Observatory Control and Astronomical Analysis System

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Overview

OCAAS is a complete software system for the computerized control of an astronomical facility, including the telescope, dome, weather instrumentation and camera. Control can be real-time and interactive or pre-scheduled batch and unattended. The former is intended for instructional situations or investigation of very current phenomena. The latter is specifically designed for remote Internet operation where autonomous operation and very high throughput are critical. Tools are included for off-line image display and scientific analysis including photometry, astrometry and automated investigation of variable stars, asteroids, supernovae and other time-varying phenomena.

OCAAS software is more than 180,000 lines of ANSI C. The Graphical User Interface uses X Windows and Motif 1.2. The system is written to be very portable to any UNIX environment, but has been tested and used most extensively under the Linux operating system on IBM PC hardware. Motion control is currently supported using the Oregon Micro Systems PC-39 intelligent stepping motor ISA-bus controller card. Virtually any brand of stepping motors, amplifiers and incremental shaft encoders should work with this controller. AC motor controls and the home and limit switches are interfaced with 5V TTL logical levels. All site-specific mechanical advantages and soft limits are captured in simple text configuration files.

History

The OCAAS has been in use at the Automated Telescope Facility of the University of Iowa since 1994. It will be an integral part of the Iowa Robotic Observatory to be installed in October 1997 near Sonoita, Arizona. OCAAS is included with all telescope systems manufactured by Torus Precision Optics. OCAAS is now being made available separately directly by the author to OEMs or to end-users for retrofitting existing facilities.

Disclaimers

Completing a fully functional robotic or remote observatory involves much more than OCAAS software. For a new facility, there are infrastructure issues such as an observatory, a support warm room, roads, communications, power and long term maintenance. The telescope itself must be fitted with several motors, encoders and switches to very high precision. Existing telescopes which were not designed for computer control will certainly require significant custom machined mounting equipment.

OCAAS is itself a sophisticated mature system. Some readers of this document will have the resources and expertise to perform all of the above functions and for them installing OCAAS is likely a relatively simple step in the overall scheme of things. For many, however, satisfaction is much more likely if a complete plan is prepared with the aid of an experienced team. Full observatory planning services on a consulting basis are available from the author and from Torus Precision Optics.

The acquisition and tracking accuracies achievable by the OCAAS depend directly on the quality of the mount hardware, and the accuracy of the position, geographic and time information provided to the software. For this reason, no claims as to accuracies can be made in this general description. The underlying algorithms used within the OCAAS, however, adhere to established contemporary astronomical practice and will utilize the underlying hardware to the full extend to which it is capable.

Hardware

OCAAS supports stepper motor control of the telescope mount, including image rotator if necessary, as well as focus and filter wheel. Each axis requires one stepper motor, one precision magnetic home switch and one mechanical limit switch at each extreme position of travel. In addition, the two main mount axes each require one incremental shaft encoder. Dome or roof controls require reversible AC motors, encoders and home and limit switches.

Follows is a more detailed discussion of each OCAAS hardware subsystem. See the next section for more information on the software capabilities.

Mount

OCAAS supports both equatorial and alt-az mounts. An image rotator axis is fully supported for alt-az mounts, or for any mount for which it is not possible, desirable or convenient to establish an accurate polar alignment.

Mount orientation is established in two phases. Phase one is called *Basic Calibration.* This is a simple procedure which uses any three known stars and takes approximately 15 minutes to perform. This procedure assumes an ideal mount and may be satisfactory for many situations, depending on the mount and observing requirements. Phase two is called *Fine Calibration*. This procedure takes images in a fine mesh over the entire visible hemisphere and maps out a variety of conditions including flexure and eccentric or irregular drive trains. This procedure takes several hours to run, although it operates unattended once initiated by a single menu option.

Focus

Focusing can be performed manually if desired, or automatically. Automatic focusing is initiated with a single menu command and will find the optimal focus position within minutes. The focus thus found and the current ambient temperature are logged. If focus is logged for at least two different temperatures, the OCAAS will adjust focus automatically throughout the night to compensate for temperature effects.

Filter wheel

Filter wheels with any number of filter positions at evenly spaced locations are supported. Each position can be assigned a name and can be commanded into position as desired. One filter position can be designated as a diagonal mirror for feeding a fiber-fed spectrometer and OCAAS will switch to an alternate camera interface whenever this "filter" is in position.

Dome

Traditional rotating domes with slits are supported as well as roll-off roofs observatories. Rotating domes require an AC reversible motor, incremental encoder, one home and two limit switches. Dome slits are to be powered by an AC reversible motor which gets power at a fixed azimuth via wiper contacts. Slit commands are configured to time-out and need no home or limit switches. Roll-off roofs require an AC reversible motor and limit switches at each extreme of travel.

CCD Camera

CCD cameras supported to date include the SpectaSource HPC-1, all models of AP and AM cameras from Apogee Instruments, and the CCD1600 camera from Integrated Scientific Imaging. Drivers for other cameras can be written if they include detailed hardware documentation.

Weather Instrumentation

The OCAAS currently supports the Peet Brothers' Ultimeter 2000 weather station for continuously monitoring, logging and reacting to current local meteorological data.

Real-time Interactive Operation

The OCAAS system allows one to operate all equipment via simple yet powerful Graphical User Interface application programs. These applications interact directly with the hardware yet are constrained to only offer the user those capabilities which can actually be accomplished in a safe and timely manner within the capabilities of the installation. Some of these programs also provide significant functionality that is useful even when the observatory is not available, including ephemeris computations for observation planning and image display and analysis.

xtelescope

The OCAAS offers direct control of all observatory hardware from a simple menu-driven graphical program named *xtelescope*. The following basic functions can be activated essentially from a single menu selection:

- Reinitialize the *Software, Home* or *Limit Switch* information
- Slew telescope to a user-defined H*ome* position
- Slew the telescope to a user-defined S*ervice* position
- Slew the telescope to a specified Altitude/Azimuth or Hour Angle/Declination
- Acquire and track any object selected from several large standard catalogs or to a specified Right Ascension/Declination
- Command the dome to rotate to a specified azimuth
- Command the dome slit or a roll-off roof to open or close
- Command a specified focus change
- Command a specified filter wheel position, by name
- Perform the *Automatic Focus* procedure
- Perform the *Basic Calibration* procedure
- Commence Batch mode operation
- Enable real-time telescope control using XEphem, a graphical sky view/planetarium program.

XEphem

XEphem is a general purpose interactive astronomical ephemeris program for X Windows systems. It is used within the OCAAS context to display the current position of the telescope in real-time on a sky map, and may command the telescope to acquire an object by simply pointing at the object on a sky map and making a mouse selection.

XEphem has many useful features beyond real-time telescope control. XEphem ...

- computes heliocentric, geocentric and topocentric information for all objects;
- has built-in support for all planets; the moons of Jupiter, Saturn and Earth; central meridian longitude of Mars and Jupiter; Saturn's rings; and Jupiter's Great Red Spot.
- supports user-defined bodies in heliocentric or Earth orbit, including satellites;
- comes with sample databases of thousands of objects;
- displays data in configurable tabular formats and in several interactive detailed graphical views including Sky View, Earth, Moon, Mars, Jupiter, Saturn and Solar System.
- supports 3-D stereo views of the Solar System particularly well suited for investigating comet trajectories;
- displays close-up views of Saturn and Jupiter moon systems which include correct sky backgrounds;
- can quickly find all close pairs of objects in the sky;
- can plot and list all data fields to disk files;
- can solve for arbitrary circumstances by solving user-written functions of any data fields;
- can serve as the control point for robot telescopes in real-time via simple ASCII command fifos.
- can connect to auxiliary database servers via fifos;
- supports the Hubble Guide Star Catalog on CD-ROM or via a network server.
- supports the PPM catalog from a unique compressed disk file format.
- displays FITS files and Digitized Sky Survey images with graphical overlays
- can compute information on demand or time can be set to increment automatically. In this way a time-series of computations and movies can be generated or the displays left to update unattended.

Quantitative information available about each object includes:

- RA and Dec,
- local azimuth and altitude,
- true heliocentric coordinates,
- distance from sun and earth,
- light travel times,
- galactic coordinates,
- solar elongation,
- angular size,
- visual magnitude,
- illumination percentage,
- local rise and set times and azimuths,

- length of time up,
- constellation,
- angular separations between all combinations of objects.

Local observing circumstance information includes:

- UTC and local date and time,
- local sidereal time,
- times of astronomical twilight and length of night,
- local temperature and pressure (for refraction),
- elevation above sea level (for parallax),
- a monthly calendar.

RA/Dec calculations may be topocentric or geocentric, and apparent or astrometric. When the Epoch is set to a fixed date the values are astrometric, that is, corrected only for precession and light travel time. When the Epoch is set for EOD (Epoch of Date) the values are apparent and are also corrected for nutation, aberration and deflection. Topocentric values are also corrected for parallax and augmentation. All Alt/Az values are, of course, always topocentric and are corrected for refraction.

Plot and listing files of selected field values may be generated as the program runs. The plot files are floating point text values intended for easy export to other plotting programs such as gnuplot. XEphem includes simple quick-look facilities to view plot files. The listing files are tables formatted for more general human reading.

XEphem can read databases of objects. The objects may be fixed; specified via heliocentric elliptical, hyperbolic or parabolic orbital elements to accommodate solar system objects such as asteroids or comets; or specified via geocentric elliptical orbital elements to accommodate Earth satellites. These are then available as candidate values for the user defined objects and all of them can be displayed in the sky map subject to type and magnitude filters. The format of the database file is described in the Help for the DB menu.

Camera

The CCD camera has its own graphical interface tool which is independent of the particular brand of camera connected to the system. This tool, named *camera,* allows basic camera operations to be performed including the acquisition and saving of new images in FITS file format. The same tool includes general image display and analysis functions which can be performed on any images in FITS format which contain the appropriate header entries, whether or not they were format which contain the appropriate header entries, whether or not they were taken by the OCAAS system. Follows is a list of the operations available:

Direct camera control:

- Setup camera exposure parameters, including duration, subimage size and location and whether the shutter will be opened.
- Set the desired cooler target temperature, and inquire as to current temperature and cooler status.
- Take one image, or take images continuously until interrupted, using the established exposure parameters.
- Acquire bias, thermal and flat reference images, including multiple images which are averaged for improved accuracy.

Image display and analysis functions:

- Set overall image display magnification, from 1/4X to 4X
- Pan image if larger than current window size
- Display cursor [x,y] location, and [RA, Dec] position if suitable WCS fields are in the FITS header
- Perform relative photometric comparisons of two or more stars in one image
- Compute Gaussian centroidal [x,y] and [RA, Dec} position of any star
- Perform absolute photometric computations on any star in any image (if standard Landolt fields are available)
- Connect a magnifying glass to the cursor, and control the glass size and power
- Display statistics of pixels under the glass
- Display graphs of horizontal and vertical cross-sections centered on the glass, including best-fit Gaussian overlays
- Optionally force glass to snap its center to the brightest pixel within its range
- Display the image inverted or using several standard pseudo-color maps
- Interactively establish an Area-of-Interest
- Display a histogram of the pixel values within the AOI
- Use the histogram to set display brightness and contrast
- Display statistics of pixels within the AOI, or crop image to AOI
- Draw a cross-section graph connecting any two points, including delta x/y and RA/Dec
- Compute angular velocity of any position appearing on two images taken at different epochs
- Blink any two images, based on registering their largest common area
- Blink an image with a catalog reference image, based on having the same OBJECT FITS header name
- Use the Hubble GSC to perform a pattern match and compute new WCS header fields for the image.

Batched Scheduled Operation

Much of the cost-effectiveness of automating an observatory comes from maximizing the number of images acquired in all available observing time without requiring operator attention during most of that time. This is achieved with the OCAAS by preparing typically many unrelated observing requests, combining them into an overall observing list, then letting the system process the list completely unattended. A typical scenario is to prepare and install a list in the afternoon and log off, then check the next morning to find all images are fully corrected and calibrated and waiting for analysis. The OCAAS even accepts lists spanning several days duration if this is desired.

The first step in preparing for scheduled operation is to create an *Observing Request* for each principle target. For administrative purposes, each observing request must be assigned to a user code. The request is in the form of a simple text file consisting of many *keyword=value* pairs in a free-form syntax. The form may be created by hand using any text editor, submitted remotely using a form in a Web browser (form included with OCAAS), or by using a simple dedicated GUI program (NYA). In a multi-user environment, each request might come from a different user. In a single-user environment, each request might be part of a larger investigation program. (These distinctions are for example only and are not captured explicitly by the OCAAS).

Follows is a list of the keywords accepted in the observing request file:

- TITLE: assign a title to this request
- OBSERVER: specify the name(s) of the person(s) involved in the investigation
- COMMENT: adds any text to the final images as FITS comment fields
- SOURCE, CATALOG: specify a target from a catalog
- RA, DEC, EPOCH: specify a target as an explicit celestial location
- RAOFFSET, DECOFFSET: specify offsets from target
- REPEAT: number of images in this set
- REPEATDELAY: elapsed time between each image in this set
- DURATION: exposure duration (may be different for each image in a set)
- FILTER: filter to be used (may be different for each image in a set)
- BINNING: CCD pixel binning in each dimension (may be different for each image in set)
- SUBIMAGE: CCD frame location and size (may be different for each image in set)
- UTDATE: date when this set is to be taken (optional)
- COMPRESS: H-transform scale factor to be applied (0 for none, 1 for maximum lossless, >1 lossy)
- CCDCALIB: whether to use cataloged bias and thermal frames, or take fresh
- HASTART: specify the Hour Angle when exposure should start (optional)
- LSTSTART: specify the Local Sidereal time when exposure should start (optional)

(optional)
- PRIORITY: priority to give this request when scheduling (optional)
- BLOCK, BLOCKREPEAT: allows multiple independent image sets to be repeated (optional)

Once one or hundreds of observing request files have been created, they are then sorted to prepare an *Observing List*. This list is an interleaved set of basic instructions to the observatory equipment which, when completed as a whole, accomplishes all of the images specified in the individual observing requests. The list is arranged to minimize the overhead involved in slewing and camera pixel digitization. Hence, the OCAAS might seem to be skipping images throughout the course of a night but is in fact keeping track of partial results as things progress.

telsched

Sorting the requests into the final list is performed by using the OCAAS tool known as *telsched*. This is an interactive GUI program which reads request files and sorts them to create a trial observing list. A graph of the entire night is presented to the operator which quickly shows the times at which images will be acquired. Requests which would violate local observing or equipment limits are never scheduled. If LST or HA starting times are not specified, objects are observed as near transit as possible. Objects which transit while the sun is down but before dusk or after dawn are given preference in the evening and morning hours, respectively. If conflicts occur, an attempt is made to resolve them in favor of requests which include fewer constraints (such as a large or unspecified LSTDELTA) or with higher PRIORITY. If conflicts remain they are marked in red on the graph. As a practical matter, one generally keeps loading more requests, watching the night utilization graph until conflicts occur, then makes judgments to selectively remove and replace individual requests as desired. Details of the requests can be edited if desired. Statistics as to total utilization, conflicts, and illegal requests are displayed.

Once a night's (or several night's) list has been designed, it is loaded as the current observing list, batch observing mode is enabled, and the operator is free to leave. If desired, the system status may be checked from a Web interface. This allows accessing the current state of all observatory equipment; statistics as to the number of images taken so far and the number of requests outstanding; information about the next action scheduled; and the most recent image acquired.

As OCAAS works through the observing list, it logs all activities to a common engineering log. It also logs those actions relevant to a given schedule request to a separate log for each request. In this way, when images are distributed the next day the user also gets a log which contains information relevant only to them.

OCAAS always monitors for meteorological limits, such as excessive dew point or wind speed or the detection of precipitation. If these occur, the dome shutter (or roof) is closed. If the conditions cease, full operation is resumed with the current list item. List items which occurred during the closed period are marked as failed. In this way, some schedules may not be completed but the night is utilized to the maximum extent possible. OCAAS automatically opens the shutter (or roof) shortly before the first list item is due to begin and closes it after the last item is finished or at dusk, whichever comes first. All images taken include all meteorological data in their FITS headers.

Batch mode can also be intentionally interrupted, This can be done manually by the operator by simply turning it off using the *xtelescope* GUI interface. Or software can be written to respond to priority requests from external sources such as from the Internet. The implementation of the batch mechanism makes it very easy to either temporarily replace one scheduled list with another, or suspend one list during manual control. This feature has been added to allow interruption of scheduled operation for rapid follow-up of Gamma ray alerts, but can be of course be used for any priority purpose.

All images taken in batch mode are automatically fully corrected using appropriate bias, thermal and flat frames. The exact names of the frames used are added to the FITS header of each image. Then the stellar objects are extracted from each image and compared to the Hubble Guide Star Catalog. A pattern matching procedure computes the best center location, image rotation and scale and adds standard World Coordinate System FITS header fields. Thus, when the user gets their images the next day, they are already fully processed and ready for analysis.

Remote Access

Since all of the OCAAS is written for UNIX in X Windows, any of the GUI tools may be operated remotely over an ether net connection, including of course the Internet, as easily as from the local control computer. This includes computers running other operating systems, such as VMS, Windows 95 and NT, so long as they are running an X server. Many X servers are available as supported commercial products and as free software. This means that all real-time controls, image display and analysis, and all batch setup, sorting, loading and monitoring may be performed remotely.

In addition, the OCAAS is designed in a modular fashion to support HTML forms interfaces, in conjunction with CGI perl scripts or small C programs, to offer a variety of custom capabilities to users with a Web browser. One example built for the University of Iowa offers a convenient way to create, check and submit observing requests. We have implemented several Web pages to display current system status, tabulate progress statistics in the current observing list, and display the last image acquired. We have implemented a distribution script which runs automatically each morning after the nights observing is completed. This script moves all files off the acquisition computer onto the ftp server and sends each user an email message listing his or her set of new images and complete instructions on how they may be retrieved using ftp.

All of these Web capabilities are build from small shell or perl scripts, and of course HTML web pages, on top of the OCAAS system. Other facilities may often be easily created as well with little programming required.

A critical issue related to remote access is bandwidth. Real-time control and observing lists require relatively little bandwidth. Modern telephone modems or ISDN are quite satisfactory. The X Windows programs gain particularly from the lbx (Low Bandwidth X) protocol supported by Broadway (X11R6.3).

Of significant separate concern is transfer of the image data itself. In a typical evening, a few hundred images might be acquired, each of order one megabyte. Thus, data sets approaching one half gigabyte can be generated in one night. At 56kbps, this would require nearly 20 hours to transfer. If high speed connections are not available, an alternative approach is to store a nights images on removable media such as an Iomega Zip or Jaz drive, and have a local technician mail it to the host facility every few days. Two or three media can be used in constant rotation. The Iowa Robotic Observatory is using this approach, with scripts which dial up over a simple 33.6 modem line once each day to retrieve basic system health statistics and download the next observing list.

Scientific Analysis Tools

In addition to the interactive *camera* image display and analysis tool already described, OCAAS includes several command-line tools which are designed to scale to largely automate the wholesale scientific analysis of large numbers of images in a pipeline fashion. The tools are primarily aimed at performing field photometry to monitor known variable stars or discover new ones, and the detection of transient phenomena such as supernovae. All tools which specify positions or regions of interest do so using RA and Dec, and so images must include the WCS FITS header fields.

fphotom

Fphotom is a program for producing absolute photometric magnitudes for all stars in a a color field, that is, all stars that are found in common among a set of four images taken through B, V, R and I filters. Photometric calibrations constants for the night of the image set are determined from a set of standard Landolt images which have also been taken the same night. The output from *fphotom* is a table, one star per line, of star positions, their true apparent B, V, R and I magnitudes, with error estimates, and the geometric mean and ratio of their full-width-half-max brightness values.

photcal

Photcal scans a directory of images of Landolt photometric standard fields and, along with standard field information, determines a set of 8 photometric parameters which best characterize the data for instrument correction, color and air mass dependencies. *Photcal* must be run before programs which perform absolute photometric calculations, such as *Camera* and *fphotom.*

photom

Photom is a program which performs relative aperture photometry of known objects on sparse-field star images. It is driven by a configuration file. The file lists the images to be analyzed, and the positions of stars and asteroids. The first image listed serves as the magnitude reference and its last star is a reference star against which all magnitude are relative. Asteroid positions are given for any two images and are automatically interpolated in time for other images, based on the JD FITS header field, which must be present.

snsearch

Snsearch searches a list of test images against a list of reference images (of the same OBJECT name) for star-like objects which exist in the test image that are not in the reference image. The search region may be delimited by an area of interest.

vsmon

Vsmon is a program for monitoring a set of known variable stars over an extended period. It uses a catalog file which contains name, position, color correction and check star information. *Vsmon* scans a given directory containing FITS images and checks each image against the list to produce one line of output for each image whose OBJECT field is found in the catalog. The output includes heliocentric time of the observation, air mass, computed true magnitude, and estimates of all errors.

vssearch

Vssearch searches for variable stars in a set of FITS images as follows. Given a set of images taken with a given filter scan each image and build lists of positions of all qualifying star-like objects found in each image. Match these stars by position. Find the brightest star that is on the most number of images and designate it as the calibrator star. Discard all images which do not contain the calibrator star. Find the magnitudes and errors of each star on each surviving image. Stars which have too much intrinsic error or that are not on at least three images with the calibrator are discarded. For each remaining star, compute how well the magnitudes over time fit a straight horizontal line of constant magnitude, allowing for their noise estimates. Stars with an average deviation from the mean below a threshold are discarded. Remaining stars are sorted by a figure of merit based on the mean squared error in increasing likelihood they are variable.

Pricing

A retail binary license for the complete OCAAS software suite for use on one computer running Linux 2.0 ELF or newer is $4,000.00 US. Portions may be purchased separately as follows:

Prices are for OCAAS software only, and do not include any hardware items whatsoever. Prices subject to change.

$1,199.00	*Camera* GUI program with your choice of one driver for Apogee, SpectraSource or ISI camera. *Includes source code for selected driver for maximum portability to your system..*
$1,199.00	*xtelescope* and supporting subsystem for Real-time GUI control of telescope, focus, filter, dome and shutter or roof.
$1,199.00	*telsched* and supporting subsystem for Batch-scheduled control of telescope, focus, filter, dome and shutter or roof. *Requires camera software package above to operate camera.*
$799.00	All Off-line analysis tools for photometry, astrometry and time series analysis.
$0.00	XEphem, with the Sky View preconfigured for fully integrated scope control. *Includes full source code.*
$4,396.00	Save $396.00 when purchased together.

Inquires are welcome for clubs, wholesale/OEM, site and full source code licenses.

More Information

Follows are ways to obtain more information about OCAAS.

User Manual

The current works-in-progress OCAAS user manual, ocaas.doc, is available in Microsoft Word 6.0 format via ftp.

Email the author

Thank you for your interest in OCAAS. For more information on OCAAS, please contact Elwood C. Downey at ecdowney@noao.edu.