Automatic site-testing monitor of Sternberg Astronomical Institute

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Abstract. The paper describes the Automatic Site Monitor (ASM) built for accumulation of astroclimatic data on the top of Mount Shatdzhatmaz near the site chosen for installation of the new 2.5 m telescope of Sternberg Astronomical Institute (SAI) at Northern Caucasus. The instrumentation and software organization are presented.

Keywords: robotic astronomy – site testing – optical turbulence – software

1. Introduction

In case of ground-based astronomy, star-light undergoes influence of the Earth atmosphere in many ways before it reaches a telescope. The light can be absorbed and scattered by different atmospheric agents, such as molecules of air, aerosol particles and also statistical and turbulent fluctuations of air density. The latter also cause a phase distortion of the initially plane light wave, which leads to the fact that the image of a point-like source formed by a telescope is far from the diffraction image. Influence of turbulent inhomogeneities of the refractive index on light propagation is described in terms of optical turbulence (OT).

Additionally to phase and amplitude distortions of the light wave, an external background light makes observations difficult. So, the suitability of a site for astronomical observations is characterized by the following key parameters often referred to as the basic astroclimatic parameters:

- Clear skies (night or day) statistics.
- Characteristics of OT above observatory.

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Sky background (mainly light pollution).
Atmospheric extinction, precipitable water vapor (PWV).

These characteristics affect the efficiency of any optical telescope. The optical turbulence is a principal factor, limiting both classical and advanced ground-based observations. There are two main sets for OT determination methods: 1) indirect methods (meteorological ones), 2) informative and adequate optical methods.

As a rule, these astroclimatic studies are performed to achieve two somewhat different goals which are site testing for future astronomical observatories and characterization of atmospheric conditions in the operating observatories.

Studies aimed at the first objective (see Kornilov et al. 2010), and references therein) are based normally on the measurement of phase distortions (like in differential image motion method, DIMM), or measurement of stellar scintillation (like MASS or SCIDAR). They all consist of accumulation of measurements data over a number of years followed by the analysis of these data, comparison with other sites, site characterization and, may be, selection. Typical requirements for the instrumentation are mobility, autonomy, reliability, low price. Usually, small \( \approx 30 \text{ cm} \) telescopes are used as feeding optics in these studies.

To provide the second function, nearly real-time information on the current astroclimatic parameters (delay \( \lesssim 2 \text{ minutes} \)) is needed, although the same type of instrumentation may be involved. This information can be used for a forecast of conditions and operative scheduling of observations and/or a support of advanced observational technologies.

2. Automatic site testing monitor (ASM)

In order to obtain reliable statistics of astroclimatic parameters or to provide actual information, they should be monitored continuously over a long time. Just as in other monitoring tasks with small instruments (such as optical transient phenomena observation) effective implementation of astroclimatic measurements is only possible under full automation of the process. Generally, a robot-like site testing monitors are needed. Worldwide astroclimatic practice confirms this need.

As an example, one can mention the Thirty Meter Telescope (TMT) site testing program (Schöck et al. 2009) carried out recently. Five identical site testing monitors have been deployed in different sites to collect comprehensive information needed to select the site optimal for the future telescope (Travouillon et al. 2011). Namely the use of autonomous automated monitors has allowed small team to get reliable information on atmosphere above several summits in Chile, Mexico and Hawaii.

The second example, well known in the site testing community, is the ASM on
Figure 1. Map of the local relief (sides are ca. 2 by 2.5 km) around the site for new SAI observatory. Mount Shatdzhatmaz (2127 m) is located in Karachay-Cherkess Republic of Russia, 20 km southward from Kislovodsk. The mountain belongs to the Skalistiy ridge which is parallel to the Main Caucasus ridge ≈50 km away to North. The solar station of Pulkovo observatory is situated about 1 km from the place chosen for installation of the new 2.5 m telescope.

The ESO Paranal Observatory. It works automatically for more than 10 years and provides VLT with current atmospheric conditions and seeing data (Sandrock et al. 2000). This monitor is often used as the reference facility for comparison of different site testing methods and instruments.

Sternberg Astronomical Institute of Moscow State University started the project of a new observatory at Northern Caucasus in 2006, when an agreement with SAGEM-REOSC was signed on manufacturing of a 2.5 m telescope. The selection of the site for this telescope has revealed the absence of the reliable and contemporary information on the astroclimatic conditions of Caucasian region of Russia, so the site near the Kislovodsk city (see Fig. 1) was chosen on the basis of sparse results obtained 40–50 years ago and some economical reasons.

This situation has enforced us to start the comprehensive site characterization using modern astroclimatic methods in order to get a clear view of the astronomical potential of the site. It is very important in order to determine the strategy of using the telescope with maximum efficiency.

For these studies in 2006 we developed the SAI Automatic Site testing Monitor on the base of MASS/DIMM instrument (Kornilov et al. 2007) which combines Multi-Aperture Scintillation Sensor (Kornilov et al. 2003) and Differential Image Motion Monitor (Sarazin & Roddier 1990). The ASM installation was performed during the summer 2007 and since September 2007 it began to work.
The main purpose of the SAI ASM is to carry out continuous observations in order to collect the statistically reliable data on; 1) seeing; 2) OT vertical distribution; 3) clear night skies and 4) on-site weather parameters. These data collected in first several years (since 2007 and until telescope installation) are aimed for description of the site potential, development of the optimal strategy for the 2.5 m telescope operation and to design the telescope instrumentation.

In future, after the telescope becomes fully operational, the ASM will provide the observatory with information on current atmospheric conditions, help observation scheduling, and support the advanced astronomical observations (adaptive optics etc.).

3. The ASM structure and instrumentation

ASM structure was defined based on the following reasons: 1) instrumentation set must provide measurements of necessary atmospheric parameters and 2) structure must achieve a certain autonomy of the monitor (although habitable area is located at about 1 km) using a limited capacity power supply. It was necessary to gain experience for further astroclimatic (and just astronomical) observations on sites without any infrastructure.

The ASM tower was erected at 40 m to SW from the spot reserved for the 2.5-m telescope. The ASM feeding optics was mounted on a concrete 5-m high pillar, thus its tube is at 6-m elevation above the ground. Such a height is typical for DIMM facilities at observatories; the 2.5-m telescope primary mirror will also have similar elevation. External view of the ASM tower with enclosure is shown in Fig. 2 for different seasons.

Thus, our site testing monitor consists of the following instrumental components:

1. MASS/DIMM instrument to measure integral value and vertical distribution of the optical turbulence.
2. Automatized telescope Meade RCX400 on alt-azimuthal mount with aperture 30 cm to feed the MASS/DIMM instrument.
3. Finder/guider with CCD camera for accurate pointing to target stars and telescope guiding.
4. Control computer #1 for MASS and DIMM data acquisition, the telescope and the instrument control.
5. Automated enclosure made of close cloth with capacity for the telescope at any position.
6. Anemometer, air temperature and humidity sensors at mast placed near ASM tower.
7. Boltwood clouds sensor on Solar station, custom clouds sensor at the ASM dome.
8. Two web-cameras with good sensitivity for internal and external surveillance.
9. Controlled DC/DC power supply for the instruments.
10. Service computer #2 to monitor environment and support ASM operation.
11. Wi-Fi bridge to Solar station where ASM server #3 is located.

The equipments 1–4 are placed under enclosure and powered on only during OT measurements. The telescope with the MASS/DIMM instrument is presented in Fig. 3.

![Figure 2. Left: Night time view of the SAI ASM on the top of Mount Shatdzhhatmaz, July 2008. Right: Day time view, January 2010.](image)

The additional devices work permanently and support meteodata acquisition and infrastructure services: surveillance, power control and distribution, local area network and Internet connections. The entire structure of the ASM and connections between its hardware components is represented schematically in Fig. 4.

Different digital interfaces are used for hardware connections: MASS instrument uses serial bus on the base of RS485 interface and DIMM CCD camera works with IEEE 1394 interface. All the custom-made controllers use also serial RS485 interface. Finder/guider camera and surveillance cameras are connected by USB. The computers are interfaced by local network segment.

The ASM power is supplied by the batteries with a 400 A·h capacity. This provides 7 – 10 days of operation as the permanently running part consumes about 20 W and the night-time observations need 40 W in addition.
4. Principles for building the ASM software

Since the ASM represents a typical distributed system, which is more or less complex, the software for its automatic operation should also be distributed. During the process of designing and programming, we generally adhere to the principles, which...
were formulated on the base of our experience of development and operating the MASS/DIMM software obtained in 2002 – 2006. Thus, in the process of the development of the basic software we tried to use the following philosophy:

- The software consists of separate software components that run and operate independently, and if necessary one interacts with another. Partition of the software into the components enables 1) to increase the flexibility by performing some functions at the operating system level, 2) to simplify the developing and debugging, 3) to ensure the stability of the whole system, 4) to define and simplify a logic in a separate component and 5) to provide a smooth parallel execution of some functions.
- Each software component implements a single logical task or function of the ASM. This implies a division of the whole work into separate, fairly isolated and self-contained parts. In this division, priority is given exactly to the problem, not to the handling of a device. For example, the program tlsp is responsible for pointing the telescope, centering and guiding. For this, the program interacts with the telescope, the telescope power controller and the finder CCD camera.
- Background operation of the program is a basic property, so there is no user interface. However, components start in the foreground to have the detailed information about the failed startups. The transition into the background is performed by the program itself but not with help of shell. Thus, during normal working all the software components are functioning as “daemons”.
- Reports on progress and errors are always recorded in the log file of the program. Some components do not produce output data. In such cases the log file should contain all the information about the program execution. The names of the log files are generated using the format YYMMDD-programname.log, where YYMMDD — the program start date (calendar date in the evening of the observational night, the date changes at local noon).
- Controlling of the programs is carried out using 1) options on the command line at startup, 2) configuration file information and 3) the commands coming over network connections. The options have the same meaning for all programs and relate to the program context. Configuration files contain the settings of the functional part of the program and external devices. Commands coming via network connection initiate specific actions.
- Synchronization of ASM operation is done at the command level. The program ameba performs the role of a supervisor which implements a general algorithm for operation of the ASM. The others software components are functioning as servers. However, there may be exceptions to solve local tasks. For example, for precise guiding, the program tlsp uses an information from DIMM. To do this, it individually sends needed requests to dimm program as a client. In this and similar cases, the synchronization is carried out according to the rule: the first request is satisfied.
- Logical structure of the software components is built on a common base. The
same functions within the programs are provided by common modules. In particular, they include the configuration support, error handling, network exchange, analysis of external commands, exchange through the RS485 interface, time and astronomical coordinates conversions. The structure of each program contains a static part and a dynamically generated object which is created in the active (initialized) state.

- Software components are mainly implemented in C++ with the intensive use of standard template library. A common programming style is maintained. In a mandatory manner, the source code is stored and developed in Concurrent Versions System (CVS). All software is designed to run on the operating system GNU/Linux.

These approaches to development and support of the ASM software correspond to modern ideas of pattern design and have allowed us to develop and debug the entire set of components with minimum expenditure of resources.

5. The ASM software components

The ASM operation is currently performed by the following software components running on different machines including the monitor structure:

- **mass** — the program controls the MASS-channel of the instrument and provides the measurements of star fluxes, computation of needed statistical moments of the stellar scintillation and records them in output data file. The mass runs on the machine #1 and interacts with the instrument via a special driver and device /dev/rs485lpt0.

- **dimm** — the program controls and acquires images from the CCD camera of the DIMM-channel. It finds the image centroids on the CCD frames and calculates statistics of their motion and records them in the output data file. This component also runs on the machine #1 and can work with cameras supporting IIDC standard at IEEE1394 bus through standard Linux driver and library libdc1394.

- **tlsp** — the program controls the telescope Meade RCX400 and finder/guider CCD camera connected to the machine #1 via serial port and USB handled by V4L Linux kernel driver. The tlsp provides pointing, searching, centering and guiding the target star. When guiding is provided by the DIMM camera, it works as a client, requesting dimm for the position of a star image in the field aperture of the instrument. Such a derogation from the basic principle was allowed to encapsulate the guiding inside a single program.

- **shutdown** — the daemon for remote shutdown of the machine #1 allowing control of a number of users.
- **dome** — the component controls the ASM enclosure and power supply. It continuously runs on the machine #2 and interacts with equipments with help of special driver and device /dev/rs485com0.

- **monitor** — the program is a continuously running daemon on the machine #2 collecting information about ambient conditions from temperature sensors, humidity sensor and anemometer. This program allows only to request for the current data on environmental conditions so no active functions exist. It interacts with sensors like the program dome does.

- **ameba** — This is a central element of the interactions which manages the observational process and provides synchronization of other components. It runs on the continuously working ASM server (machine #3).

In the normal mode, these components are started with help of the system utility cron or during the computer start. Also, there are some service routines and scripts providing http-server with current information and data archiving.

### 6. The inter-program command protocol

A simple inter-program text protocol was implemented in 2002 for integration of the MASS software Turbina in systems providing automatic observations under control of a special script named supervisor. Format of the command line terminated by <CR> symbol looks like

```
id command [param1=val1 param2=val2 param3]
```

Here id — the command identifier to match server replies, command — the command keyword, param1=val1 — a number of parameter keyword-value pairs, param3 — parameter keyword without value.

The identifier should be an arbitrary alphanumerical word, unique for successive commands. The parameter keywords are optional and are defined by the logic of a specific program. The protocol defines seven command keywords only:

- **init** — Initialization of the program involves the following steps: reading the configuration file, creation of program objects, opening the output data file, the connection with the equipment and its initialization. After a successful initialization the program goes into the status READY.

- **set** — Setting specified parameter value or performing infinitely short action such as switch on or switch off. The exact list depends on the program to which this message is sent. Each parameter name must be followed by the parameter value separated from it by ‘=’ sign.
• **get** — Extraction of relevant data from server. It returns the values of requested parameters. Expected reply is OK parameters=values. Parameter-value pairs are not allowed, only the not empty list of requested parameter names is accepted.

• **run** — Start the specified action or function. It returns an estimate of executing time for the action with help of reply OK WAIT=duration. The command locks the execution of next commands **run** and **set** until its completion.

• **stop** — Stop the running action or function.

• **park** — Parking is done in an order reverse to initialization: disable hardware, closing exchange and output files. After parking, the program is in the status PARKED. Also, parking is performed before program will quit after receiving the command **quit**.

• **quit** — Parking and completion of the server program. Connections with clients are closed.

Commands **set** or **run** cannot be executed if the server is in the parked state or in the state BUSY. In the parked state, one can only obtain information about the general state of the program, for which the parsing module processes 3 commands by itself: **get status**, **get ident**, **get error**.

The server response to a command received is mandatory. The response consists of keywords **OK** in the normal state and **ERROR** in the fault situation. As a rule, the server current status is also included in the server reply. The server response to a client request (command **get param**) is parameter-value pair(s). Special keyword **WAIT** is foreseen for prolonged transaction, it informs the client about expected duration of the command execution, in order for the client to be ready to obtain the response with a final information.

Here is an example of exchange illustrating some of basic principles of described protocol:

```
101 OK WAIT=100 : action started; to be acknowledged in 100 s again
101 OK RAM=VAL : parameter value returned
101 ERROR STATUS=BUSY : rejection due to busy state
```

The clear text structure of the protocol permits to use system utilities **telnet** for manual control, and **netcat** for control shell-scripts.

### 7. Some results of the ASM observations

The first results of measurements performed on the top of Mount Shatdzhhatmaz with the ASM are presented in Kornilov et al. (2010). The total duration of the observations
Figure 5. Example of night data on turbulence intensity profile. **Top panel:** lines stand for turbulence layers with altitudes indicated on the left. Width of each line represents intensity of the respective layer restored from MASS/DIMM data (see gray segment on the right for scale). One can see that turbulence profile is strongly variable; for example, at 19 p.m. UT a temporary increase of turbulence strength at 0.7 km was observed. **Bottom panel:** black dots stand for total seeing measured by DIMM and gray dots stand for free atmosphere seeing (integrated from 0.5 km to infinity) measured by MASS.

> 3000ʰ in the period 2007 November – 2011 April. The number of accumulated OT profiles and seeing estimations is ~ 150000. During this period the telescope performed ≈ 3500 pointings to target stars. For example, Fig. 5 shows the OT vertical profile evolution over night February 19, 2009 restored from the measurements with the MASS/DIMM instrument.

Overall median seeing on the site is $\beta = 0.93''$. The most probable seeing is $0.82''$. In 25% of the time seeing is better than $0.73''$. The best seeing (minimal OT strength) is observed in October – November. The typical median value for that period is $\approx 0.83''$.

The entire monitoring period is also covered by computerized weather data. Me-
dian temperature over year is $+1.8\,^\circ\text{C}$, temperature span is not very large: from $+15^\circ\text{C}$ in summer to $-15^\circ\text{C}$ in winter. Median wind speed is 2.3 m/s, the dominant winds direction is from west or south-east when night sky is clear.

Annual clear astronomical night skies is $\approx 1340^h$ or 46%. The maximum of the clear skies amount is observed from mid-September to mid-March, where about 70% of the clear weather is concentrated.

8. Conclusion

ASM efficiency (ratio of used time to clear nautical sky) is $\approx 70\%$ in total. Over the last year the efficiency was $> 80\%$. In the beginning of monitoring (before 2008 July) main problems were connected with testing and debugging of the ASM software and the lack of power supply of enough capacity or permanence. In last years, failures in the Meade telescope operation were a root cause of the loss of observational time. In general, the work of the ASM is characterized by the diagram shown in Fig. 6 where for each calendar day the duration of measurements is plotted. The real-time status of the ASM is available at http://eagle.sai.msu.ru, where the information needed for operative control is permanently updated.

The statistics of the ASM operation proves that both hardware design and software conception and its implementation is not far from optimal solution for autonomous automatic small telescope installation for monitoring purposes. Meanwhile, it should be noticed that many problems, such as access authentication, have not yet been solved completely. In this regard, we are relying on the goodwill of persons which have access to the resources of the ASM.
Simple command protocol developed by our team is also used in automated systems of other site evaluation projects working with MASS/DIMM instruments. The basic ideas incorporated in the software modules are exploited in variety of projects, both related to astroclimatic research (ESO-ELT, Thirty Meter Telescope, Giant Magellan Telescope) and to others astronomical studies (the control system of some Moscow University telescopes, the global network MASTER II for optical transients monitoring).

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References

Kornilov V., Tokovinin A. A., Vozyakova O., et al., 2003, SPIE, 4839, 837