Occultation Recording System Configuration

The recording system is composed of three major elements: a control computer running oaCapture, a timing reference module (PTR), and an imaging camera. During a capture sequence, the timing module is configured through oaCapture to generate trigger pulses at precise intervals while the camera is configured to capture an exposure of defined duration in response to each trigger pulse. The PTR creates a timestamp for each trigger pulse. Timestamp and image data are merged by oaCapture into a single FITS file for each exposure.

A calibration LED may be connected to the PTR and enabled through controls within oaCapture. When enabled, the LED is illuminated within a few microseconds of the beginning of each GPS second, for a duration of (nominally) 20 ms. Calibration flashes recorded before and after an event provide an independent timing reference in an image sequence.

The PTR incorporates a GPS receiver module as a primary source of geolocation and timing data. The GPS module includes an integrated patch antenna. A connector for an active external GPS antenna is also provided by the PTR. While not normally required, an external antenna may be useful in metallic domes or situations where the PTR cannot be positioned on a horizontal surface with a clear view of the sky. The GPS module automatically switches to the external antenna if connected.

Interconnections between the components of the recording system are illustrated in the diagram below. All connectors are unique and polarized, so it is not possible to attach cables incorrectly.

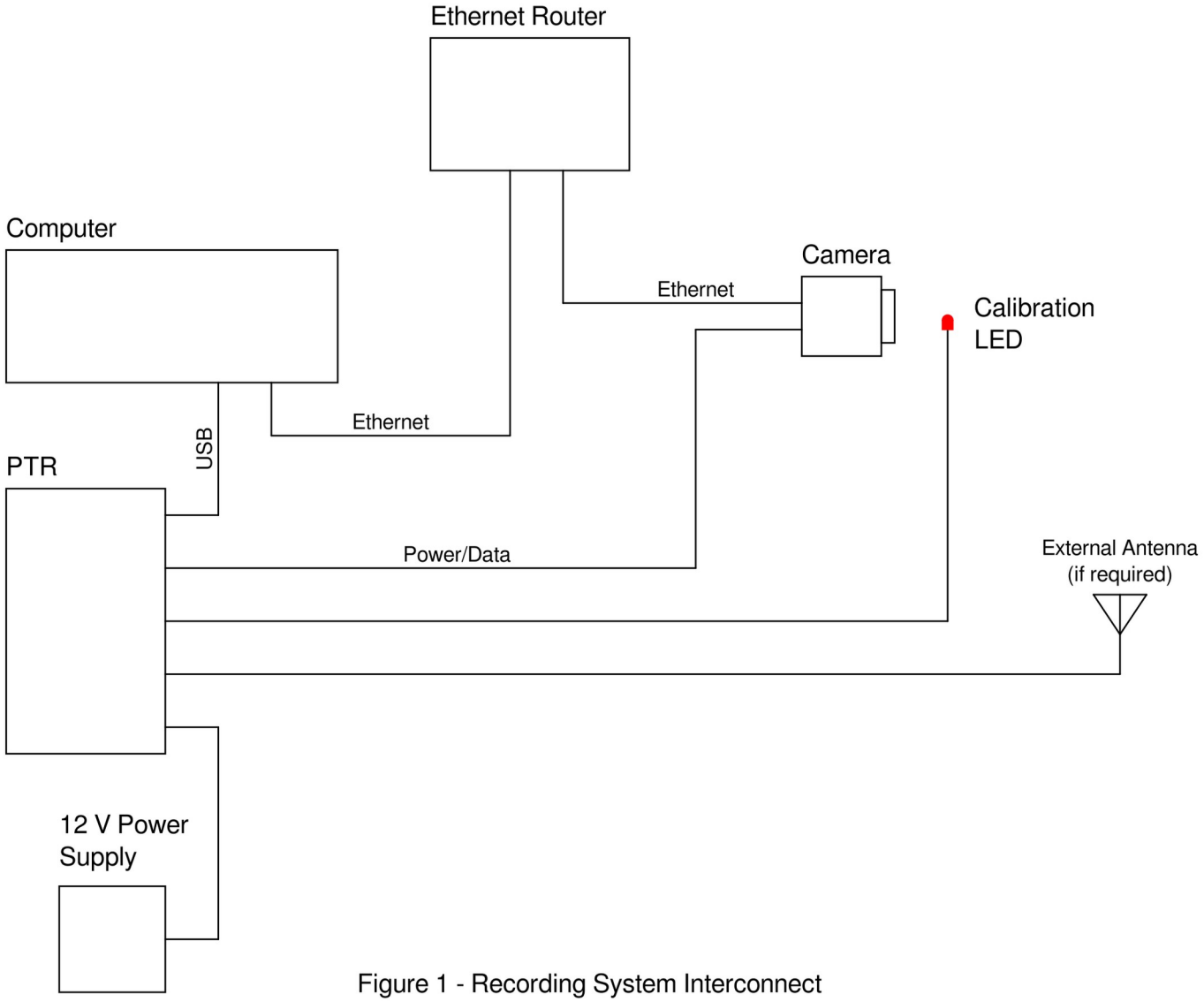


Figure 1 - Recording System Interconnect

External Environment

It is expected that the evaluation system will reside on a 1 Gb/s network with a router configured to provide IP addresses in response to DHCP requests. A separate computer capable of running a VNC viewer which supports Tight encoding is required to remotely access the desktop session for user *tblank*.

Note: Because of the VNC server configuration running on the computer by default, it is not possible to log in from the laptop keyboard/mouse interface except as user *console*. The VNC server for user *tblank* may be disabled or enabled as shown below if necessary.

115 VAC power (2 A max) is required for the PTR and computer power supplies.

VNC Server Controls

By default, a VNC server is enabled for user *tblank*. If necessary, this server may be temporarily or permanently disabled, or restarted if stopped as follows:

Stop VNC server until reboot or manually re-enabled:

1. Terminate VNC session for user *tblank* if running.
2. Log in as user *console* using the laptop keyboard, mouse and display.
3. Open MATE Terminal session (double-click icon on desktop).
4. Execute the following from the command prompt:

```
console@harrison:~$ sudo systemctl stop vncserver-tblank@9.service
```

The password for user *console* will be requested before the command can complete.

Manually restart VNC server:

Reboot, or follow sequence of instructions below.

1. Log in as user *console* using the laptop keyboard, mouse and display.
2. Open MATE Terminal session (double-click icon on desktop).
3. Execute the following from the command prompt:

```
console@harrison:~$ sudo systemctl start vncserver-tblank@9.service
```

The password for user *console* will be requested before the command can complete.

Disable VNC server (will not restart following boot):

Stop VNC server as described above.

From command prompt (as user *console*), execute the following command:

```
console@harrison:~$ sudo systemctl disable vncserver-tblank@9.service
```

The password for user *console* will be requested before the command can complete.

Re-enable VNC server:

From command prompt (as user *console*), execute the following commands:

```
console@harrison:~$ sudo systemctl enable vncserver-tblank@9.service
console@harrison:~$ sudo systemctl start vncserver-tblank@9.service
```

The password for user *console* will be requested before each command can complete.

Image Sequence Capture

oaCapture can be configured to collect an arbitrary number of images from the camera, storing each image along with timing and status information from the PTR in a FITS file. Prior to commencement of an image sequence, a number of parameters must be configured, e.g., integration (exposure) time, camera gain, interval between successive images, etc.. Most parameters are stored in a configuration file, so it is usually not necessary to change more than a few settings from one oaCapture session to the next. In the event that the configuration file is corrupted or an error occurs during a capture sequence, it is sometimes necessary to assign a full set of configuration parameters. The steps required to complete that task are provided in Appendix B.

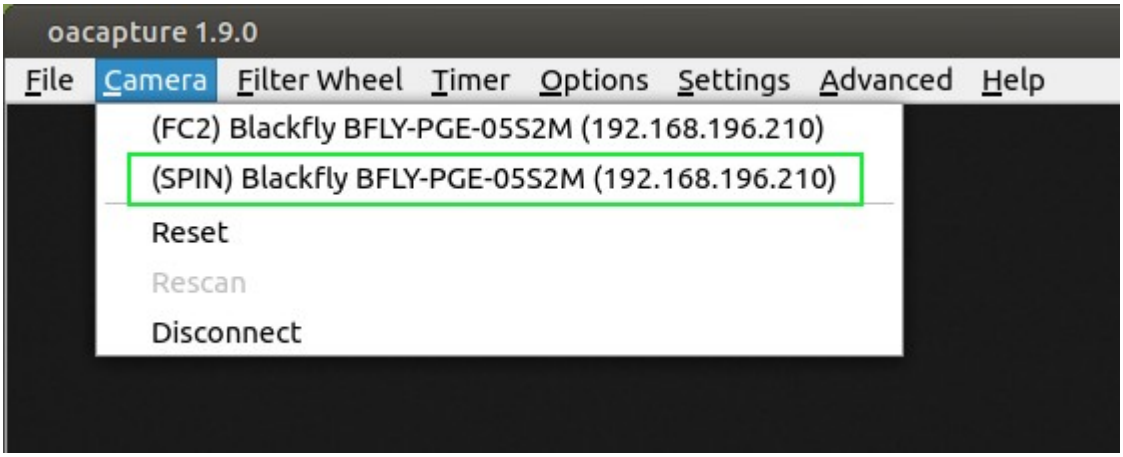
In the sequence described below, it is assumed that the camera and PTR have been configured for overlapped exposure trigger-mode operation, and that image file format and filename variables have been properly assigned.

1. Connect the recording system components as shown in Figure 1.

2. Apply power to PTR. Red LED visible through opening in cover will blink once per second when GPS receiver has obtained time and position fix, typically within one minute of power-on. If the LED does not start blinking within five minutes, the external antenna may be required.

3. Launch the capture program. If a PTR module is connected to the computer, oaCapture automatically attempts to reset the device during iniitialization.This operation will stall until the GPS has acquired lock, so oaCapture should not be started before the LED on the PTR starts blinking.

4. Click on Camera menu to display list of connected cameras. The occultation camera should appear twice, as shown below.

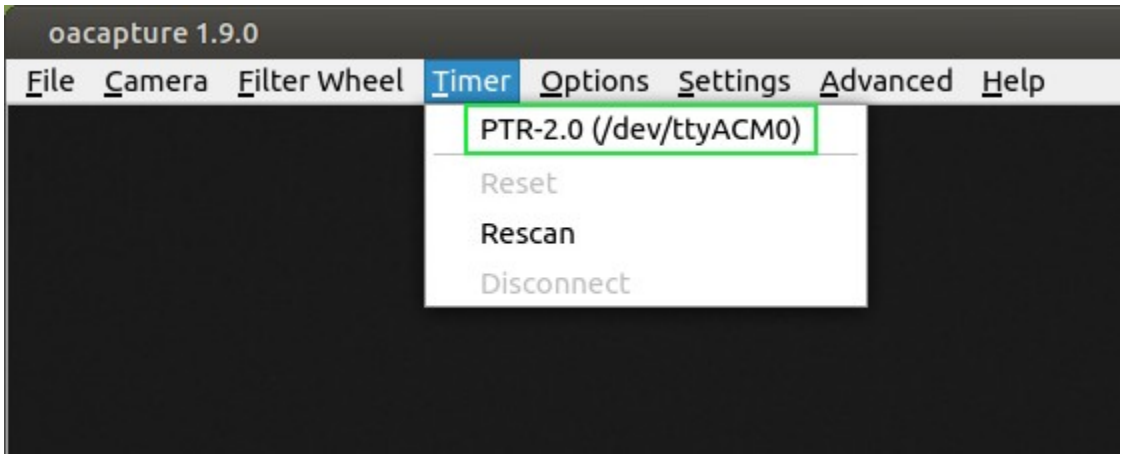


Notes:
1. Camera model and IP address will differ from those pictured.
2. Other cameras may appear in the list as well, if present. These may be ignored.

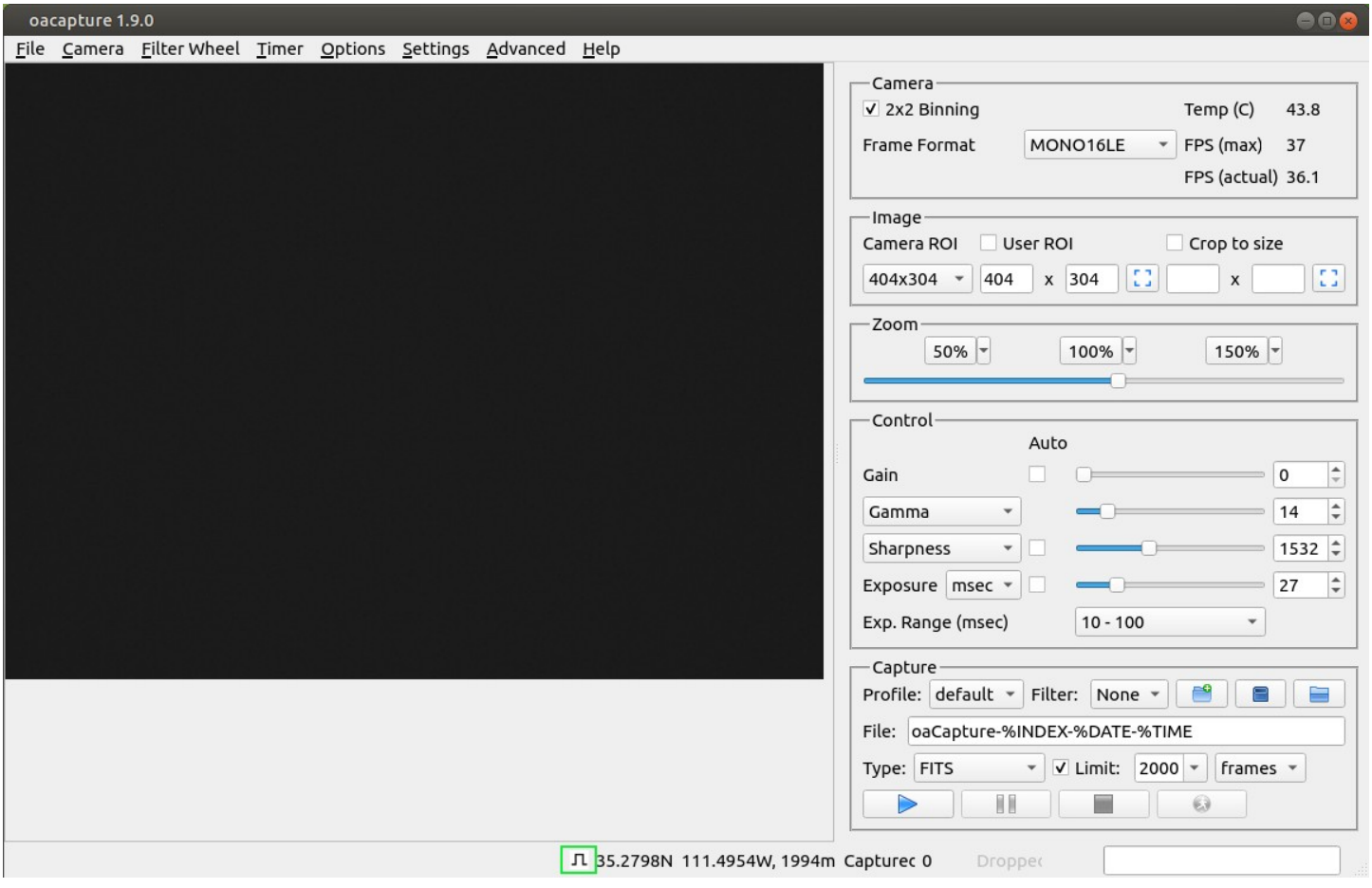
5. Click on the SPIN camera entry in the selection menu (highlighted in green in the example above).

Images from the camera will be displayed in the oaCapture window if connection succeeds.

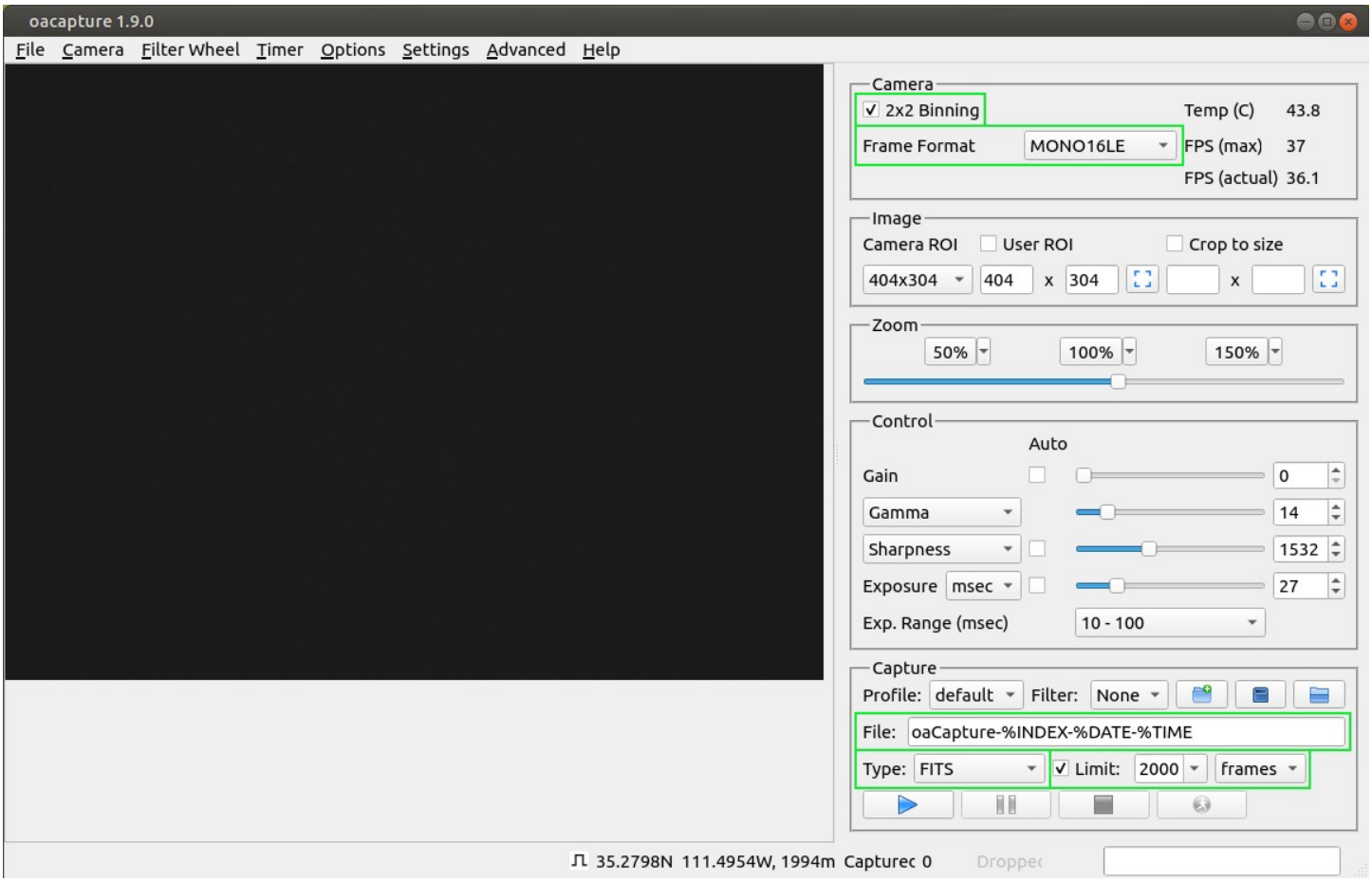
6. Click on the Timer menu to display list of connected timers. The PTR should appear in the list, as highlighted in the illustration below.



7. Click on the PTR selection in the list. A pulse waveform icon (highlighted below) will appear at the bottom of the window to confirm that communication between oaCapture and the PTR has been established. Geographic coordinates from the PTR are normally displayed along with the icon, however under some circumstances they are not. So long as the icon is displayed, the system will function correctly.



9. Inspect the fields highlighted below to confirm that all are correctly configured as shown. The frame count limit (2000 in the example) isn't critical at this time, however a frame count limit must be enabled as indicated by the adjacent checkmark.



Note: If the Gain slider is positioned near mid-scale as shown and displayed image is very small in the upper left corner of the display, misconfiguration of the camera is indicated and capture attempts will likely fail. The simplest remedy is to uncheck the 2x2 Binning control. This will generally cause the oaCapture window to close. Re-starting the program and repeating Steps 3 - 9 should result in images from the camera beingdisplayed correctly.

10. Click on the folder icon to the right of the Filter selector, then navigate to a directory where FITS files will be stored during the capture sequence.

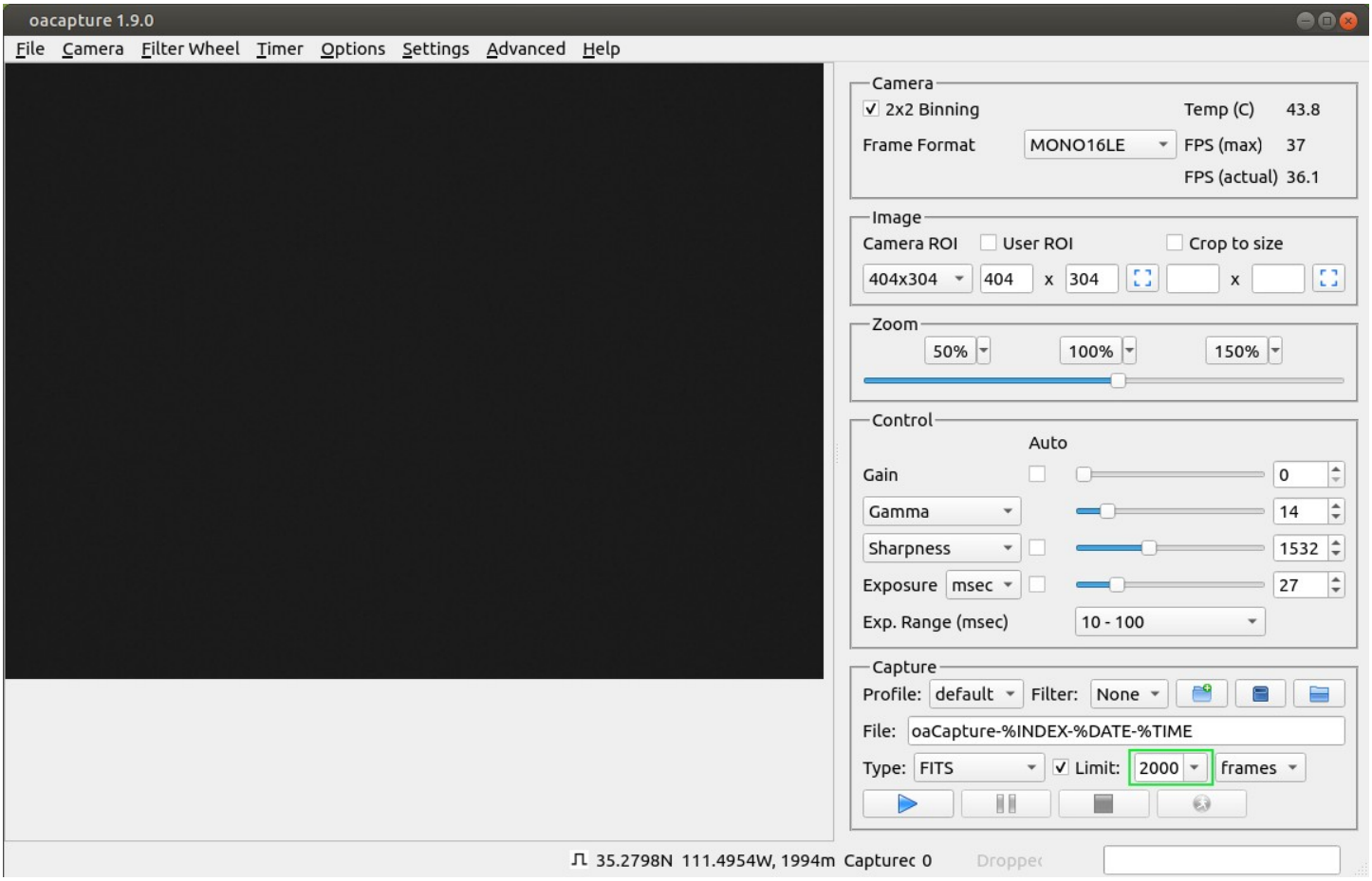
11. At this point, preliminary preparations for an observation are complete and an exposure time which provides good balance between signal level and time resolution may be determined. The Gain setting also affects this balance. As a general rule, a gain value of 250 works well. Selecting an exposure time which shows the target star faintly but steadily in the display should yield good SNR. Longer exposure times yield higher signal to noise ratios at the expense of time resolution, but depending upon predicted duration of the event and seeing conditions, may be a good choice.

12. After assigning an appropriate exposure time, it is necessary to specify a corresponding trigger interval. This setting controls the time between successive trigger pulses from the PTR, each of which initiates exposure of a new image. Due to processing bandwidth limitations imposed by the computer provided with the evaluation system, minimum trigger interval is 30 ms, and the trigger interval must exceed exposure time by 2 ms. Trigger interval may be specified in the Settings -> Timer dialog, however it may be more convenient to open the Occultations Capture Control Dialog via Options -> Occultations Mode.

13. Determine the number of frames to be captured. This value may be calculated by dividing the desired duration of the recording by the frame interval, with both values expressed in seconds.

    Example:
    Expsosure time: 48 ms
    Frame interval : 50 ms (exposure time + 2 ms) = 0.050 s
    Recording duration: 5 min = 300 s
    Frame count = 300 / 0.050 = 6000

14. Enter the frame count value in the Limit box highlighted below. Confirm that the Limit selection box is checked, and that the Limit unit is Frames.



15. At the designated time prior to the event, click the blue Record button in the Capture section to initiate the capture sequence. Triggered captures always commence at the beginning of a GPS second, so there may be a noticeable delay before the capture count shown in the status bar near the bottom of the window begins to increase.

16. For post-event timing quality assurance, calibration flashes are recommended both before and after the event. The calibration LED can be placed in the optical path and enabled through either the timer configuration window (Settings -> Timer -> Enable LED) or the Occultations Capture Control Dialog (Options -> Occultations Mode). The calibration LED will illuminate for 20 ms at the beginning of each GPS second when enabled. Because the image display in the oaCapture window does not always update with each frame received from the camera, only some flashes may be visible in real time.

    Hint: If screen area is limited and it is not possible to position the Occultations Capture Control Dialog separately on the desktop, (Right mouse button -> Always on top) will prevent the dialog from being covered by other windows.

17. After recording a few flashes at the start of a capture sequence, disable the calibration LED. No further user interaction is required until near the end of the sequence, when the LED may be re-enabled to record a second set of flashes.

18. The capture sequence terminates when the frame count reaches the frame limit.

19. File -> Save Config will store the current settings which automatically be loaded the next time oaCapture started. Settings which must be configured each time the program is started are camera and timer (PTR) selection.

20. Before exiting oaCapture it is recommended that the camera and timer are disconnected through the Camera and Timer menus.

Image sequence capture is complete when the frame limit is reached. A set of sequentially numbered FITS files will be present in the directory selected in Step 10. These files may be analyzed directly using PyMovie or Tangra.

To ensure accuracy of timing data, several mechanisms have been incorporated into the system to provide independent metrics. These are described below.

- Frame Index
  If the File: field is configured as described in Step 9, FITS filenames produced during a capture sequence are formatted as follows

  oaCapture-*nnnnnn*-*YYYYMMDD*-*hhmmss*.fits

  where *nnnnnn* is an incrementing file index count and *YYYYMMDD*-*hhmmss* is the filename creation date and time. The file index count may be reset to zero by clicking the Reset Capture Counter button in the Occultations Capture Controls dialog or via Settings -> Capture -> Reset capture counter.

- Camera Image Count
  When connected, the camera is configured to generate a sequentially increasing image count value included in the metadata tranferred along with image data to oaCapture. This count value is stored as a FRAMESEQ record in each FITS header.

- Timer Status - Sequence Count
  The timer module includes a sequentially increasing index value with each timestamp transferred to oaCapture across the USB link. These values are stored as TSSEQ records in each FITS header.

- Timer Status - GPS Lock
  Under normal conditions, the GPS will maintain a fix on the satellite constellation continuously once locked. When locked, the receiver produces an electrical pulse (1 PPS output) at the beginning of each GPS second. The timer resynchronizes its internal timebase each time the hardware pulse is detected. If the pulse is not detected, the timer continues to operate indefinitely using only its internal timebase and a correction factor determined between successive 1 PPS events. A two-character status code is provided with each timestamp to indicate GPS lock status and any correction which may have been necessary if a loss-of-lock condition occurs during a capture sequence.

  Timer lock status is stored as a TSQUAL record in each FITS header.

- Computer Time
  File creation time is stored as a DATE record in each fits header. This value represents the time maintained by the computer's internal clock, and will lag the time of the start of exposure by the exposure time plus some overhead which depends upon processing bandwidth.

- GPS Time
  Timestamp data from the timer module is stored as a DATE-OBS record in each FITS header. This value represents GPS time that the trigger pulse to the camera is generated.

- Calibration Flash Images
  If the calibration LED is placed in the light path and enabled during a capture sequence as recommended in Step 16, images captured within 20 ms of the start of GPS seconds will show visible indication of each flash event.

- Summary Data File
  At the completion of a capture sequence, oaCapture produces a flat text file (oaCapture-nnnnnn-YYYYMMDD-hhmmss.txt, where frame index and date/time correspond to the values in the last capture FITS file) which summarises a number of attributes associated with the sequence.

FITS Header Inspection

Records stored in FITS headers may be viewed using any number of tools. Two of note are AstroImageJ (accessible via the AIJ desktop icon) or the WCSTools *imhead* program in conjunction with a text paging program, launched from a command prompt. The latter may be more convenient when inspecting multiple file headers.

AstroImageJ documentation is available from the website below:

https://www.astro.louisville.edu/software/astroimagej/guide/AstroImageJ_User_Guide.pdf

A particularly useful function in AstroImageJ is the ability to load a sequence of images which can be stepped through using the left and right arrow keys. The FITS header for the displayed image is displayed when the "display fits header" button above the image display is clicked.

To display FITS header data from a command prompt, the following sequence may be performed:

1. Double click the MATE Terminal icon on the desktop to open a command window.
2. Navigate to the FITS file directory (folder):

   `$ cd Data/oaCapture/`*`YYYY-MM-DD`*

   where YYYY-MM-DD is the UT date of the event

3. Extract header data from each file, using a paging program (/usr/bin/less) to enable display positioning within the terminal window:

   `$ imhead *.fits | less`

   Header information from each FITS file is extracted and displayed in order. The following character sequences are useful for navigating through the displayed data:

   <space> or Page Down
   Scroll display one page (screen) at a time. If the space bar is used, space character will not be displayed. The window may be resized to select the number of lines displayed. If the last displayed line above the ':' prompt is a FITS END record, the display can be advanced by one file header each time a subsequenct <space> or Page Down is entered.

   Page Up
   Scroll display up one page.

   /^oaCapture<enter>
   Search for the next instance of the string "oaCapture" starting at the beginning of a line. Because of the way filenames are displayed, this will scroll to the top of successive FITS file headers.

   n
   Repeat the last specified search. The n is not displayed. If entered following the search specification shown above, header data for successive FITS files will be displayed in order.

   1G
   Return to the top of the first FITS file header (or any arbitrary line number in the file). The line number and G are not displayed.

   G
   Jump to the end of the last FITS file header. The G is not displayed.

   Ctrl-G
   Display range of displayed line and character numbers along with line and character number totals.

   q
   Exit to command prompt.

Timing Quality Assurance

The process described below is optional, but recommeded to ensure that timing value reported for an event are as accurate as the system allows.

1. Dropped Frame Detection
   Note the following values associated with the first FITS file in the capture sequence:
   1) Filename Index Value
   2) FRAMESEQ Value
   3) TSSEQ Value
   Add the sequence image count minus 1 to each value listed above, and compare to the numbers for the last frame in the sequence.

2. Capture Summary
   Inspect the summary file to determine if any gross errors are reported. Fields of interest are first, middle and last frame times, frames captured and duration. Note that first, middle and last frame times correspond to file creation values as opposed to timestamps.

   Note: Exposure times in the summary file are erroneously reported in microseconds, despite the units being shown as milliseconds.

3. GPS Lock Status
   The Timer result code reported in the last line of the summary file provides a summary of all individual timer status codes provided in the individual timestamps. The code C000 indicates that no condition which would adversely affect timing accuracy was detected during the capture sequence. Other codes are described in Appendix A.

4. Capture Sequence Duration
   The expected DATE-OBS value for any image in the sequence may be calculated based upon the DATE-OBS value of the first frame plus a multiple of the trigger interval value specified in Step 12. Confirm that the last DATE-OBS value in the sequence is correct by comparing the expected versus reported DATE-OBS value in the FITS header for the last image in the sequence.

5. DATE-OBS vs. DATE records
   As noted above, file creation time is stored in each FITS header as a DATE record, and should lag the DATE-OBS value by a small interval. If a variance of more than 1 second is noted at any point within the capture sequence, other checks may be required to determine accurate timing information.

6. Calibration Flash Inspection
   If calibration flashes were recorded, locate the frames showing flash effects and note the DATE-OBS values. Flashes should be evident only in images caputured between 0 and 20 ms of the start of a GPS second.

Appendix A - Timer Status

The timer module (PTR) generates a two-character status code which is included in each timestamp. This code is subsequently reported in the FITS file oaCapture produces for each image as a TSQUAL record.

Under normal conditions, the GPS receiver in the timer module will acquire a sufficient number of signals from the satellite constellation to synchronize its internal clock and determine a position fix well before an image capture sequence is initiated, and maintain the fix throughout the duration of the sequence. So long as the receiver has a valid time/position fix, it will produce an electrical pulse to signal the beginning of each GPS second, with a nominal precision of +/-10 ns. The timer module uses this pulse to resynchronize its internal timebase. The interval between successive pulses is also measured to determine a correction factor for the oscillator in the timer module used to maintain the internal timebase. The correction factor is applied once each second to compensate for oscillator frequency errors initial calibration offset, aging or temperature effects.

Depending upon antenna placement, obstructions, changing satellite orientations, etc., it is possible that the GPS could lose lock on the constellation for an indefinite interval during a capture sequence. Should this occur, the timer will report loss-of-lock status then continue to function using only the internal timebase as a reference. Because of the correction factor, gross oscillator frequency errors will be compensated to minimize drift between the internal timebase and GPS time. Over small ranges of temperature, the internal timebase will typically remain within one time step of GPS time for more than ten minutes.

If GPS lock has been lost then regained, lock-acquired status is reported and the internal timebase is compared to GPS time. If adjustment of the internal timebase is required, a separate status code is reported. The duration over which lock was lost and magnitude of the adjustment required to bring the internal timebase back into synchronization with GPS time may be used to calculate an approximate correction to be applied to times reported during the outage.

Date and time information produced once per second by the GPS receiver is compared to the corresponding values maintained by the internal timebase.

Timer status codes are summarized in the table below.

Status Code		Description
TN	Timing Nominal	GPS has valid lock, internal timebase synchronized to GPS time
LL	Loss-of-Lock	1 PPS signal from GPS receiver not detected
IC	Internal Clock	Internal timebase operating from oscillator with correction factor
LA	Lock Acquired	1 PPS signal from GPS receiver detected
TA	Timer Adjust	Timebase adjustment of <1 ms applied following reacquisition of GPS lock
TR	Timer Resync	Gross timebase adjustment (≥ 1 ms) applied

At the conclusion of a triggered capture sequence, the timer produces a five-character string which oaCapture includes as the *Timer result code* in its summary text file. A value of C0000 indicates that no timing anomalies were encountered during the capture sequence and DATE-OBS values in each FITS file are correct to within +/-50 µs. If any other code is reported, contact the author for further guidance.

Appendix B - Camera Configuration

Future documentation.