Controlling the Hamburg Robotic Telescope: a description of the software

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ABSTRACT

The Hamburg Robotic Telescope (HRT) is a fully automatic 1.2m telescope designed for high resolution spectroscopy of active stars. It uses the Heidelberg Extended Range Optical Spectrograph (HEROS) which is fed by a $50\mu m$ fiber connected to the Nasmyth focus of the telescope through an adapter. Here we present the software that controls the whole system of the HRT. This software works both in fully automatic and interactive mode. It organizes the interaction between the Central Control System (CCS: the core of the system) and the subsystems: building, telescope, spectrograph, adapter, environmental sensors (weather station and sky monitor) and scheduler. The CCS performs its operation by sending commands (ASCII messages through TCP/IP sockets) to the different subsystems. The robotic operation is divided into discrete procedures, such as "Initialization", "Observation" or "Calibration". Each procedure consists of a set of commands which will be carried out (sequentially or even in parallel) if a set of conditions is met: e.g. only when one command is successfully accomplished, the next will be sent. Furthermore, the Error Handler takes the necessary actions when a problem inhibits the normal progress of the observation (e.g. bad weather, non-detection of the target or technical problems). The scheduler selects the target from a primary list in a manner which combines the scientific priority with observational feasibility and the history of observations. Finally, we present the Automatic Reduction Pipeline developed on the basis of REDUCE, an IDL reduction package, to obtain the final spectrum from the raw data.

Keywords: Robotic telescope, robotic software, high resolution spectroscopy

1. INTRODUCTION

Many astrophysical studies would profit from the use of robotic telescopes. Examples are monitoring programs for variability studies, large surveys, observations of a large sample of objects, as well as rapid-response observations, like follow-up monitoring of γ-ray bursts. To take large amount of "similar" data, the use of robotic telescopes improves the efficiency of the observations, regarding both time and data quality. With the development of hardware and software during the last 10 years, robotic astronomy has changed from an exception to a wide spread and powerful tool.

Although there are dozens of working robotic or automated telescopes worldwide (see the list compiled by Hessman in Ref. 1), the vast majority use an imaging camera as instrumentation. Only very few can perform high-resolution spectroscopy.

With the aim to study the many manifestations of activity in stars, we have developed the Hamburg Robotic Telescope (HRT). Its scientific goals are among others simultaneous observations with space telescopes, determination of stellar rotation periods, observation of stellar activity cycles, the study of differential rotation by means of the stellar butterfly diagrams, observation and monitoring of starspots, search for low-mass stellar companions (brown dwarfs and planets), and spectroscopic surveys.

In this paper we present the HRT control software: how it is structured and how the robotic operations are performed. Sect. 2 and 3 are devoted to the detailed description of the HRT and its parts, respectively. Sect. 4 gives a general picture of the software and its structure, while in Sect. 5 the different parts of the software are described with emphasis on the scheduler and how the data taken by the HRT are reduced. Finally, in Sect. 6 we explain how the robotic operations are performed.

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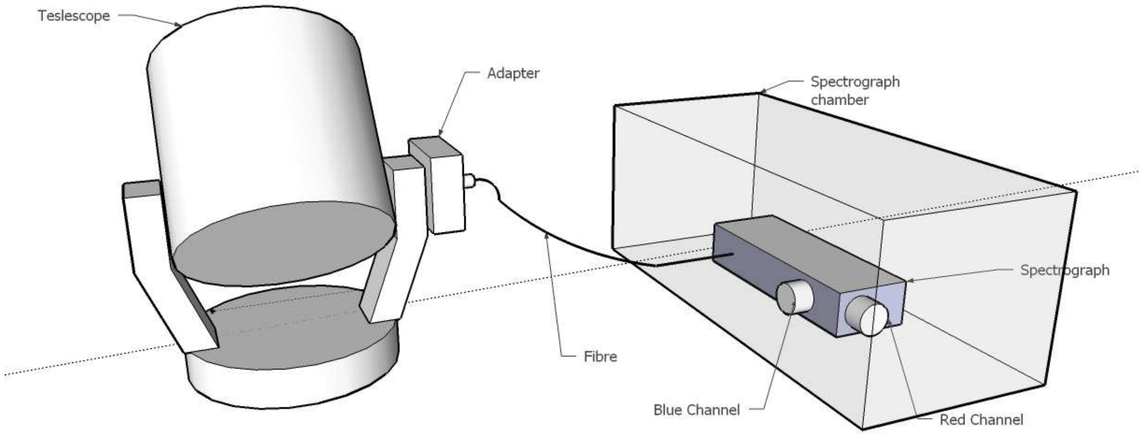

Figure 1. Sketch of most components of the HRT

2. THE HAMBURG ROBOTIC TELESCOPE

The Hamburg Robotic Telescope (HRT) is a 1.2m aperture Cassegrain-Nasmyth F/8 type telescope which was built by the German company Halfmann Teleskoptechnik GmbH and delivered to the Hamburg Observatory in 2005. The manufacturer of the three-mirror optics consisting of Schott Zerodur glass ceramics was Zeiss. The parabolic M1 mirror is actively supported with 18 axial and 12 radial levers. Tests have shown that its optical performance is limited by seeing under Hamburg sky conditions.[2]

The HRT has an Alt/Az mounting with a hydraulic bearing in azimuth and a high-precision roller bearing in elevation. This, in combination with direct final drives and high-precision absolute encoders, offers high slewing speeds and also precise pointing and tracking provided a good pointing model is available.

A first pointing model was determined during commissioning in September 2005 at the average temperature of 17°C. During that time the temperature was steady and the pointing model was stable with typical mispointings of the order of 1-3". In the course of the season a systematic trend of mispointing was observed which turn out to be correlated with ambient air temperature. Therefore repeated pointing model determinations at very different temperatures were carried out between autumn 2005 and summer 2006, which confirm that the pointing model parameters do indeed depend on temperature. Finally, the inclusion of the temperature dependence in the pointing software led to a stable pointing performance of the telescope.[3]

An instrumental platform is mounted on a field of view derotator at one Nasmyth focus. An adapter is mounted at this platform which interfaces the telescope with the spectrograph via a fused silica fiber.

The telescope control system (TCS) works under LINUX. It was delivered with the telescope by the telescope manufacturer. However, the TCS is only one part of the HRT software and is under control of the Central Control System (CCS).

3. COMPONENTS OF THE HRT SYSTEM

The HRT is a complex system consisting of the telescope as described above, the instrumentation, an adapter between the telescope and the instruments, the enclosure and a weather monitoring component. A sketch of the HRT is shown in Fig. 1.

At present, the only instrument is the fiber-fed echelle spectrograph HEROS (Heidelberg Extended Range Optical Spectrograph) that covers an optical range between 345 and 865nm, split into two channels with a spectral resolution of approximately 20,000 when a 100μ fiber is used. Currently, only the blue channel is in operation because the red CCD-camera is still under construction. With the use of a 50μ fiber, an enhancement of the resolution in the red channel is expected while, due to the optical design, an enhancement of the resolution in the blue channel is not possible. Measurements of the throughput in the laboratory yielded a better performance of the 50μ fiber in comparison with the 100μ one so that – independently of a possible improvement of spectral resolution – the substitution of the present 100μ fiber by the 50μ fiber is planned. Core of both CCD cameras is an E2V 2048x2048 13.5μ pixel chip. It is electronically cooled to -50°C – enough to minimize the dark current to a level of $0.01e^-$/pxl/sec. Read-out noise was measured to be $6e^-$/pxl.

The interface between the telescope and the spectrograph is an adapter which is mounted on the derotator in one Nasmyth focus of the telescope. The adapter contains the acquisition and guiding unit which feeds the stellar light into the fiber via a microlens, and the calibration lamps unit (flat field and ThAr lamps). The microlens matches the F/8 beam of the telescope to the F/4.5 collimator beam of the spectrograph. The microlens/fiber combination is embedded in a flat, tilted mirror. The mirror surface is imaged by a SBIG ST7 CCD-camera thus allowing the acquisition of the target star and centering it at the entrance lens of the fiber. A second ST7 camera serves as guider where a few percent of the light from the target star is taken out by a Pellicle beam splitter. The duty cycle of the guiding process is dominated by the exposure time of the guiding camera which is chosen sufficiently long to avoid a misestimation of the star center due to seeing. Typical values are 10-15 seconds. Neutral filters allow an adaptation of the stellar brightness to the sensitive range of the ST7 cameras. The relatively long duty cycle of the guider is possible because of the excellent pointing and tracking accuracy of the telescope; the latter is better than 0.05 arcsec/minute (mean value of tracking loss rate) at zenith distances larger 1°. As another important feature, the instrument adapter feeds the light of the calibration lamps into the fiber by help of retractable motor-driven mirrors and prisms.

The HRT building is a simple motor-driven roll-off roof construction enclosing the telescope and its external devices like the hydraulic pump and the electric control cabinet as well as a climatic chamber containing the spectrograph. Temperature and humidity inside this chamber are held at 19°C and 40%, respectively. A Vaisala WXT510 weather station is mounted on top of the building. It measures temperature, humidity, wind speed and direction, as well as precipitation (rain). Because this precipitation sensor is insensitive to snow and, for the sake of redundancy, a second precipitation sensor (snow and rain) is installed at a neighboring building. The second part of the environmental system is a sky monitor which measures the degree of cloudiness. The sky monitor consists of an electrically cooled CCD camera equipped with a fish-eye lens that provides a field of view of 160° with a mean resolution of 0.5° per pixel. The camera is directed to the zenith and is sheltered by a stainless steel housing and a circular turnable cover. In the cover, there is a circular aperture that can be positioned above the lens for exposing and at the diametrical position during idle state to shelter the lens. This cover is positioned by a computer-controlled electric motor.

4. GENERAL DESCRIPTION OF THE SOFTWARE

In the design and construction of the software, we aim at a compromise between simplicity and a fully automatic operation. With simplicity we mean that this fully automatic operation should be achieved with the simplest software system possible. Such a simple software facilitates the debugging and extending of the software and should offer the most robust and reliable performance.

We have chosen a modular concept in which the control software of all parts of the system are completely independent programs and the communication between them is performed with TCP/IP ASCII messages.

The structure of the system is shown in Fig. 2. The Central Control System (CCS) is on top of the hierarchy; it is the core of our software. The CCS controls the whole system by sending ASCII commands to the subsystems.

The “intelligence” of the system is split between the scheduler and the CCS. The scheduler (see Sect. 5.5) will decide which is the next observation to be performed, depending on the current time, sky conditions, and the history of observations. The CCS will then take the actions necessary to successfully and efficiently perform the observations demanded by the scheduler. Furthermore, the CCS continuously monitors the status of the whole system, of the individual processes, and environment conditions. Furthermore, in the case of a problem (whether during the processing of a command or not) the CCS will take the appropriated actions to solve it.

Apart from the already mentioned CCS and scheduler, the HRT software system incorporates subsystems corresponding the different parts of the HRT: the TCS for the Telescope; the Building Control System (BCS); the Environment Control System (ECS) for the weather monitoring components; the Adapter Control System (ACS); and the Spectrograph Control System (SCS). Furthermore, the two other parts of the software are the Archive, which contains all CCD images and a protocol of all operations done by the HRT, and finally the Automatic Reduction Pipeline (ARP) described in Sect. 5.8.

The communication between all software subsystems is performed using ASCII messages that are sent through TCP/IP socket connections. The only subsystem that can send commands is the CCS. This avoids possible interferences in the operations of the system, which could arise when two different components of the system send conflicting commands to a third component. This also facilitates and simplifies the development of the software. There is, however, one exception to this rule: the adapter can control the telescope by changing the offsets and the focus position. This is necessary, because the focus command (to obtain the optimal focus of the telescope) and the acquire/guide commands (set/keep the star in the entrance position of the fiber) are commands of the adapter, which takes and analyzes images obtained with its cameras. During the process of the focus command and in order to fit the FWHM of the star vs focus position, the adapter takes images of the target star with different focus position of the telescope. From those measurement the optimal focus is calculated and sent to the telescope. During the acquire/guide commands, the adapter takes images of the target star, determines the position of the star in the frame, and sends new offsets to the telescope to place the star on the fiber entrance.

Messages include not only commands to the different subsystems (a command indicates that the subsystem should carry out a certain action), there are also answers to the commands that the subsystems send back to the CCS (see below): status messages with which every subsystem informs the CCS about its situation; information messages to give to the CCS certain information, as for example, the FWHM or instrumental magnitude of the target as observed by the adapter or the remaining tracking time for the current target. Furthermore there are warning messages that inform about a problem of a subsystem that does not affect the normal operation; and error messages that report a serious problem that does affect the normal operation.

The operation of the system is carried out by a set of commands that the CCS sends to the different subsystems. The steps in the processing of a command are similar to those in the STELLA telescope.[4] There are two answers to a command. First, an acknowledgement is sent back immediately after receiving the command. The acknowledgement indicates that there is no problem with the communication, and it contains the maximum completion time for the command to be carried out. Second, a done message is sent when the operation is terminated; it indicates whether the command was successfully carried out or not.

It is expected that in the case of a non-successful command process, an error message is also send. All errors/information/warning messages report not only the type of problem or event, but also additional parameters with information that helps to the CCS to decide which actions to take. However, the errors can not only occur during the processing of a command. There are also problems, e.g. bad weather events, that appear independently of a command.

The system has two operational modi: interactive and robotic. The difference between both modi is that in the first modus a human operates the CCS while in the second it is the CCS which decides what to do. However, in both cases the same collection of commands are sent to the subsystems. For the subsystems, the operation is the same in robotic or interactive modus, because all subsystems are programs that only react after the reception of a command.

The software is almost completely written in Java under Linux. There are two exceptions. The first is the automatic reduction pipeline (see Sect. 5.8) which was developed in IDL. The second is the software that operates the ST7 cameras and analyzes their images. It was written in C and integrated in the Java software using the Java Native Interface.

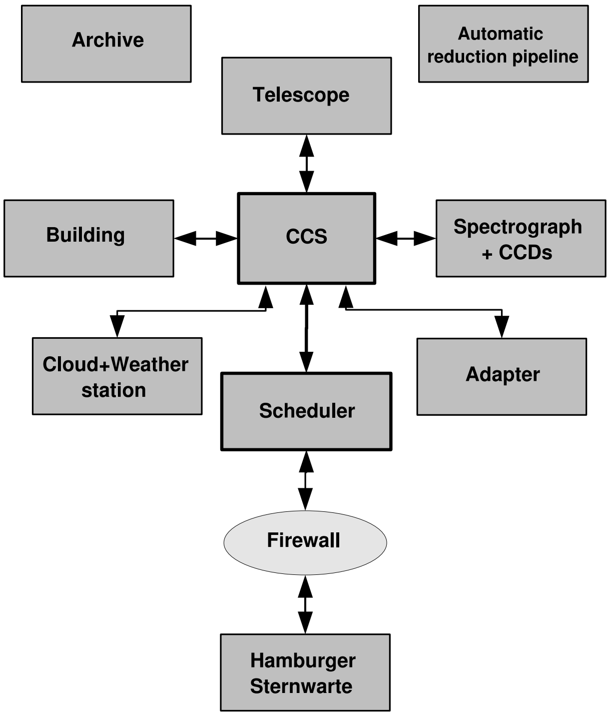

Figure 2. Structure of the software of the HRT

5. COMPONENTS OF THE SOFTWARE

This section describes each part of the software of the HRT. There are three groups of subsystems. First, the CCS, controlling the whole HRT system; second, subsystems controlled by the CCS. Finally, third, the archive and the automatic reduction pipeline (ARP). The archive is not only used to store the images, it also protocols every parameter, operation and message of the telescope. This is very useful to monitor the proper operation of the HRT system, including the software. The ARP will be run at day time to obtain the scientific data, it is not yet decided whether the ARP will start its operation automatically or after an order of the CCS.

All subsystems hierarchically below to the CCS (as shown in Fig. 2) react only when a command is received, except for the cases described in the following. As seen from the CCS, all subsystems are similar, the only difference for the CCS is that each subsystem requires a different collection of commands. In all subsystems, upon receiving a command, a new thread is launched to grammatically and syntactically analyze the command and finally process it. Therefore, they are always ready to receive and process new commands, even if they are already processing previous command.

5.1 CCS

The Central Control System is composed of several parts that work in parallel in their own (one or several) threads. In the following, there is a description of each part.

5.1.1 Robotic operator

The robotic operator decides which task to perform next. This is done taking into account the current time, weather conditions, Sun elevation, and previous operations of the HRT. The operation of the HRT is divided into procedures, each procedure is composed of a different set of commands. Therefore, the robotic operator decides at the end of a procedure, which procedure to carry out next. Sect. 6 explains the logical structure of the operation with procedures and commands in more detail.

5.1.2 Error handler

The error handler receives and analyzes all error, information, warning and status messages. There is a dedicated server socket for these messages. After a message has been received, a new thread is launched to analyze it, and the error handler is again ready for new messages. The information, status and warning messages are archived and their information can be used for subsequent operations. For error messages, it is expected that some actions will be carried out to solve the problem. Some errors require only a reset of the affected device. Other errors, however, require a more complex solution, such as stopping the robotic operation, dropping the current target observation, closing the telescope and building, or even shutting down the whole system in case of fatal errors. At present, only a small group of errors, those more frequent and important (e.g. bad weather or target not detected) are handled. In the next months, with the experience obtained about the performance of the HRT, we will extend the number of error messages to be handled.

5.1.3 Data server

In some cases, processing a command on one subsystem requires parameters of another subsystem. As an example, the SCS writes the current weather conditions, position of the telescope, target name, etc. in the header of the spectrograph CCD images. To this end, the data server can deliver parameters describing the status of the whole system. Therefore, there is also a dedicated socket server that accepts ASCII queries of every subsystem asking for parameters. A new ASCII message containing the requested value is immediately returned to the asking subsystem.

5.1.4 Status thread

For a successful operation of the HRT, the CCS needs an up-to-date status of the whole system. This is done by the status thread, a parallel process that regularly requests status messages from all subsystems. In response, the subsystem sends status messages that are read and analyzed by the error handler (see above).

5.2 Adapter

The adapter is the most complex device of the HRT after the telescope. It contains two cameras for guiding and focusing (camera 1 images the tilted mirror that contains the fiber entrance and camera 2 used for guiding purposes), a flat field and a ThAr lamps, moving parts (a mirror and a prism, needed to guide the light of the stars or of the lamps to the fiber entrance). Finally, there is also an USB controller card, used to control these moving parts and the relays for the lamps, ventilators, cameras and filter wheels.

Furthermore, the operation is quite complex. The ACS has not only to control the devices mentioned above, but it also has to analyze the images which were taken with the ST7 cameras. It can do a target detection, using an algorithm similar to the task DAOFIND of the IRAF* package NOAO.DIGIPHOT.DAOPHOT. Furthermore, the ACS also computes the center of the stars with the centroid method; the brightness is determined by adding all counts inside an aperture and subtracting the value of the sky computed in a ring around the aperture. Finally, the FWHM is also computed by fitting the radial profile of the star with a Gaussian.

The commands that the ACS accepts include the following:

- Acquire/guide. The target is first detected and, using the computed centroid of the star, new offsets are sent to the telescope until the target is located on the fiber entrance.
- Search of the position of fiber entrance as seen by the guiding camera. For this command there are several methods. In one of the methods, at first the actual transformation from one camera to the other is determined (by taking several images at different telescope offsets with the two ST7 cameras). Then, the position of the fiber entrance on camera 1 is determined from a flat field illumination of the entrance mirror, and it is then transformed to the other camera. In the second method, the fiber hole is mapped by placing the star on different positions of the guiding camera, while the brightness of the star is simultaneously measured by the camera 1. The center of the fiber entrance is determined by the minimum brightness on

*IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

this camera 1 (as the light feeds the fiber and is not reflected by the mirror). In the third method, similar to the second, the fiber is also mapped and the maximum brightness as observed by the spectrograph camera is searched for.

- Focus. Also here several methods are used. In the first, the FWHM of the target is computed for different focus positions as described above. Other methods (similar to the the search of the fiber entrance) search for the focus yielding the maximum brightness as measured by the spectrograph camera or the minimum brightness obtained by the adapter camera that looks at the mirror containing the fiber entrance.

We have intensively tested these algorithms and found them to work successfully and to be robust to the different observational conditions.

5.3 Spectrograph

Currently, the spectrograph contains only one CCD camera in the blue channel. The CCD was delivered with its own control computer and software. The SCS controls this camera by means of TCP/IP messages to this computer. A disk commonly mounted at the SCS and CCD control computer is used to store the obtained images. The control of the camera allows to set its cooling and take images with different binnings.

In the future, the spectrograph will also have a second CCD, of the same type but optimized for the red channel, as well as a switching device (similar to the one of the adapter), that allows to switch the CCD cameras and their (additional) water cooling on and off.

5.4 Building

The BCS only controls the roof of the building. This is done via relays connected to the roof motor, controlled by a serial card.

5.5 Scheduler

The scheduler controls the flow of observations, therefore, one should expect it to be a client of the CCS. However, on the contrary it is a server of the CCS the one with the largest impact on the efficiency of the observations. The efficiency depends on the degree of sophistication – the "intelligence"– of the scheduler.

When the CCS and its subsystems have successfully finished a task (usually the observation of a star or a calibration task), the CCS requests for a new observational target.

Currently, there are two schedulers in operation: the "engineering" scheduler which has the higher priority and the scientific scheduler which sends a target to the CCS whenever the first scheduler has no target or task available. This means that the engineering scheduler contains all observational tasks that are time-critical. These are all calibrations as well as also stars that require an observation at a special time.

The engineering scheduler is a rigid program which is organized by a human operator in daytime. It is completely void of intelligence in contrast to the scientific scheduler which is in parts self-organizing and will be developed to higher intelligence step by step. However, at present most of the intelligence of the scientific scheduler is still fed in by the human operator who delivers the list of target stars. Each target is assigned a scientific priority; the simplest priority sequence is numbering the target stars in a manner a human operator would. However, at present the priorities in the observation list are changed daily based on an analysis of the observations of the foregoing clear night and on the scientific urgency. During operation of the HRT, the scientific priority is folded with a feasibility at a given time and in the future as well as with the history of observations this night.

Each star of the list is described by the following parameters: scientific priority, name, right ascension, declination, equinox, proper motion in right ascension, proper motion in declination, V magnitude, B-V magnitude, number of exposures, exposure time and a flag whether the sky background shall be observed sequentially or no background observation is required.

The basic principle for processing a demand for a new target by the CCS is folding the scientific priority with feasibility and history of observations. For the latter purpose the scheduler continuously updates a list of

the observations of this night where a history flag is set to zero whenever the star has been observed. In the next step, a weight of feasibility is built up. It is set to zero when the stellar elevation is expected to be below a certain value at any time during the observation. The weight is also set to zero when the distance to the Moon is below a threshold. In all other cases the weight of feasibility is calculated from two values:
i) the ratio of air mass to the airmass at the stellar position in the meridian and,
ii) a correction factor that accounts for the remaining time of visibility of the star. That means stars in the west are (slightly) preferred to stars in the east.

Finally, the priority is calculated as the product of the scientific priority, the history value and the weight. Then, the star with highest priority is reported to the CCS. In case that all priorities are zero a further check will be carried out: for all stars with a non-zero history value, it is checked whether they become visible later in the night. If such potential targets exist, an error message will be sent to the CCS: "target not yet available" and a waiting time is delivered. If there is no potential target left, an error message "no target available" is sent. In this case, the CCS will reset the target list by setting all history values to unity and then sending a new target request to the scheduler (a restart is surely better than prematurely finishing observations). However, if the star list still does not contain any available target direct following a reset of the history, the observatory will be closed.

This kind of scheduler is surely at a relative low level of intelligence. The future step of enhancement shall be the automatic determination of a scientific priority from more abstract categories, and keeping a history of observations over longer times than only one night. Another significant problem at present is that the scheduler lacks information about other stars than the target in the field of view of the acquisition camera. This can lead to acquisition of a false star although from our experience only with about a one percent probability.

5.6 Telescope

As mentioned above, the telescope was delivered including a control software. We have only developed an interface between the CCS and this software.

5.7 Environment control system (ECS)

The weather station (Vaisala WXT510) is connected to the computer via RS232 and automatically sends weather values.

The sky monitor usually takes exposures of 60 seconds every 5 minutes while the Sun is below an elevation of -12°. To reduce saturation effects, the exposures are split into several exposures for the time of positive Moon elevations. The positions of stars brighter than 5^{th} magnitude that should be visible on the CCD for the time of the exposure are computed. The sky is divided into 13 regions of equal size for which the relative number of positive detections is determined. Finally, a quality value from 0 to 10 is calculated for every region. The ECS also obtains the sky monitor values through a TCP/IP connection to the computer where the sky monitor is installed.

The ECS, unlike other subsystems, automatically reads, monitors, analyzes and archives the environmental values, irrespective of any order from the CCS. When the CCS is in operation, the ECS automatically sends error messages to the CCS in case of a bad weather event.

5.8 Automatic reduction pipeline (ARP)

The automatic reduction pipeline is called HEROS Pipeline. It is a reduction pipeline for echelle spectroscopic images taken with the HRT, optionally it includes an automatic wavelength calibration.

The HEROS Pipeline is based on the IDL (Interactive Data Language) reduction package REDUCE,[5] which comprises powerful and robust routines for processing echelle spectra.

The layout of the HEROS Pipeline in shown in Fig. 3, it can be split into four main parts, which are described in the following.

In the first part the initial parameters for the reduction are defined, e.g. the extraction width.

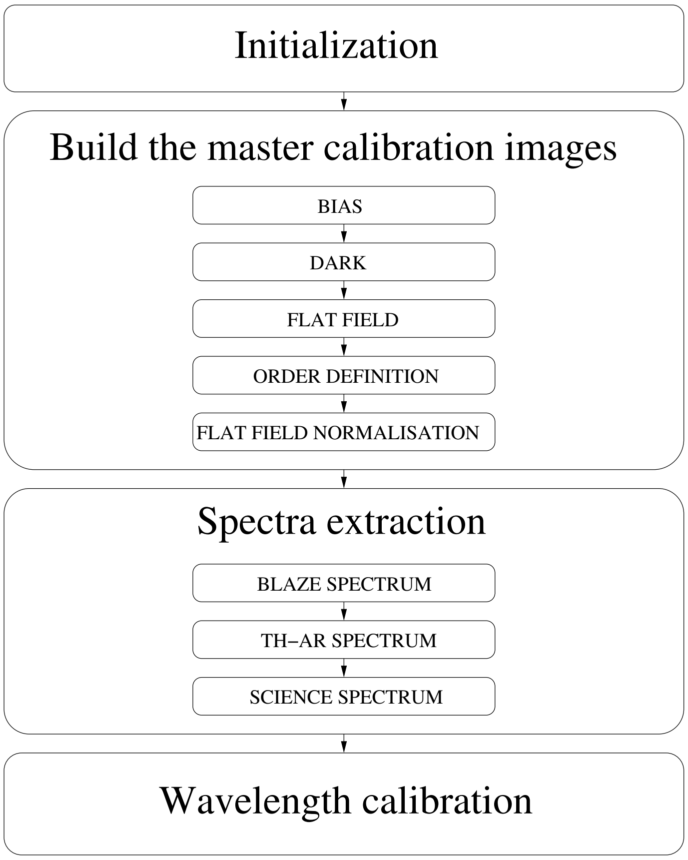

Figure 3. Layout of the reduction pipeline

In the next step the reduction process starts by creating master calibration images: an average bias, a time-normalized average dark frame, and an average flat field frame. The average flat field is used to determine the echelle order positions. Using these order positions, the flat field is then normalized.

The blaze function and ThAr spectrum are part of the calibration. But they are also spectra and therefore, the extraction of the blaze and ThAr spectrum is included in the section of the spectra extraction.

In the third part all spectra are extracted. For each frame, the scattered light is modelled and subtracted based on the inter-order regions. The optimum extraction uses a sophisticated order profile modelling, developed by N. Piskunov.[5] Finally, the science spectra are continuum normalized after extraction.

The last step is an optional automatic wavelength calibration. For this wavelength calibration, the shift between the most recent ThAr spectrum and a reference ThAr spectrum is determined using a cross correlation. With this shift a 2D wavelength solution can be constructed based on a solution for the reference ThAr spectrum.

6. LOGICAL STRUCTURE OF THE ROBOTIC OPERATION

From the operational point of view, we have divided an observation night into procedures which are composed of one or several commands.

6.1 Commands

Above, we have described what is the structure of the commands, how they are sent to the subsystems and how the subsystems process the commands. A command causes a subsystem to carry out a single task. However, this task usually comprises several different actions, some of them are rather complex. For example, when the adapter changes its configuration for a flat field exposure, which means that the light of the flat field lamp is fed into the fiber, first it moves a mirror, then a prism to a certain position. After that, the flat field lamp is turned on. In any case, from the CCS point of view, this is a single operation, because the CCS does not care how a command is performed.

6.2 Procedures

As mentioned above, in order to facilitate robotic operation, a night is divided into subsequent procedures. Only after the end of a procedure the robotic operator of the CCS decides which procedure is to be carried out next (or simply to wait if the conditions are not favorable, i.e. during bad weather or in daytime). When the CCS processes a procedure, there is usually a fixed, though sometimes variable, series of commands that are sent to the subsystems in a defined order. We have designed the different procedures in such a way that the number of different procedures is small while still allowing to perform all operations needed by the HRT.

At present, the following procedures have been implemented:

- Initialization: performed in the evening. All subsystems, except for the telescope, are initialized.
- Evening and morning calibrations: these procedures carry out the calibrations that can be done at day time, e.g. taking the bias, flat field and ThAr calibration images of the spectrograph cameras. These procedures are carried out after initialization and before sunset for the evening calibrations, and after the sunrise for the morning calibration directly preceding shutdown.
- Open: the roof is opened and the telescope is initialized after sunset if the weather conditions allow it.
- Start of night and end of night calibrations: these calibrations are carried out at the start of the night or end of the night at twilight, when the sky is not dark enough for the scientific observations, but still sufficiently dark for certain calibrations, such as focusing and searching for the entrance of the fiber.
- Observation: performed at night if weather conditions allow it. This procedure is repeated continuously during the night until there are no more targets observable or until morning twilight. The first command of this procedure requests a new target from the scheduler. As the procedure is repeated, usually a new different target is selected. So, although the robotic operator repeats the procedure, different observations are performed. The information message about the new target contains not only the name, positions, and properties of the star, but also the type of observation. This type can be scientific as well as engineer measurements, e.g. pointing model observations, or additional calibrations.
- Close: At sunrise the telescope is shut down and the roof is closed.
- Shutdown: carried out in the morning, after all calibrations are done. All subsystems are shut down.

Furthermore, apart from the mentioned procedures for "normal" robotic operations, there are also procedures whose aim is to solve problems that can occur during a night of observations (see Sect. 5.1.2 for the error handler). We are currently extending these error solution procedures. In some cases they are more complicated than the procedures described above, because the actions to take depend on the current status of the system/environment and on the current "normal" robotic procedure and command.

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