parameters are loaded from this file silently, and the input dialog does not open. The user can change parameters or add new cameras at any time by pressing the button "Configuration" (shortcut: C).



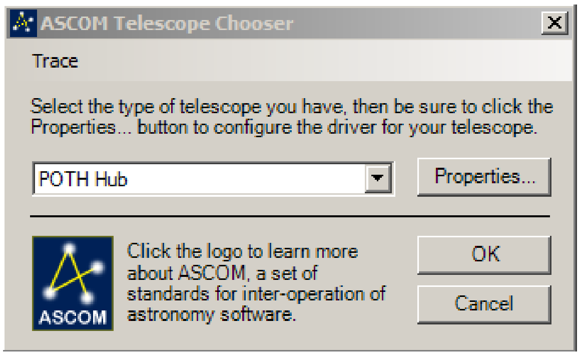
Selecting the option "MoonPanoramaMaker" in FireCapture.

In this context two things are important to note:

- If the parameter "Camera automation" is set to "True", the external program FireCapture must be started **before** MoonPanoramaMaker begins with its recording workflow. In the FireCapture menu "PreProcessing" the entry "MoonPanoramaMaker" must be selected. If the entry is missing, a wrong FireCapture version is used, or the MoonPanoramaMaker plugin folder has not been copied yet into FireCapture's plugin directory (see Section 2). MoonPanoramaMaker requests the user to make sure that this is done, and to acknowledge with pressing "enter".
- If parameters are changed later during execution of the panorama photography workflow, the workflow is started all over again. Only information relating to the telescope mount alignment are kept. For this reason it is recommended to do all parameter changes at program start only.

3.2 Choosing the ASCOM Hub

At program start a dialog window opens for entering the name of the ASCOM hub. The hub is used by MoonPanoramaMaker and other application programs for connecting to the telescope mount simultaneously. The hub which is set in the configuration dialog is preselected. Usually it is sufficient to acknowledge this selection with "OK".



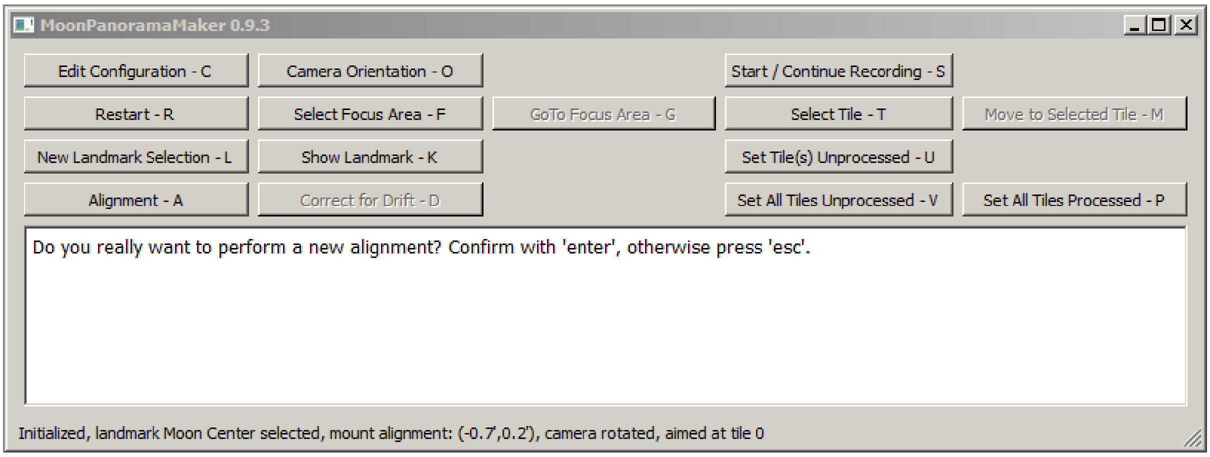
When the selection window closes, the GUI of the ASCOM hub opens. Here the connection to the telescope mount driver must be configured and started. How this is done depends on the ASCOM hub chosen, so please consult the documentation of the hub software.

3.3 Layout of the Main Window

When the hub is connected, the main window opens. It can be controlled entirely without using a mouse. For using the shortcuts, make sure that the focus is on this window. The main window contains three sections (from top to bottom):

- The control section contains buttons to start the various program functions. If at a given time a function cannot be used, the corresponding button is grayed out and de-activated. Every button shows the shortcut letter by which it can be invoked from the keyboard. For every button a tooltip gives a short explanation of its function.
- Via the text window the program prompts the user to start the next action, and it gives warnings in case of a dangerous user input. If the user is requested to do something, he or she is asked to acknowledge the successful completion by pressing the "enter" key.

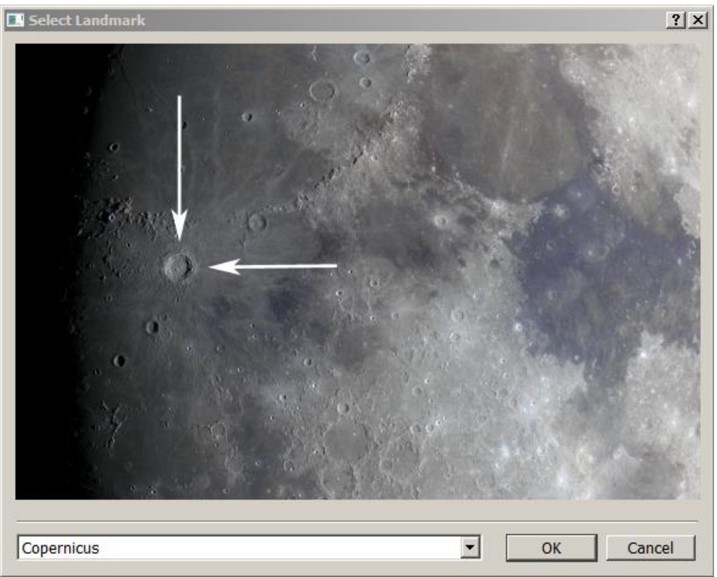
- The status line summarizes the state of the whole system. It lists actions that have been performed, gives quantitative information on the mount alignment and drift rates, and it shows the number of the tile at which the telescope is pointing.



3.4 Selecting a Landmark on the Moon for Mount Alignment

Since the equatorial coordinate system of the telescope mount will never be perfectly aligned with the coordinates in the sky, the difference has to be determined by comparing the computed Moon position with the read-out values returned by the mount. In the following this procedure is called "alignment". Since the coordinate difference depends on the position in the sky, the alignment procedure should be repeated occasionally. If several alignment points have been determined, MoonPanoramaMaker offers to extrapolate the development of the coordinate differences into the future. This process in the following is called "drift".

Since MoonPanoramaMaker itself deals with the alignment, this step can be left out when the telescope mount is initialized. It is sufficient to aim the polar axis of the mounting approximately at the celestial North Pole.

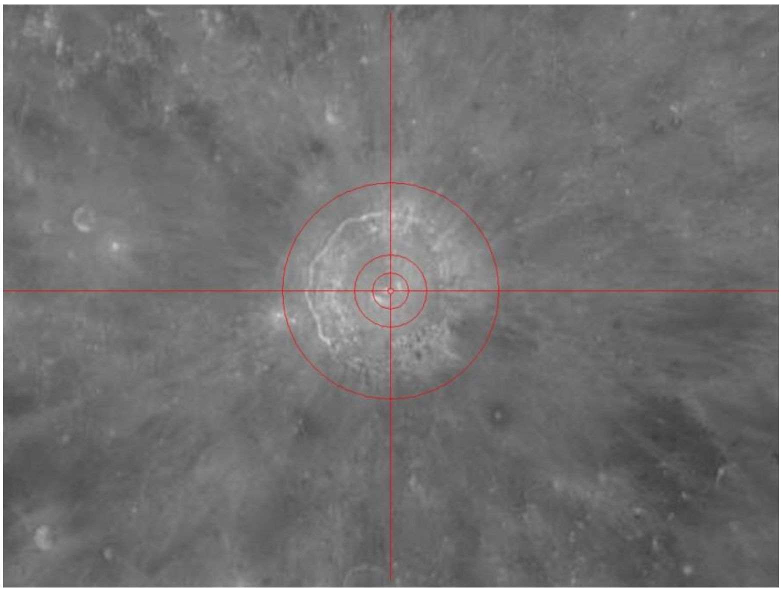


Selection of the landmark to be used for aligning celestial coordinates with the coordinate system of the telescope mount.

Ideally one would perform the alignment by comparing the computed and measured positions of the Moon center. This location, however, is difficult to identify in the telescopic view. It may even be within the unlit part of the Moon. Therefore, MoonPanoramaMaker performs the alignment using some well-defined surface feature selected by the user, in the following called "landmark". For this to work, two things are necessary: First, the selenographic coordinates of the landmark must be known. MoonPanoramaMaker, therefore, keeps a list of the selenographic coordinates of many potential landmarks. Second, these coordinates must be translated into equatorial coordinate offsets (in right ascension and declination) relative to the Moon center. This coordinate transformation is not straightforward and requires as input the Moon's libration angles and the position angle of its rotational axis. The algorithmic details are summarized in Appendix B.

At program startup, MoonPanoramaMaker offers the user a list of landmarks to choose from. Apart from the Moon Center which is always included, the list only shows landmark candidates which are currently located within the sunlit part of the Moon. When the user selects a combobox entry, a picture of the Moon with arrows pointing to the selected feature is shown. The choice is acknowledged by pressing the "OK" button. A view of the selected landmark can be recalled later at any time by pressing the button "Show Landmark".

Next, MoonPanoramaMaker slews the telescope to a position in the sky close to the Moon. For a first alignment of the celestial coordinates with the internal coordinate system of the telescope mount, the user is requested to center the selected landmark in the telescope.



The landmark is centered in the camera live-view window.

This is done best using the camera live view in FireCapture. The FireCapture option to display central cross hairs greatly facilitates this process. The telescope mount can be moved using either the direction buttons of its hand controller, or the arrow keys of the computer with the focus being on the main MoonPanoramaMaker window. **It is important to approach the landmark in declination from the same side as the telescope does during a GoTo operation. Otherwise any backlash of the declination gear would reduce the alignment precision.**

When the landmark is properly centered, the user acknowledges this by pressing "enter". At this point MoonPanoramaMaker knows both the celestial landmark coordinates and those returned by the telescope mount. The difference between the two coordinate sets provides the first alignment point. The offset values (in minutes of arc) in right ascension and declination are displayed in the status line under the keyword "mount alignment".

3.5 Camera Rotation

After the first alignment the orientation of the camera must be adjusted. To this end MoonPanoramaMaker drives the telescope to the point on the sunlit Moon limb where the limb should run parallel to the short side of the field of view.

The user is requested to turn the camera in the eyepiece holder until the Moon's limb runs vertically through the center of the live view window (see the illustration above), and to acknowledge with "enter". It does not matter if the Moon is standing upright or upside down. **From now on, the orientation of the camera should not be changed any more throughout the whole recording session.**

After these preparatory steps MoonPanoramaMaker has gathered all information needed to compute the optimal tile coverage of the sunlit part of the Moon, and to steer the telescope towards them. The GUI buttons for controlling the video acquisition ("Record Group Buttons") get activated.

3.6 Selection and Positioning of the Focus Area

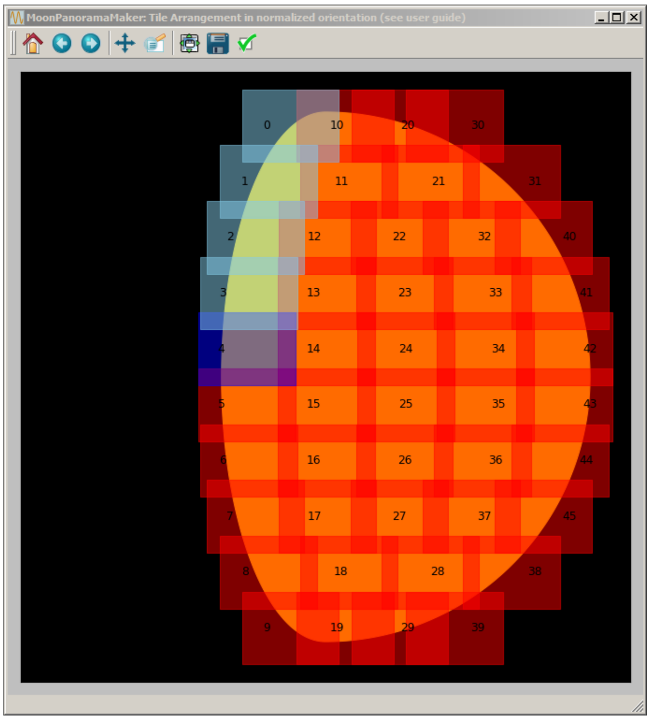
Before recording the videos, the precise telescope focus has to be set. The user selects an area on the Moon which is not too dim and contains enough high-contrast features, so that focus errors are recognized as easily as possible, and presses the GUI button "Select Focus Area". After driving the telescope to the selected place using the arrow keys (either on the hand controller or computer, see above), the user stores this position by pressing "enter". Later on, when during the image acquisition process the focus is to be re-adjusted, the GUI button "GoTo Focus Area" brings the telescope back to the selected focus position.

3.7 Image Acquisition

Now, finally, the image acquisition process can begin. The GUI buttons of the "Record Group"

- "Start / Continue Recording – S",
- "Select Tile – T",
- "Move to Selected Tile – M",
- "Set Tile(s) Unprocessed – U",
- "Set All Tiles Unprocessed – V", and
- "Set All Tiles Processed – P"

are activated. The visualization window named "Tile Arrangement" shows the recording status of each tile with the following color codes:



The "Tile Arrangement" window shows the moon in the so-called "normalized orientation", i.e. with the sunlit limb pointing to the right. Please note that for the waning moon this means that South is up.

- Red: Tile not yet processed, no video file available
- Light Blue: Recording finished
- Dark Blue: Active tile, recording may begin or is underway

When the button "Start / Continue Recording" is pressed, MoonPanoramaMaker selects the next tile which has not been processed yet, and centers this tile in the telescope's field of view. Depending on whether the parameter "Camera automation" was set to "True" or "False" in the configuration dialog, MoonPanoramaMaker either triggers the camera itself, or requests the user to do so, and to acknowledge the successful completion of the video by pressing "enter". After this, the program automatically selects the next un-processed tile and repeats the process.

If the videos are recorded in automatic mode, the user selects the video file name format in FireCapture. Additionally, MoonPanoramaMaker appends to each file name the string "_Tile-nnn", where "nnn" is the current tile number. A full file name could then look like "Moon_210531_Tile-023.ser". If a tile is recorded more than once during an observing session, the encoded tile number makes it easier to identify the corresponding video files.

During video acquisition, MoonPanoramaMaker automatically sends guiding corrections in both coordinate directions to the telescope mount. The topocentric movement of the Moon among the stars is accounted for, as well as the coordinate system drift (see below). Since the algorithm is based on the computed path of the Moon and does not use video feedback from the camera or a guide scope, periodic worm gear errors or backlash in declination are not corrected.

The acquisition process can be interrupted at any time by pressing the "Esc" key. If "Camera Automation" is set to "False", the program stops issuing guiding corrections immediately and awaits a new command. This could be, for example, a new alignment request or moving the telescope to the focus area for a focus adjustment. If "Camera Automation" is set to "True", the program waits until FireCapture has finished the current exposure. The color of the active tile changes to light blue, and the program awaits the next instruction. The recording workflow is resumed by pressing the "Start / Continue Recording" button again.

The configuration parameter "Limb first" determines the order in which the tiles are processed. If set to "True", the program starts at the sunlit Moon limb, otherwise at the Terminator. In any case the tiles are processed column-wise, to reduce inconsistencies caused by changing shadows. The optimal ordering depends on the particular situation. If, for example, the recording session starts during evening twilight, it is best to begin with the bright limb. When later on the process arrives at the dimly lit tiles close to the terminator, the surrounding sky will be darker. The opposite ordering is to be preferred, for example, if a recording session at dawn proceeds well into the morning twilight.

All tiles are shown with their numbers in the window "Tile Arrangement". Numbering starts with zero. If the "Start / Continue Recording" button is pressed, the program continues with the unprocessed tile with the lowest number. Hitting the "Select Tile" key opens a dialog where the user can select a tile number, either by entering a number, or by browsing through the available numbers using the "up" and "down" keys. The choice is acknowledged either by pressing the "OK" button or the "enter" key. If the chosen tile has already been processed (shown as light blue), it can be reset to red by pressing "Set Tile(s) Unprocessed". If the selected tile is marked unprocessed, pressing "Start / Continue Recording" instructs the program to continue with the selected tile. Pressing "Set All Tiles Unprocessed" resets all tiles to red color. Conversely, pressing "Set All Tiles Processed" marks all tiles as processed (light blue).

As an alternative to using the "Select Tile" key, contiguous tile patterns can be selected in one go by drawing a rectangular area in the "Tile Arrangement" window while keeping the left mouse key pressed. The rectangle is colored light grey. Pressing "Set Tile(s) Unprocessed" will reset all tiles which lie completely within the rectangle. A single mouse click in the "Tile Arrangement" window resets the selection rectangle.

Recording can be restricted to a limited area from the outset by pressing the "Set All Tiles Processed" button, drawing the appropriate tile selection rectangle in the "Tile Arrangement" window, and then pressing "Set Tile(s) Unprocessed". "Start / Continue Recoding" will start recording the selected tiles only.

Pressing "Move to Selected Tile" instructs the program to steer the telescope to a tile without the need to invalidate a previous recording. If, after moving to the tile, the user decides to repeat the video acquisition, he or she can do so by pressing "Set Tile(s) Unprocessed" followed by "Start / Continue Recording".

3.8 Determining and Correcting the Coordinate System Drift

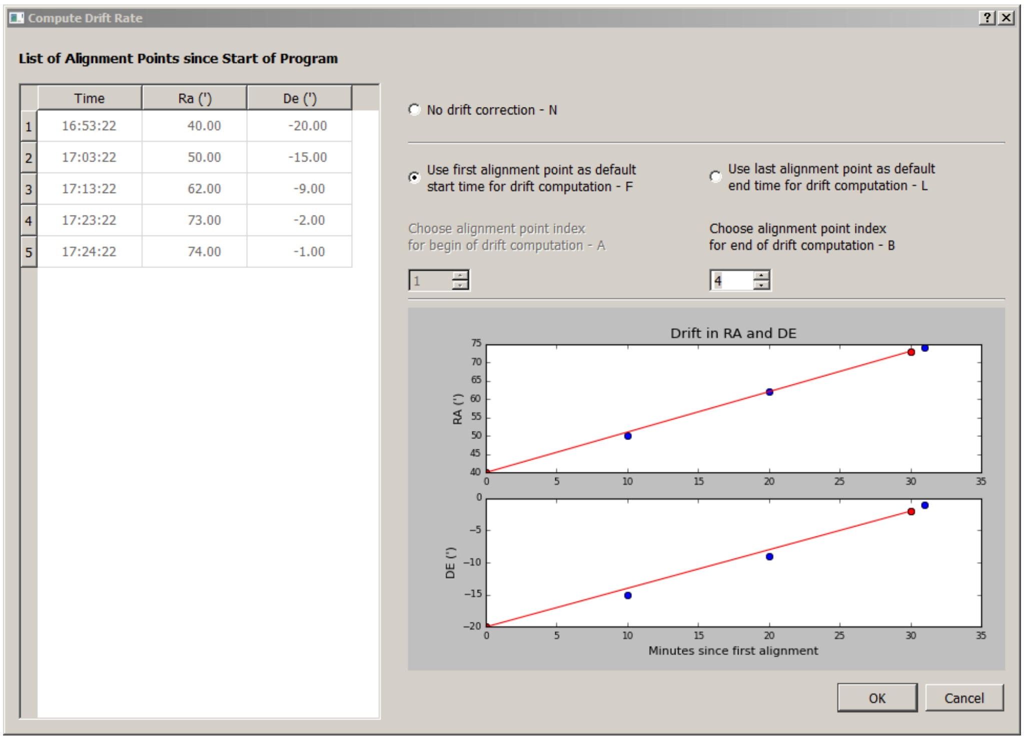
If after the initialization phase no additional alignment has been performed, the program assumes that the offset between the celestial coordinates and the internal system of the telescope mount is constant along the Moon's path across the sky. Obviously, this can only be a first approximation. Therefore, it makes sense to repeat the alignment procedure at regular time intervals during a recording session. This could, for example, be done each time a column of tiles is processed. The interruption of the recording process could also be used to adjust the camera focus (see Section 3.6).

The only purpose of repeating the alignment is to update the offset between the coordinate systems. The motion of the Moon among the stars is always accounted for with high precision automatically.

As described in the previous section, the user can interrupt the recording session at any time by pressing the "Esc" key. If a video acquisition is running in automatic mode, the program waits until it is finished, before giving back the control to the user. Pressing "Alignment" then instructs the program to steer the telescope to the landmark selected during initialization. If the landmark is not placed precisely at the center of the camera live view, the deviation gives an impression of the accuracy with which currently the telescope hits the pre-computed tile positions. If this offset is too large, a non-uniform tessellation of the Moon surface or even gaps between tiles may be the result.

By means of the arrow keys (of the hand controller or computer), the user moves the landmark under the cross hairs in the camera live view. Please remember to approach the landmark in the same direction as the telescope does during a GoTo operation (see Section 3.4 above). When the user acknowledges by pressing "Enter", the MoonPanoramaMaker stores an additional alignment point.

As soon as more than one alignment point is available, MoonPanoramaMaker can predict how the coordinate system offset will change with time. This change is called "drift". It is predicted by using linear extrapolation. In order to base the extrapolation on as long a time span as possible, by default the program uses the first and last alignment points for the computation. If the time span is shorter than ten minutes, the extrapolation would not be reliable enough, so no drift correction is applied.



Dialog for drift correction

If drift correction is active, the status line in the main window displays the computed values under the keyword “drift rate”. They are defined as the change of the alignment offsets in right ascension and declination, respectively, expressed in arc minutes per hour.

If for any reason the user does not want the drift rate to be computed according to the standard procedure, he or she can call a dialog window by pressing the “Correct for Drift” button. As soon as the focus switches to this window, its keyboard shortcuts are activated for input. The user may choose to switch off drift correction altogether (uppermost radio button, or “N”). If this button is toggled off (i.e. drift should be accounted for), by default the first and last alignment points are used to compute the drift rate. The user can override this choice, separately for the begin or the end of the time interval, by un-checking the corresponding radio button. Pressing a button activates a chooser box, where the number of the first or last alignment point, respectively, can be set manually.

Deviating from the default choice can make sense to exclude an unreliable alignment point from the drift determination. If, for example, the camera is not centered precisely in the eyepiece holder, rotating the camera as described in Section 3.5 may render the previous alignment point useless. In this case it is a good idea to begin the determination of the drift rate with the first alignment point after turning the camera.

The change of the alignment with time is visualized by a viewgraph in the lower right corner of the dialog window. Colored dots show for all available alignment points the offsets in right ascension (top) and declination (bottom). The two red alignment points are currently selected for drift computation. They are connected by red lines showing the drift in both coordinates. All the other alignment points are colored blue.

Please note that the last alignment point always plays a special role: Even if not used in drift rate computation, it is still used as the starting point for computing the current alignment offset. If the last alignment point is known to be inaccurate and, therefore, should not influence the offset computations any more, this can only be achieved by performing an additional alignment.

Since no drift corrections are applied before the alignment points cover a time span of at least ten minutes, in the beginning the telescope pointing is usually less accurate. Especially if the telescope mount is not well aligned with the North Pole, it therefore makes sense to wait with the video acquisitions until drift compensation has been established. In practice this waiting time may be necessary anyway to get the telescope close enough to thermal equilibrium with its environment.

3.9 End of Program

If all tiles are processed and marked light blue in the tile visualization window, the program gives the control back to the user. All tiles needed for the panorama have been recorded, and the program may be closed. Alternatively, the user may decide to repeat the acquisition of some or all tiles. To this end he or she selects (as described in Section 3.7) the corresponding tile numbers and resets them. Pressing “Start / Continue Recording“ starts the repeated acquisition of only the selected tiles.

Another choice is to reset all tiles by pressing “Set All Tiles Unprocessed”. After that, a whole new panorama may be recorded. This can be achieved as well by pressing the “Restart” button. In this case, however, the program guides the user through the selection process of a new landmark and the corresponding alignment.

Of course, a new panorama can be recorded as well by closing the program and starting all over again. In this case, however, all alignment points are lost, so they cannot be used any more for drift corrections. Therefore, it is recommended to stay in a program session for as long as possible.

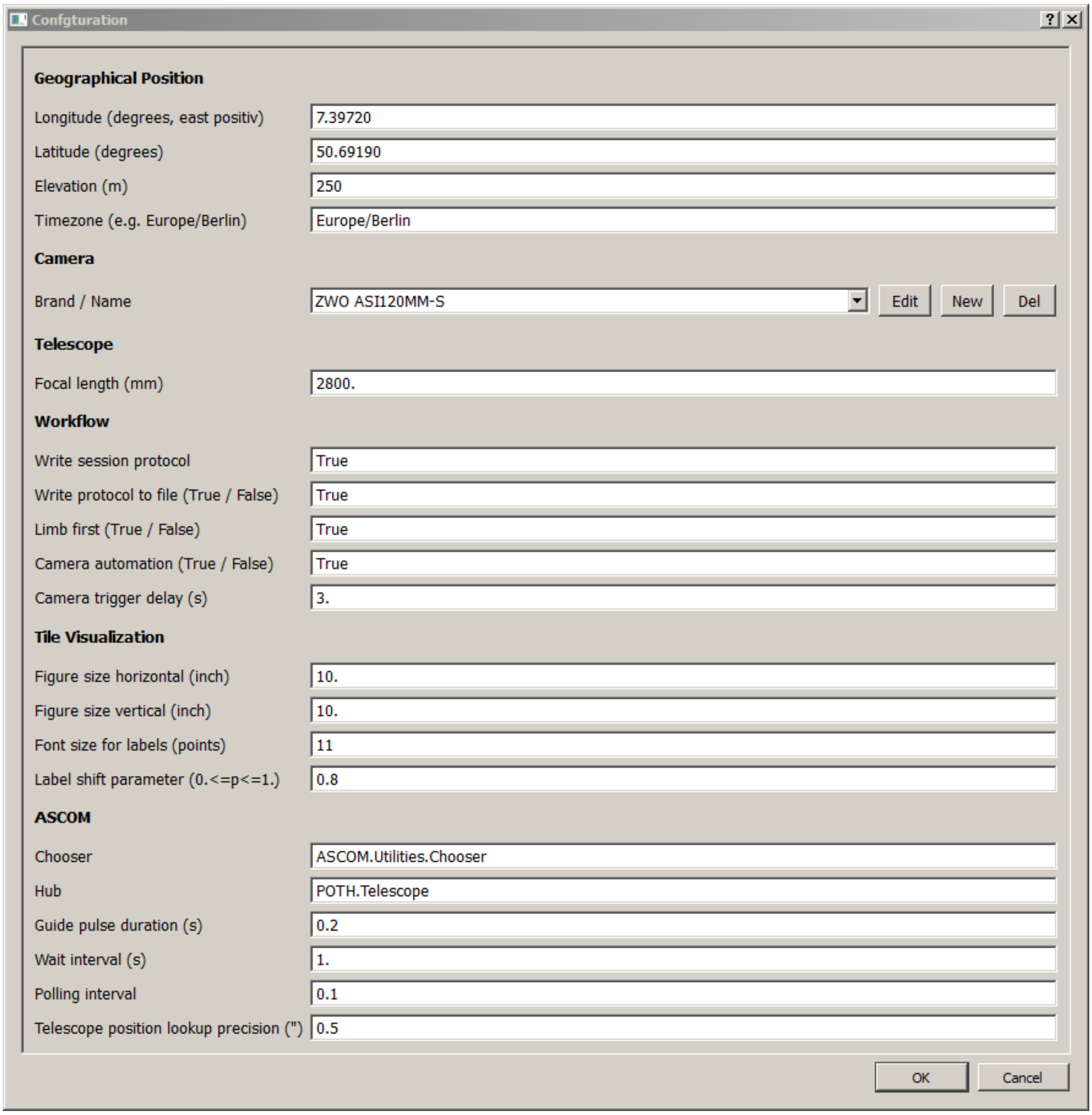
If the telescope is mounted on a "German Equatorial Mount" and the moon during the recording session crosses the meridian, the mounting will perform a meridian flip when the target coordinates of a GoTo command are located on the other side of the meridian. If possible, this situation should be avoided during the acquisition of a panorama. Otherwise, the following points need to be considered:

- Make sure that the cabling of the telescope, camera and all other accessories allows the meridian flip without unplugging, and that no moving part will collide with the telescope pier or any other obstacle.
- After the meridian flip a new alignment point must be set before the next tile is recorded. Generally it is a good idea to wait a few minutes until the whole moon has crossed the meridian. Otherwise the mounting in GoTo operations could flip back and forth repeatedly. If drift correction is enabled, it must be computed using alignment points which both were set either before or after the flip. This can be achieved by selecting non-default values in the dialog window which opens on pressing the "Correct for Drift" button. If one alignment point was set before the flip and the other one afterwards, mechanical imperfections of the telescope and mounting could lead to very inaccurate drift rates.
- Videos taken after the meridian flip will be turned upside-down as compared to the ones taken before the flip. This can be corrected during panorama construction later on. It might be a good idea first to produce partial panoramas using all images taken before and after the flip, respectively. In a second step one part is turned around and then combined with the other one.

Appendix A: Parameters at the Configuration Dialog

The main window of the configuration dialog allows entering user-specific values for various parameters. They are arranged in the following groups:

- Geographic Position
- Camera
- Telescope
- Workflow
- Tile Visualization
- ASCOM



In the following, definitions for all parameters are given. Please note that for fractional values a decimal point (no comma) is used.

Geographical Position

Longitude: Geographic longitude (in degrees and fractional part), counted from the Greenwich meridian, positive to the East.

Latitude: Geographic latitude (in degrees and fractional part). Northern latitude positive.

Elevation: Elevation above sea level (in meters)

Timezone: Text string of the time zone to which the computer time refers. Valid entries for Europe and the U.S. are:

Europe/Amsterdam, Europe/Andorra, Europe/Athens, Europe/Belgrade, Europe/Berlin, Europe/Bratislava, Europe/Brussels, Europe/Bucharest, Europe/Budapest, Europe/Busingen, Europe/Chisinau, Europe/Copenhagen, Europe/Dublin, Europe/Gibraltar, Europe/Guernsey, Europe/Helsinki, Europe/Isle_of_Man, Europe/Istanbul, Europe/Jersey, Europe/Kaliningrad, Europe/Kiev, Europe/Lisbon, Europe/Ljubljana, Europe/London, Europe/Luxembourg, Europe/Madrid, Europe/Malta, Europe/Mariehamn, Europe/Minsk, Europe/Monaco, Europe/Moscow, Europe/Oslo, Europe/Paris, Europe/Podgorica, Europe/Prague, Europe/Riga, Europe/Rome, Europe/Samara, Europe/San_Marino, Europe/Sarajevo, Europe/Simferopol, Europe/Skopje, Europe/Sofia, Europe/Stockholm, Europe/Tallinn, Europe/Tirane, Europe/Uzhgorod, Europe/Vaduz, Europe/Vatican, Europe/Vienna, Europe/Vilnius, Europe/Volgograd, Europe/Warsaw, Europe/Zagreb, Europe/Zaporozhye, Europe/Zurich, GMT, UTC,

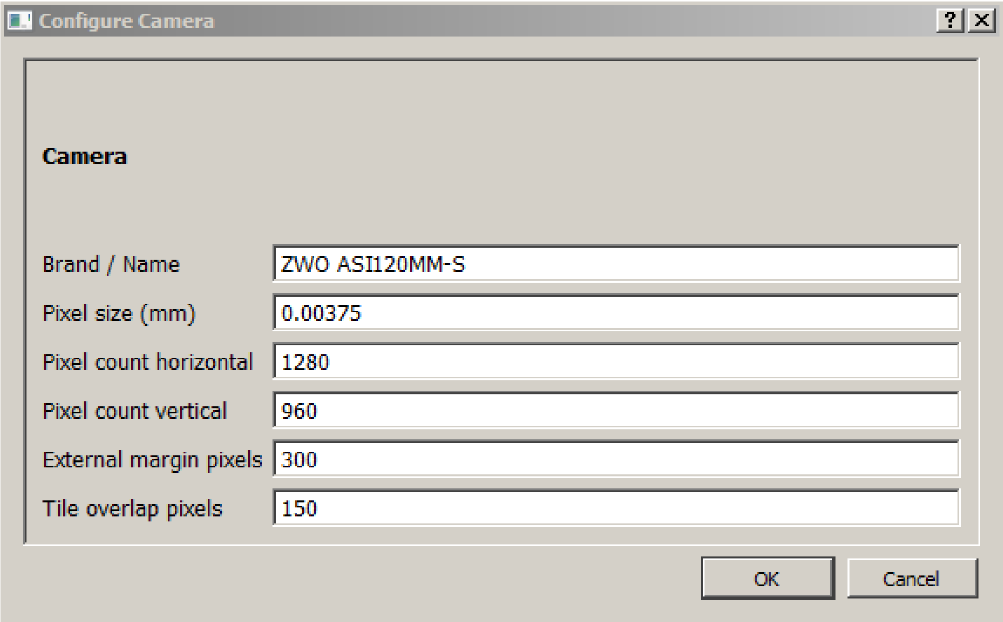
US/Central, US/Eastern, US/Hawaii, US/Mountain, US/Pacific.

At the end of the configuration dialog the program checks the validity of the entered text string. If an unknown string has been entered, the user is prompted for correction.

Camera

Brand / Name: Drop-down list of all camera models for which specifications have been entered. With the buttons "Edit", "New" and "Del" the user can modify parameters for existing models, add specifications for new models, or delete models from the list.

The sub-dialog for entering new models or editing existing ones additionally contains the following parameters:



Pixel size: Horizontal or vertical distance ("pitch") of two adjacent pixels of the camera sensor. In general this is not the size of the light-sensitive cell itself. It is assumed that the distance is the same in both directions. Please note that the value is given in millimeters, not in microns.

Pixel count horizontal / vertical: Number of sensor pixels in horizontal and vertical direction, respectively.

External margin pixels: Minimal width of the area surrounding the Moon to be recorded (in pixels). If this value is chosen too small, sunlit mountain peaks beyond the terminator could lie outside the recorded area. Also, less than perfect mount alignment could cause marginal areas of the Moon to be lost. Too large a value unnecessarily increases the number of tiles to be recorded.

Tile overlap pixels: Minimal overlap between neighboring tiles in pixels. Again, experience is needed to strike the right balance between safety and too much overhead.

Telescope

Focal length: Focal length of the complete optical system in millimeters, including any projection system between objective lens and sensor. If such a projection lens is used, the resulting focal length of the overall system is difficult to predict. In „Appendix C: Determination of the Focal Length of the System" it is shown how the focal length can be determined experimentally.

Workflow

Write session protocol: "True" if all activities during program execution are to be logged in detail (including time stamps), otherwise "False".

Write protocol to file: "True" if the protocol should be written into the file named „MoonPanoramaMaker.log" in the user's home directory (in append mode), "False" if the protocol is to be written to standard output.

Limb first: "True" if the tiles at the bright Moon limb are to be recorded first, "False" otherwise.

Camera automation: "True": Automatic camera control via FireCapture. In this case the FireCapture program must be started before the recording workflow begins, and in FireCapture's "PreProcessing" menu the entry "MoonPanormaMaker" must be selected. Camera parameters, such as exposure time, total frame count, data storage location etc., are set via FireCapture's user interface.

"False": MoonPanoramaMaker for each tile requests the user to trigger the camera manually.

Camera trigger delay: Time in seconds between moving the telescope to a new tile and triggering the camera (has no effect if "Camera automation" is set to "False"). The optimal value is found experimentally. The goal is to trigger the camera not before the view has become steady.

Tile Visualization

Figure size horizontal / vertical: Width and height (in inches) of the "Tile Arrangement" window, respectively.

Font size for labels: Size (in points) of the tile numbers in the "Tile Arrangement" window. Large values in case of a fine tessellation can cause overlapping labels.

Label shift parameter: This parameter causes the tile numbers to be printed centrally (value = 0.) or shifted horizontally (maximal shift for value = 1.) into the tiles. In the case of large tile overlaps shifting the labels can help avoiding that labels overlap in print.

ASCOM

Chooser:	Path name of the GUI program to be used for choosing the ASCOM hub. In most cases it is okay to use the preselected program which comes with the ASCOM platform.
Hub:	Default name of the ASCOM hub (e.g. POTH). This name is pre-selected in the drop-down list of the chooser. This is convenient because in most cases the user just has to press "enter" when the chooser appears.
Guide pulse duration:	Duration of single pointing corrections in northern, southern, eastern and western direction. The user can issue corrections manually by pressing the arrow keys of the computer keyboard (continuous operation by keeping a key pressed). Automatic corrections are generated for guiding during video exposures.
Wait interval:	Looking up the current coordinates where the telescope mount points to is implemented as an iterative loop. The loop finishes when the readouts stop changing. This way it is avoided that a moving mount "on its way" returns some intermediate readouts. The parameter sets the length of one iteration step (in seconds).
Polling interval:	Control of the telescope mount is implemented as a separate thread. The main program writes positioning and query instructions into a queue which is processed asynchronously by the control thread. The "Polling interval" defines how often the control thread checks the queue for new instructions. Too short an interval increases the processor load, while a long interval reduces the responsiveness.
Telescope position lookup precision:	As explained for the "Wait interval" parameter, the mount position lookup is implemented iteratively. Two consecutive readouts are interpreted as being "equal" if their difference both in right ascension and declination is not greater than specified by this parameter (in arc seconds). For some telescope mounts (e.g. Vixen Sphinx NexSXD) the readout keeps on changing in very small erratic steps even if it is running in constant siderial tracking mode. In this case, too small a value can cause an infinite loop.

Appendix B: Algorithms Used by the Program

Shape and Orientation of the Sunlit Part of the Moon

For the construction of an optimal tessellation of the sunlit part of the Moon, the precise shape and orientation of the Moon phase must be known. To this end, the following quantities have to be determined:

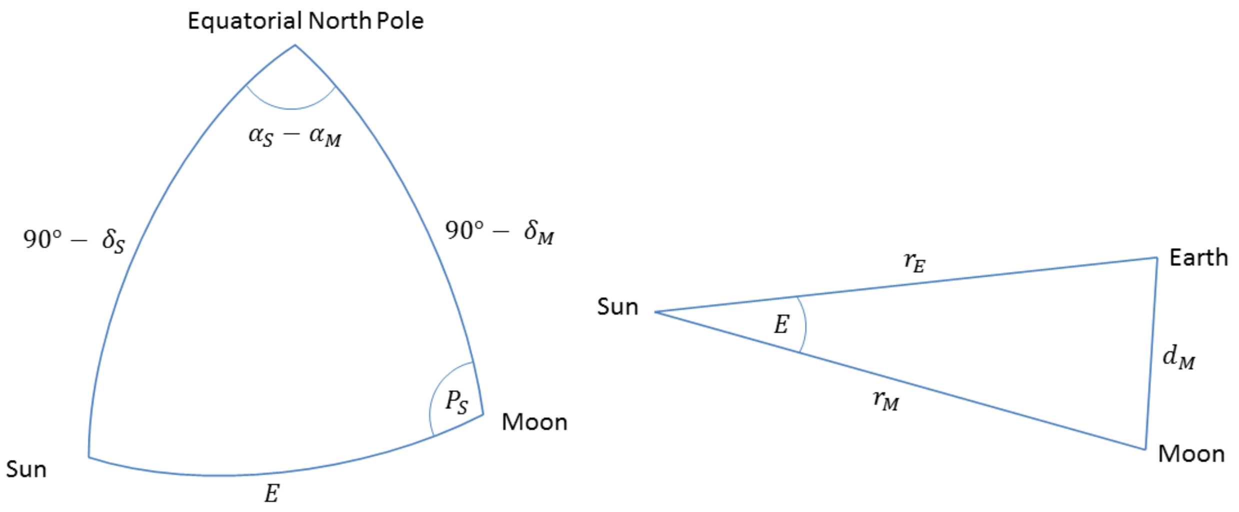
E: Elongation of the Moon from the Sun ($0 \leq E \leq 180°$)

r_M: Distance between the Moon and the Sun

φ: Phase angle of the Moon ($0° \leq \varphi \leq 180°$). A value of $0°$ corresponds to new Moon, $90°$ to half Moon und $180°$ to full Moon.

P_S: Position angle of the great circle through the Moon and the Sun, as measured at the Moon's position in topocentric equatorial coordinates, counted from North counterclockwise.

P_N: Position angle of the "upper" pole of the sunlit Moon phase, counted from equatorial North counterclockwise. The upper pole ("N" in the illustration below) is defined as follows: If it is pointing up, the sunlit Moon limb is pointing to the right. The terminator runs from top to bottom somewhere between the right and left Moon limbs. The construction of the optimal tessellation is based on this normalized orientation of the Moon.



In the spherical triangle Moon-Sun-Celestial North (left illustration) the following equation holds:

$$\cos E = \sin \delta_M \sin \delta_S + \cos \delta_M \cos \delta_S \cos(\alpha_S - \alpha_M) \quad (1)$$

And from the plain triangle Sun-Moon-Earth (right illustration):

$$r_M = \sqrt{{r_E}^2 + {d_M}^2 - 2 r_E d_M \cos E} \quad (2)$$

From the spherical triangle Moon-Sun-Celestial North it also follows:

$$\sin\varphi = \frac{r_E \ \sin E}{\sqrt{{d_M}^2 + {r_E}^2 - 2 d_M r_E \cos E}} \tag{3}$$

$$\cos\varphi = \frac{{r_E}^2 - {r_M}^2 - {d_M}^2}{2 r_M d_M} \tag{4}$$

$$\sin P_S = \frac{\cos\delta_S \ \sin(\alpha_S - \alpha_M)}{\sin E} \tag{5}$$

$$\cos P_S = \frac{\sin\delta_S \cos\delta_M - \cos\delta_S \sin\delta_M \cos(\alpha_S - \alpha_M)}{\sin E} \tag{6}$$

$$P_N = P_S + {}^{\pi}/_{2} \tag{7}$$

with the following definitions:

α_M, δ_M: Topocentric right ascension and declination of the Moon (true coordinates referring to the current epoch and equinoctium)

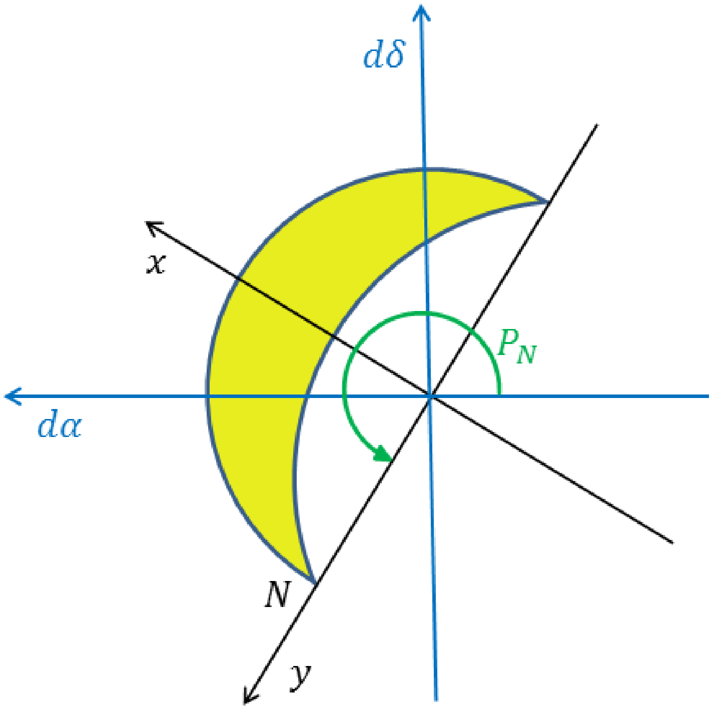
α_S, δ_S: Topocentric right ascension and declination of the Sun (true coordinates referring to the current epoch and equinoctium)

r_E: Topocentric distance between Earth and Sun

d_M: Topocentric distance between Earth and Moon (r_E, r_M, d_M have to be defined using the same units)

The input values for $\alpha_M, \delta_M, \alpha_S, \delta_S, r_E, d_M$ are computed for the observing site by using the astronomy program package "PyEphem" (http://rhodesmill.org/pyephem/index.html).

As explained above in the definition of the angle P_N, the tile layout is constructed for a normalized orientation of the Moon phase. The center coordinates of all tiles are computed in the corresponding (x, y) plane first. Only at the end they are converted into offsets from the Moon center in right ascension $(d\alpha)$ and declination $(d\delta)$. Please note that in the normalized orientation the sunlit limb is on the right side, even for waning Moon phases. P_N denotes the angle between the two coordinate systems. This situation is depicted in the illustration below.



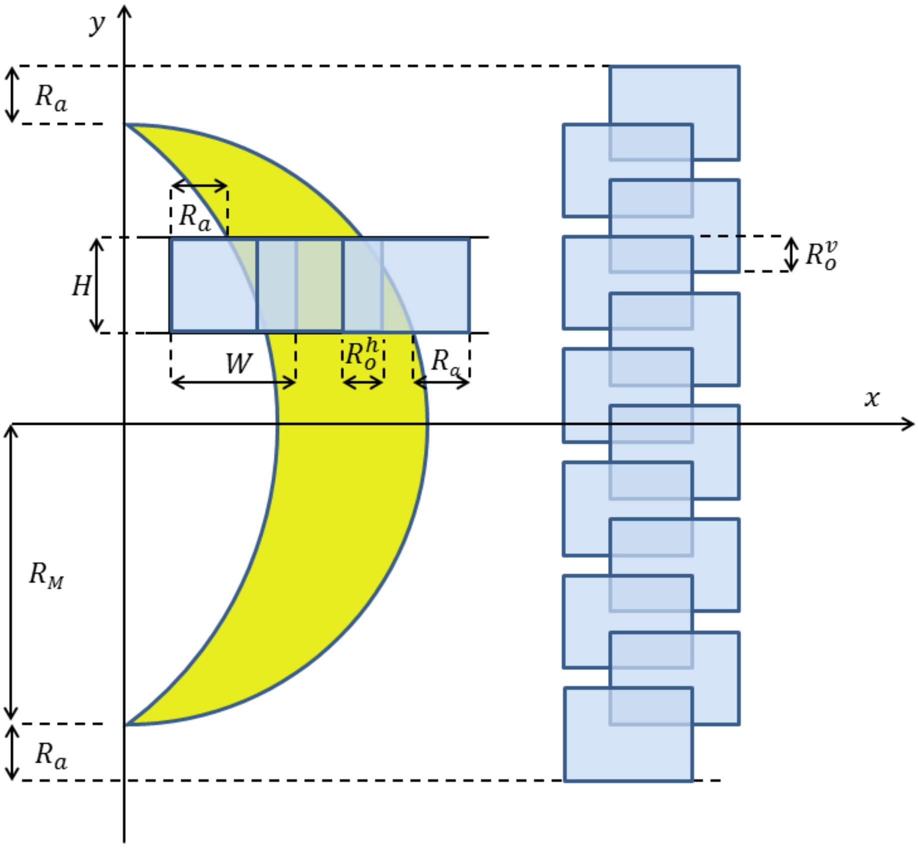
Apart from the ephemeris data mentioned above, the construction of the tile layout is based on the following variables which are either provided by the user directly, or computed using simple transformations from user-defined parameters:

H, W: Height and Width of the camera's field of view (angle). These variables are computed from the linear pixel size, the horizontal and vertical pixel counts, and the focal length of the telescope system.

R_a: Minimal width of the space around the Moon to be covered by the tiles, given as an angle (same in vertical and horizontal directions). The user specifies the minimal number of pixels. From this R_a is computed using the linear pixel size and focal length of the telescope system.

R_o^m: Minimal overlap between neighboring tiles (angle, both in vertical and horizontal direction). Again, this value is computed from the corresponding pixel count as specified by the user.

The definition of these parameters is illustrated in the following picture. Tiles are constructed row-wise, starting with the upper boundary in the (x, y) plane. When the user requirements given above lead to non-integer numbers of tiles in x and y direction, they are rounded up to the next higher integer value by slightly enlarging the tile overlaps. Larger overlaps will help later when the panorama is produced from the tiles. The external margin width is not increased.



The following algorithm computes for all tiles the center coordinates (x_i, y_j) and the corresponding angular offsets relative to the Moon center in right ascension and declination $(d\alpha, d\delta)_{i,j}$. Here i denotes the row index and j the column index, both counted from zero. R_M is the topocentric radius of the Moon (angle). It is provided by PyEphem as part of the Moon ephemeris.

$$n_z = \left\lceil \frac{2R_M + 2R_a - R_o^m}{H - R_o^m} \right\rceil \quad (8)$$

$If\ n_z > 1$:

$$R_o^v = \frac{n_z\, H - 2R_M - 2R_a}{n_z - 1} \quad (9a)$$

$Else$:

$$R_o^v = R_o^m \quad (9b)$$

$For\ i = 0, \ldots, n_z - 1$:

$$y_t = R_M + R_a - i(H - R_o^v) \quad (10)$$

$$y_b = y_t - H \quad (11)$$

$$y_i = \frac{y_t + y_b}{2} \quad (12)$$

$$x_t^l = \sqrt{R_M^2 - min(y_t^2, R_M^2)} \quad (13)$$

$$x_b^l = \sqrt{R_M^2 - \ min(y_b^2\ , R_M^2)} \tag{14}$$

$$x_{min} = \min(\ x_t^l, x_b^l)\ \cos\varphi \tag{15}$$

$If\ \ y_t y_b > 0$:

$$x_{max} = \max(\ x_t^l, x_b^l) \tag{16a}$$

$Else$:

$$x_{max} = R_M \tag{16b}$$

$$n_S = \left\lceil \frac{x_{max} - x_{min} + 2R_a - R_o^m}{W - R_o^m} \right\rceil \tag{17}$$

$If\ \ n_S > 1$:

$$R_o^h = \frac{n_S\, W - x_{max} + x_{min} - 2R_a}{n_S - 1} \tag{18a}$$

$Else$:

$$R_o^h = R_o^m \tag{18b}$$

$For\ j = 0, \dots, n_S - 1$:

$$x_r = \ x_{max} + \ R_a - j\ (W - R_o^h) \tag{19}$$

$$x_l = \ x_r - W \tag{20}$$

$$x_j = \frac{x_r + x_l}{2} \tag{21}$$

$$\begin{pmatrix} d\alpha \\ d\delta \end{pmatrix}_{i,j} = \begin{pmatrix} \frac{-\ \cos P_N}{\cos\delta_M} & \frac{\sin P_N}{\cos\delta_M} \\ \sin P_N & \cos P_N \end{pmatrix} \begin{pmatrix} x_j \\ y_i \end{pmatrix} \tag{22}$$

Coordinate Offset of the Landmark Relative to the Moon Center

In the mount alignment process MoonPanoramaMaker needs to know the coordinate differences in right ascension and declination between the landmark and the Moon center. The computation of these quantities depends on the selenographic coordinates of the landmark and the orientation of the Moon as seen from the observer. The Moon's orientation is quantified by its topocentric (observer-centered) libration angles in longitude l and latitude b, and the position angle C' of its rotational axis in the Earth's equatorial coordinate system. The following algorithm provides these three quantities with sufficient accuracy to determine the coordinate offsets of the landmark to about 3" in right ascension and declination. This accuracy is achieved by, on the one hand, including the topocentric correction of libration angles, while on the other hand neglecting the effect of nutation.

First, using the algorithm in (Simon, Bretagnon, Chapront, Chapront-Touzé, Francou, & Laskar, 1994), the obliquity of the ecliptic ε and the mean elements Ω and L_M of the Moon's orbit referred to the mean ecliptic and equinox of date are computed:

$$t = \frac{(days\ since\ Jan.1st,2000,12{:}00\ UT)}{36525} \tag{23}$$

$$\varepsilon = 23°.439281 - 0°.013002575\, t \tag{24}$$

$$I = 1°.54266 \tag{25}$$

$$\Omega = 125°.044555 - 1934°.13626194\, t \tag{26}$$

$$L_M = 218°.31664563 + 481267°.88119575\, t - 0°.00146638\, t^2 \tag{27}$$

Now, using the algorithm presented in (Taylor, Bell, Hilton, & Sinclair, 2010), and omitting the higher-order corrections due to nutation, the position angle of the rotational axis C' and the libration angles l, b are computed:

$$\cos i = \cos I \cos \varepsilon + \sin I \sin \varepsilon \cos \Omega \tag{28}$$

$$\sin \Omega' \sin i = -\sin I \sin \Omega \tag{29}$$

$$\cos \Omega' \sin i = \cos I \sin \varepsilon - \sin I \cos \varepsilon \cos \Omega \tag{30}$$

$$\cos b \sin C' = -\sin i \cos(\Omega' - \alpha_M) \tag{31}$$

$$\cos b \cos C' = \cos \delta_M \cos i - \sin \delta_M \sin i \sin(\Omega' - \alpha_M) \tag{32}$$

$$\sin b = -\sin I \cos \beta_M \sin(\lambda_M - \Omega) - \cos I \sin \beta_M \tag{33}$$

$$\cos b \cos(l + L_M - \Omega) = \cos \beta_M \cos(\lambda_M - \Omega) \tag{34}$$

$$\cos b \sin(l + L_M - \Omega) = \cos I \cos \beta_M \sin(\lambda_M - \Omega) - \sin I \sin \beta_M \tag{35}$$

with the following definitions:

ε:	Current obliquity of the ecliptic
I:	Inclination of the ecliptic to the mean lunar equator
Ω:	Longitude of the ascending node of the ecliptic w.r.t. the lunar equator
L_M	Mean longitude of the Moon
i:	Inclination of the lunar equator to the equator of the Earth
λ_M, β_M:	Topocentric longitude and latitude of the Moon (true coordinates referring to the current epoch and equinox). These quantities are computed using the PyEphem software.
Ω'	The arc of the true equator of the Earth from the true equinox of date to the ascending node of the mean equator of the Moon on the true equator of the Earth
C'	Position angle of the axis of rotation of the Moon in the equatorial coordinate system of the Earth

l, b Topocentric libration angles in longitude and latitude, respectively, in the equatorial coordinate system of the Moon

The computation of the equatorial coordinate offsets of the lunar landmark starts from the landmark's (x, y, z) coordinates in a rectangular coordinate system with its origin at the Moon's center, the positive x axis pointing east, the positive y axis lying in the equatorial plane and pointing away from the Earth, and the positive z axis pointing North. First, the position vector of the landmark is rotated by l, then by b, and finally by C':

$$da' = -R_M \sin(\lambda_L - l) \cos\varphi_L \quad (36)$$

$$y = -R_M \cos(\lambda_L - l) \cos\varphi_L \quad (37)$$

$$z = R_M \sin\varphi_L \quad (38)$$

$$y' = y \cos b - z \sin b \quad (39)$$

$$dd' = y \sin b + z \cos b \quad (40)$$

$$d\alpha = (da' \cos C' + dd' \sin C') / \cos\delta_M \quad (41)$$

$$d\delta = -da' \sin C' + dd' \cos C') \quad (42)$$

with the following variable definitions:

λ_L, φ_L: Selenographic longitude and latitude of the landmark on the Moon

R_M: Topocentric radius of the Moon (angle)

$d\alpha, d\delta$: Offsets in right ascension and declination of the landmark from the Moon center, as measured in the true topocentric equatorial coordinate system of the Earth

References:

Simon, J., Bretagnon, P., Chapront, J., Chapront-Touzé, M., Francou, G., & Laskar, J. (1994). Numerical expressions for precession formulae and mean elements for the Moon and the planets. *Astronomy and Astrophysics, 282*, pp. 663-683.

Taylor, D.B., Bell, S., Hilton, J., & Sinclair, A. (2010). *Computation of the Quantities Describing the Lunar Librations in the Astronomical Almanac.* United Kingdom Hydrographic Office, Taunton, Great Britain.

Appendix C: Determination of the Focal Length of the System

The precise focal length of the complete telescope system (from the objective lens to the sensor) determines the field of view of the camera and is thus an important input parameter for the construction of the optimal tile layout. Unfortunately, this figure usually is not known a priori if some kind of projection system (e.g. a Barlow lens) is inserted into the light path.

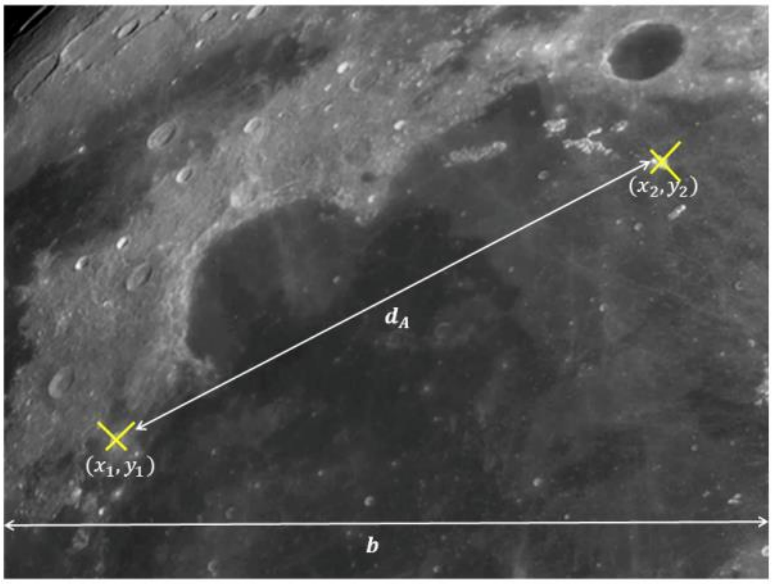
The easiest way to determine this figure is by experiment. In the following two possible techniques, both based on test exposures of the Moon, are presented.

Absolute Method:

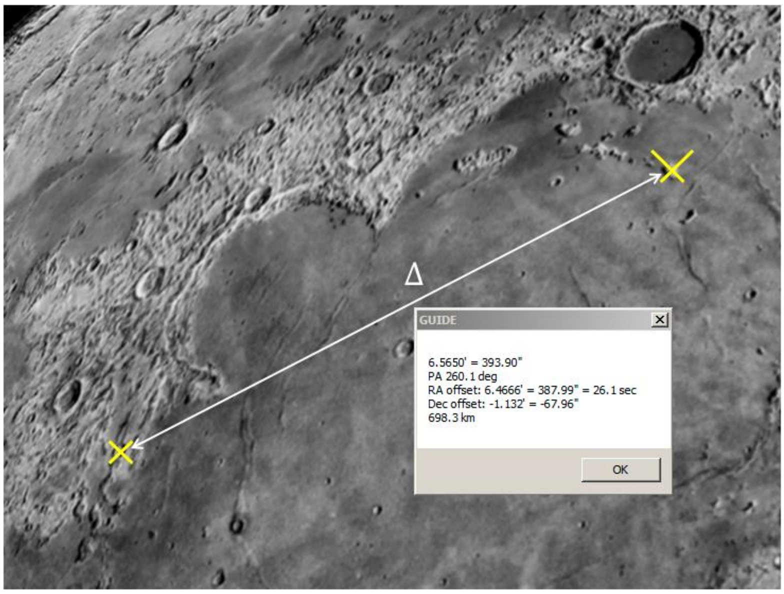
This method starts from an exposure of some area on the Moon, using the complete optical system. Two well-defined landmarks are identified in this image, e.g. small and bright craterlets on the mare floor. In some image processing program, e.g. Photoshop, rectangular coordinates (x_1, y_1) und (x_2, y_2) of both landmarks are measured. Using Pythagoras' theorem their distance is computed as

$$d_A = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \qquad (43)$$

In the same image processing program one measures the width b of the camera's field of view (in the same measurement unit as the (x,y) coordinates).



In a planetarium program (e.g. Guide 9.0) the Moon's appearance is simulated for the time when the exposure was taken. Here the angular distance Δ of the two landmarks is measured. In the example below the distance is found to be $\Delta = 393.90$ arc seconds.



With the known camera parameters (see Appendix A: Parameters at the Configuration Dialog)

P_h: „Pixel count horizontal" and

s_p: „Pixel size" (pitch)

the sought focal length f_S of the overall system is computed as:

$$f_S = \frac{P_h \, s_p \, d_A}{b \, \sin\Delta} \tag{44}$$

Please note that published values for s_p are notoriously unreliable. As explained in „Appendix A: Parameters at the Configuration Dialog", this parameter defines the horizontal or vertical distance of two adjacent sensor pixels, and not the size of the light-sensitive cell itself.

If no reliable value for s_p is available, it can be found experimentally if a telescope with well-known focal length f_S is available. For this purpose a refractor or Newtonian reflector is to be preferred. (Using a Schmidt-Cassegrain telescope is not recommended because its effective focal length depends on the location of the sensor in the light path behind the primary mirror cell.) As explained above, from an image taken with such a telescope s_p is derived as:

$$s_p = \frac{f_S \, b \sin\Delta}{P_h \, d_A} \tag{44a}$$

Obviously it is impossible to measure both the focal length and pixel distance at the same time. Fortunately, for the purpose of MoonPanoramaMaker the absolute values of both parameters do not matter, as long as they are consistent according to equation 44. A wrong value for s_p leads to a wrong value for f_S. If used as input for MoonPanoramaMaker, however, both errors cancel out each other.

Relative Method:

There is an easier way if the primary focal length f_0 of the telescope (i.e. without projection system) is known precisely enough. In this case two exposures are taken, one at the prime focus, the other one with the projection system installed.

As described above for the full optical system, the linear distance of the two landmarks is measured in the prime focus exposure as well. The resulting distance is denoted d_A^0.

With these measurements, the focal length f_S of the overall system is computed as:

$$f_S = f_0 \frac{d_A}{d_A^0} \tag{45}$$