SOFTWARE AND HARDWARE TO IMPROVE A REMOTE TELESCOPE STATION

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ABSTRACT

The telescope network SMARTnet, established and operated by the German Aerospace Center (DLR) in close cooperation with the Astronomical Institute of the University of Bern (AIUB), is conceptualised to collect and distribute data from telescope stations. Contributing stations owned and operated by DLR are running remotely and autonomously. When there is no regular personnel at hand, operational tasks include supervising hardware and software states as well as the environmental conditions. The decision in favour of or against performing observations is made by the software alone and shall be based on well-defined criteria. A decision in favour of observations may be revoked any time in the event of changing conditions. Especially in case of declining weather conditions, observations have to be stopped immediately to prevent hardware damage. Furthermore, the set-up has to be failsafe to shut down observations and station hardware in cases of emergency, e.g. power failures or dome errors. Error handling is thus a key element. If components do not receive or send answers within a reasonable time frame, observations shall be stopped or the error may be solved by the software itself.

For DLR's stations within SMARTnet, the main supervision is based on two computers running in a master-slave configuration. Only the computer in the role of the master is commanding the stations despite of both being individually capable of it. This redundancy is fundamental, and all other hardware components were integrated around this concept. Both computers are checking each other's reachability via network connection permanently. The computer in the role of the master is checking continuously the status of the station components, the environmental conditions, the observations, and the image processing. The software for controlling the telescope and for processing the acquired images is part of a software package which had already been developed by AIUB. We will show how these software modules are incorporated into the station's software. Due to DLR's network security policy, a contact from any stations' computer to the DLR network is not allowed, disabling possibilities to gain ill-intended access to DLR's high-security projects. Therefore, a superordinate layer of software monitoring each station was established and is located at DLR. We will primarily focus on the stations' software and explain the superordinate layer in cases where the communication to the station is involved.

In this paper, we will describe adaptations of hardware components and the optimisation of the stations' software after the start of operation in April 2017. This description will focus on improvements which were made in order to stabilise operations. To put the improvements into context, we will give a condensed overview of the prototype and demonstrator versions, which were already addressed in earlier publications. Subsequently, we will set up scenarios, in which different problems occur after the inauguration in 2017, some hindering observations, some allowing for continuation. We will describe how the system is reacting to ensure maximum safety for the equipment and the steps which are taken to resolve the initially unsolved problems which occured before 2017.

Keywords: Remote Telescope Station; Passive-optical Observations; Hardware & Software.

1. INTRODUCTION

The passive-optical telescope stations of the Small Aperture Robotic Telescope network (SMARTnet), which are operated by the German Aerospace Center (DLR) and the Astronomical Institute of the University of Bern (AIUB), are conceptualised to work remotely. This puts high requirements on hardware and software components. When no regular personnel is around, the system has to be fail proof to some degree. On the other hand, customised products shall be avoided, if possible, to be able to replace broken parts with locally bought ones.

We will outline the selection process of hardware components. Experience of the community was a factor as well as proximity of the manufacturers. We focus on the changes between the build-up of the first station, SMART–01–SUTH in South Africa, and the deployment of the second station, SMART–02–KENT to Australia. In the individual testing phases, which are not subject of this

paper, the stations are build-up at the Zimmerwald Observatory near Bern (Switzerland). As observations were also included into the database these stations receive the name SMART–01–ZWLD and SMART–02–ZWLD, and will be referred as such in the following.

In case of the software, we refer to [1], where the prototype functionalities of the monitoring and control software are described. The demonstrator version, which was then installed at SMART–01–SUTH, will be mentioned. To demonstrate the key differences between the demonstrator version and the improved version, we will also list the main functionalities of the former. The development after the build-up of SMART–01–SUTH will be described in more detail. The interfaces between self-written code and third-party products are pointed out.

A key point in the description of hardware and software are the improvements since the build-up of SMART–01–SUTH. We will describe how hardware components were reconsidered based on the experience in the operational phase. The software was expanded to enable several functionalities which were not considered before.

Finally, we will show problems which occurred since the build-up of SMART–01–SUTH and how we were able to solve them. We categorise these problems into software-, hardware-, and network-related. The solutions in times of a world-wide pandemic differ from those in normal times.

At the end of the document, there may be found a photograph gallery to display the main topics of this paper.

Introductions of several components were already presented in earlier papers and at ealier conferences, yet not after the assembly and testing phases. In cases where the prototype and demonstrator set-ups are mentioned before operations started in 2017, the primary sources are referenced, otherwise the applied adaptations are described.

2. HARDWARE COMPONENTS

Beginning with the telescopes, we decided to cover multiple objectives, i. e. survey and follow-up observations. A large field of view is necessary for fast survey observations to detect bright objects, to observe objects' positions which are not of the highest precision and to observe the greater area around a parent object's position in case of break-ups. A small field may be used to detect faint objects (deep survey) and observe objects with a higher positional accuracy.

We decided in favour of a two-telescope setup with different diameters of the main mirror [6]. The design was selected first, the individual manufactures were contacted subsequently. The larger telescope is the CDK20 by PlaneWave Instruments [14] and has a main mirror of $50\,\mathrm{cm}$ in diameter with a focal length of about $3420\,\mathrm{mm}$, resulting in a field of view of $36' \times 36'$. The telescope for fast surveys is the ASA 8N by ASA Astrosysteme GmbH (ASA) ([7], not produced anymore) and has a main mirror of $20\,\mathrm{cm}$ in diameter with a focal length of about $590\,\mathrm{mm}$, resulting in a field of view of $3.5° \times 3.5°$. In [6], rough estimates of mirror diameter and focal length were presented leading to deviations to the more precise values listed above.

Both telescopes are equipped with the CCD camera PL16803 by Finger Lakes Instruments (FLI) ([2], manufacturer: [11]). The chip temperature is regulated by Peltier cooling elements which leads to less maintenance than e. g. water or nitrogen cooling systems. On the other hand, there is a limit on the achievable cooling temperature of maximum $70\,\mathrm{K}$ below ambient temperature and going under requires an alternative. The astrometry is little affected by the higher chip temperature. However, in case photometric or spectral observations a different cooling system may be required.

The mount is a DDM160A by ASA [7]. The used type is not produced anymore, but subsequent developments are available. The mount is fixed to a bent pier and operates as a German equatorial mount. It is suited for tracking object in Low Earth Orbit (LEO) regime up to stellar objects. The tracking modes, depending on the objective, may be selected from stellar tracking, fixed right ascension and declination or ephemeris values.

Both telescopes are positioned on one side with a counter weight rod opposing them [6]. An aluminium plate was constructed and attached to the mount where small auxiliary devices, like ethernet switches, are also attached. The $50\,\mathrm{cm}$ telescope is located in the middle, the $20\,\mathrm{cm}$ telescope at one end of the plate. This leaves some space on the other end for a possible third telescope in the future or to attach devices for fast operations and to prevent long signal run times.

Data storage is an important part of remote telescope stations. The access should be easy as data transfer has to be automatic. It has to be fail-safe when the harddrive breaks. We decided in favour of a NAS-RAID system in RAID1 configuration, which was realised with the TeraStation 1200 by Buffalo EU B.V. [10]. A regular disk usage check is performed by the monitoring and control software.

The dome housing the equpiment is situated on top of a cylindric concrete foundation of $2\,\mathrm{m}$ height. Inside the foundation there is space for equipment, which shall not be exposed to the environmental conditions, like power supply units. It was built to order of DLR by local companies. The constructional drawings were based on information by the manufacturer of the dome, Baader Planetarium [8]. The dome has an outer diameter of $3.5\,\mathrm{m}$ with a height of about $3.4\,\mathrm{m}$ [9] and consists of various parts: a cylindric base, and the moving parts of the dome in a clam shell confguration. Contrary to slit domes, this design does not move according to the telescope motion. The segments move when opening and closing, which results in less maintenance.

In the assembly phase at the observation site, the moving segments may be lifted by four people. In the final stage, when putting the fully assembled dome onto its foundation, a crane is needed.

A weather station is mounted close to the dome without obstructing a viewing direction. It monitors the environmental conditions and allows for or prevents observations, based on given limits. It is therefore included into the monitoring and control software described in the next section.

Components for surveillance of the equipment also include webcams. We chose SNC-XM631 and SNC-VM602R both by Sony ([16, 17], both not produced anymore), as there was already positive experience within other teams at DLR. At the station we have five of them: three in the dome, one inside the container (all SNC-XM631), and one outside of the container pointing to the dome (SNC-VM602R). Outdoor capability for at least one camera is essential for checking the the dome being open or closed.

Individual components may be switched on or off with a power distribution unit (PDU), which is accessable via ethernet. There are three PDUs at the station [12, 18], one of them located at the dome to switch the devices there separately.

When power outages occur, the station has to be transferred into a secure state, i. e. the observations have to be terminated and the dome has to be closed as referenced in [1]. All other components may continue to run so that in case of short term outages observation may be restarted quickly. For this very reason, there are two uninterrupted power supply units (UPS) at the station, one for the dome alone and the other for the other components (called station UPS, [19]). The usage of a PCI card for receiving sensor readings like load, battery life time amongst others via ethernet protocol is advised. The need for securing the telescopes enforces the usage of an independent UPS for the dome.

The entire equipment is shipped inside of a container to the designated station. After the assembly, the space inside the container is used as a temporary workplace and the location of the monitoring and control computers. Those computers are desktop computers, of which three run Windows 7, and one Ubuntu Linux. An additional module is a PCIe timer card by Microsemi [13] to get a precise trigger signals for the epoch registration of the cameras. Each CCD camera needs its own timer card which are connected to a shared GPS antenna. Components like computers, switches and other devices create heat and it is ill-advised to have those close to the telescopes. Inside the container, they do not disturb the observation process. Spare parts and tool boxes may also be placed there.

From a network perspective, all devices form a local network which is completely separated from the internet. Access to the station from DLR and AIUB is possible via VPN connection from dedicated computers, whose Internet Protocol (IP) addresses has to be whitelisted as mentioned in [1]. These requirements are defined by DLR's Germany Space Operations Center (GSOC) since it also operates high-security projects such as the ISS Columbus module and various satellites in their Launch & Early Operation Phases (LEOP) as well as routine operations. For this very reason, the network is built up by GSOC's department of Communications and Ground Stations, including network switches and hardware firewalls.

Within the local network, many components may be accessed individually via assigned IP addresses. This includes computers, UPS, webcams, and also PDUs. The latter may be used to deliberately activate or deactivate individual sockets, e. g. when shutting down a computer or switch on lights for hardware inspection.

Many components of the station are redundant to ensure in any circumstance that the station can be transferred into a secure state for further inspection afterwards or until the power or network connection is re-established [1].

This stage of hardware conceptualisation was finished with the end of the testing phase for SMART–01–ZWLD in Zimmerwald in January 2017.

2.1. Adaptions between SMART–01–SUTH and SMART–02–KENT

After the build-up of SMART–01–SUTH in April 2017 and before the purchase of the components for SMART–02–KENT, some revisions were discussed. The CDK20 may also be equipped with a pair of cover flaps. Those would be mounted at the front of the tube. Although initially mounted we decided against those after the build-up. Our reasoning behind the decision was the closed dome during daytime and an open dome at night in observations-allowing condidtions when covers would be open anyway.

The mount was changed to a twin mount configuration. Instead of having both telescopes on one side, one telescope replaces the counter weight rod. In case of mass differences, sets of counter weights may be attached to the base plate of the telescope and smaller counter weight rodes. The whole system becomes lighter and more compact.

The used computers turned out not to be as persistent as initially assumed. We decided in favour of rack-mount industrial grade computers. These have the advantage of sufficient memory to run several virtual machines. We were able to virtualise computers on which we run the telescope operation software ZimControl (see below).

On the telescope side of the equipment we exchanged the ASA 8N by a ASA 10H (again [7], not produced anymore), i. e. the hyperbolic main mirror has a diameter of 25 cm and a focal length of 900 mm. The field of view

is decreased to $2.3° \times 2.3°$. Simultaneously the sensitivity could be increased and with the fast survey strategy fainter objects may be detected. The reduced field of view may be compensated by an adjustment of the observation strategy, while an increased sensitivity is the key feature. The telescope type is still a Newtonian telescope, the basic concept remains.

To monitor as much meteorological information as possible, we decided in favour of a updated sensor of the weather station. It now includes the barometric air pressure installed.

After the station SMART–01–SUTH was struck by lightning, we had to replace the module commanding the dome motors. This maintenance was combined with the swap of a computer and the outdoor webcam which were affected by the same incident.

The PDU by Wöhlke EDV-Beratung was exchanged by a PDU from Inter-Tech Elektronik Handels-GmbH to only use one type of PDU and to be able to use C13/C14 connectors based on IEC 60320 standard consistently. Cables with these connectors may be easier to find worldwide and to replace than Schuko connectors. Many plugs were rewired to use C13/C14 connectors by the personnel at the Zimmerwald Observatory.

At SMART–02–KENT, we do not need a container as a temporary workplace as we are allowed to use server racks inside the control building of the University of Southern Queensland (USQ). Therefore, we do not need the webcam inside the container. The outdoor webcams is still mounted together with the weather station onto a pole and faces towards the dome. The pole is attached to the control building.

2.2. Foreseeable further Development

As of 2020, CCD cameras are not produced by FLI anymore. Other manufacturers also retire CCD cameras in favour of sCMOS cameras. Consequentially, SMARTnet will switch to sCMOS cameras in the future. Nevertheless, our third telescope station (SMART–03) will still be equipped with CCD cameras from FLI as switching will lead to major software developments and the amount of work cannot be estimated at the moment.

A new type of surveillance webcams has to be chosen as the current ones are not produced anymore. The requirements will stay the same such that at least one of them must be able to be deployed outdoors. The same considerations have to taken into account when replacing current webcams.

Because the mount and some of our chosen telescopes are not produced anymore, we will perform a new market investigation after the build-up of SMART–03 for products which will fit our requirements.

3. SOFTWARE CONCEPT – MONITORING AND CONTROL SOFTWARE

The requirements of the monitoring and control sonftware were developed very early. A first set of requirements for the so-called prototype was described with the following functionalities in [1]:

- shut down the dome in case of bad weather conditions like strong wind, sand / dust storm high humidity or rain

- shut down the complete station in case of redundancy failure and / or link loss

- setting the station in safe mode during longer power blackout

After discussing the matter at DLR, colleagues at AIUB were consulted. They have long lasting experience in operating remote telescopes.

In the implementation phase, a first set of limits for the wind speed and humidity were defined and implemented. The rain sensors were also read out. Again for redundancy reasons, we use two rain sensors: one at the weather station, the second one is mounted at the dome and is directly connected to the dome motors. If rain hits the sensor, it sends a command for closing the dome ([9], Section "Specifications"). This second sensor works independently from the monitoring and control software.

We estimated the time duration in which the station UPS is capable of supporting the necessary components before the station has to be shut down. All other components could be shut down first, reducing the load on the station UPS. The monitoring and control computers are shut down last as they are capable of restarting all other components via software commend once power is restored.

Although not described in [1], the prototype version of the monitoring and control software was also capable of managing third-party software. This includes reading out all sensor values of the weather station, taking and saving images of the surveillance webcams, as well as starting and stopping the telescope software. The weather station is accessed via a serial interface. The webcams are accessed via LAN, their images are stored on a NAS-RAID system.

The telescope software consists of several individual modules to be started and stopped:

- ZimControl, including telescope software ZimServer and processing software ZimServerProc [5]

- focuser and mirror heater software for PlaneWave telescopes, PlaneWave Interface (PWI 3) [15]

- interface to forward weather data to ZimServer

- timing module to forward GPS timing signals to the CCD cameras

ZimControl was first utilised at ZIMLAT, an SLR/CCD dual-use instrument, and subsequently adapted for the passive-optical instruments at Zimmerwald [3]. The Zim-Server module reads the observation plan and executes it automatically, while the ZimServerProc processes the resulting images into series of measurements of single objects, called tracklets. All necessary input files have to be provided by the monitoring and control software.

The communication protocol was adapted from the one developed and used by AIUB [4]. First developed for Satellite Laser Ranging (SLR) measurements, its functionality was broadened into passive-optical observations. The communication to the weather station, dome, UPS, webcams and PDUs was included, while keeping the original structure of commands and responses.

The monitoring and control software checks regularly whether the disc has space left for images of upcoming nights and deletes the oldest images. This strategy is feasable since the image processing results in separate files including tables containing all information of comparison stars and detected objects. Compared to raw images, these tables are much smaller in size. Because all necessary information can be extracted from them, the raw images are no longer needed.

The prototype of the monitoring and control software, which was developed from scratch at DLR, was written in python 2.7. The programming language was kept for the demonstrator version and the first improved versions. The development of the prototype took place by implementing the different hardware interfaces in the office. During the test phase, which again is not subject of this paper, the prototype was finalised into the demonstrator version of the monitoring and control software and was finished by the end of the testing phase for SMART–01–ZWLD in Zimmerwald in January 2017.

3.1. Software Improvements after the Built-up of SMART–01–SUTH

After the build-up of SMART–01–SUTH in April 2017, we discovered that several core functionalities were missing in the demonstrator version of the monitoring and control software. The range of functionalities now also includes a back-up of log files written by the monitoring and control software. As we collect data via ftp and sftp, open files cannot be transferred. The back-up files are updated regularly and may then be copied to a computer at DLR for further analysis.

As multiple instances of a module or third-party software may hinder a successful start or restart of that application, the multiple instances are selected and securely terminated. This improvement leads to a more stable observation process with less necessary interference by the operator.

After the exchange of the dome motors command module, we implemented a regular communication to the dome to check the state of the segments. As mentioned above, in a night with nominal conditions, the dome segments move twice, once opening and closing. For safety reasons, Baader Planetarium implemented in its module that the dome closes automatically when there is no command or status request for about $4\,\mathrm{min}$. Hence, before the limit of $4\,\mathrm{min}$ is reached, a command is sent to the dome to receive its status and to keep it open during operations. This enhances safety of the instruments in case of failure of the computers.

The defined limits for weather data proved to be insufficient as the real limits depend on the final location. We also added a hysteresis: e. g. the mean wind speed exceeds $40\,\mathrm{km\,h^{-1}}$ and observations are stopped, the mean wind speed has go under $35\,\mathrm{km\,h^{-1}}$ before observations can be restarted. This is important when the mean wind speed varies around $40\,\mathrm{km\,h^{-1}}$ for some time, and switching the devices on and off may set the system into an ill-defined state. Similar hysteresis procedures were also implemented for the peak wind speed, the relative humidity, and the estimated cloud level.

3.2. Software Improvements between SMART–01–SUTH and SMART–02–KENT

As python 2.7 has reached its end of life, a new version has to be considered. Initially, python 3.6 was chosen, but meanwhile newer versions are available. A final decision is based on when SMART–03 enters its testing phase.

A part of the observation planning process was transferred to the station. In case of maintenance when a planning schedule is needed, this script can be run and a schedule with survey field definitions is produced. As the station network is separated from the internet, no recent satellite data can be downloaded, hence the survey-only mode.

To be applicable at the station SMART–02–KENT, the software ZimControl was upgraded for a global application. A known issue of ZimControl is running into the state "Not Responding" under Windows. This behaviour is due to a conceptual error in the software itself. The solution in the source code is currently realised at AIUB, while as a temporary solution, a tool was developed by AIUB to enable a continuation of observations automatically. This tool is currently used at the Zimmerwald Observatory, SMART–01–SUTH, and SMART–02–KENT.

ZimControl in general is not developed specifically for SMARTnet. Ongoing work and improvements are implemented by AIUB, tested at the telescopes of the Zimmerwald Observatory and then deployed at SMARTnet telescopes.

The individual processing steps of ZimControl from images until tracklets is conflated to establish a coordinated complete process. The tracklet creation is now a near

real-time process. The tracklets of single nights are stored in separate daily folders. This speeds up a listing and transfer process from the station to DLR because solely the tracklets of the concerning night are looped over. Tracklets are inserted faster into the database and may be provided faster to the partners of SMARTnet.

We added another safety measure with calculating the elevation of the Sun in the monitoring and control software. If the conditions improve too close to dawn, we don't start observations, as we may not be able to take a full series of images. Cooling the cameras takes some time which might exceed the time until dawn. Furthermore, we send a closing command to the dome when the Sun is $4°$ below the horizon, regardless whether it is already closed. This way we ensure a closed dome at sunrise to avoid direct sunlight onto the telescopes and telescope-near hardware.

3.3. Forseeable further Software Development

In case of SMART–01–SUTH and SMART–02–KENT, the upgrade to a subsequent version of python will be made, when maintenance is due. Python 2.7 will still be running, the inclusion of new functionalities may not be possible for this version. When SMART–03 exits its testing phase and is ready to be deployed, we will have a further improved version of the monitoring and control software written in python 3.X, which will then be installed at the other stations. All stations will have the same version of the monitoring and control software in the end, with station-specific minor differences.

As several manufacturers of cameras, focusers, and filter wheels use the ASCOM interface, it will be included into the ZimControl software. We aim for the possibility to use a multitude of components.

As of now, switching from one telescope to the other on the same mount requires parking the telescope and closing the TCP/IP connection to the ZimServer software when using the ASA proxy server to create a well-defined state of the system before switching the telescope. There will be a possibility implemented to enable a faster switch of two telescopes on a single mount.

The processing steps within ZimControl (ZimServer-Proc) are constantly undergoing developments. Already tested at the Zimmerwald Observatory and almost ready for a roll-out for SMARTnet telescopes is a direct read-out of UCAC4 star catalogue data to avoid incomplete data sets in some cases when a separated star catalogue server is accessed. The detection of interrupted star streaks is implemented as well and will lead to a higher accuracy in the stage of differential astrometry.

A big software project within SMARTnet is the development of a telescope software from scratch. At the moment, we are depending on a variety of hardware components which may use different interfaces or protocols.

Those may still be present as a kind of proxy server, because they come from the manufacturers, nevertheless the communication with these proxy servers will be performed with a unified protocol. It will affect all major hardware components, like sCMOS cameras, focusers, mounts, filter wheels, amongst others. The functionalities described above will also be included.

4. PROBLEMS AND SOLUTION STRATEGIES

Occurring problems may be put into three categories: hardware, software, and network. They are not strictly distinct from each other, yet for the sake of simplicity we use this terminology.

Network problems affect the connection to the station as a whole. It might be as simple as a missing IP address on the whitelist or very severe like a deliberate destruction of a network knot. The latter happened in South Africa in 2020, where nobody at the station nor at DLR had any influence on the repair. In these cases, we have to rely on external companies and their schedules.

Software problems are most likely the easiest, because as long as an access to the corresponding hardware component or the monitoring and control computers is possible, issues with software may be solved quickly. Solutions include debugging and implementing new routines for the observation process. Like the aforementioned opening of the dome too close to dawn, the dome was found open in the morning. The reconstruction of the later stages of the night led us to the origin and the solution with sending a close signal when the Sun is at $4°$ below the horizon.

An easy solution is not necessarily possible for software updates. In case of our separated network, access to the internet is not possible. A new software version or a module has to be downloaded off-site, transferred and then installed offline. Especially for python modules, the direct access to package repositories (e.g. via pip) is not possible. Solutions with tarballs or manually downloaded wheel files should be treated carefully because of possible dependencies of the modules among each other.

Any hardware-related problem is severe and might hinder observations for a longer time period. The decision to avoid secluded areas and choose sites with experience personnel alleviates this problem, although the installation of a replacement may still take weeks or even months. In normal circumstances, team members of SMARTnet would order replacement parts, send them from a DLR site to the station, and travel there themselves, afterwards. The fact that all components at the station are not customised but off-the-shelf makes a replacement much easier. In other cases, it was simpler to send a member of the SMARTnet team with a transport crate containing the necessary replacements. The decision depends on the amount of work and amount of people needed.

These strategies have to be modified in times like the COVID-19 pandemic. Business travels are prohibited and even if possible, the situation in the country of the station might change rapidly, rendering work impossible at worst. SMARTnet profits in this situation from experienced personnel even more. In case of the broken main board of the mount at SMART–02–KENT, we were able to ship a replacement part to USQ directly, where staff could install it. Regarding work safety rules at the station, it still may take some time, but the local personnel may be able to work much earlier than business trips from DLR.

5. SUMMARY

In this paper we described the hardware selection process for building up a remote station of passive-optical telescopes. As two stations with this equipment are operational, this concept proves viable. We selected telescope types based on objectives: one for fast survey, another for high-accuracy follow-up observation. Where the hardware components were not as reliable and persistent as assumed, we described the replacements. We also pointed out how we selected improvements based on new developments. This includes using a different type of camera in the future or a different type of computer at present.

In terms of software we described how the development progressed after the implentation of the demonstrator version. We included new functionalities, like a near real-time image processing. This creates much lower latencies between acquiring the observation and including the resulting tracklets into the database at DLR. Issues with third-party software, where we do not have the source code, were dealt with by a safe termination and a restart. The monitoring and control software has to perform these operations automatically as not regular human observer is around. The applied improvements led to a more stable version of the monitoring and control software.

As the entire station is in a separated network we described the necessary requirements for the situation and the difficulties which arise.

Lastly, we set up some scenarios where different kinds of problems had to be solved. These scenarios were based on real-life experience since 2017. A solution strategy for each scenario was presented. The change in strategy during the COVID-19 pandemic and how to deal with the new situation was mentioned as well.

Finally, we are able to look back at four eventful and successful years of operation.

PHOTOGRAPH GALLERY

Figure 1. Telescope station SMART–01–SUTH with dome, lightning rod, and container, by courtesy of H. Fiedler
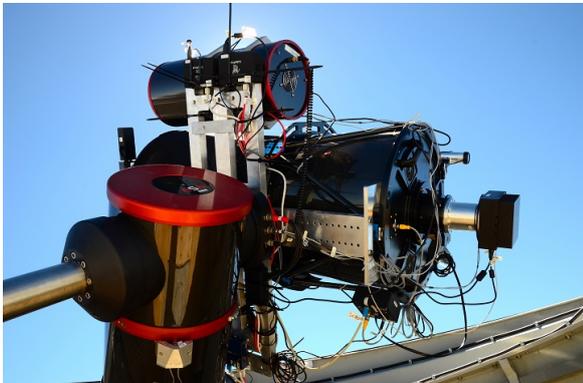

Figure 2. Mount and 20 cm *telescope above* 50 cm *telescope, SMART–01–SUTH, by courtesy of M. Prohaska*

Figure 3. Dome, mount, 25 cm *telescope (foreground), and* 50 cm *telescope (background), SMART–02–KENT, by courtesy of J. Herzog*
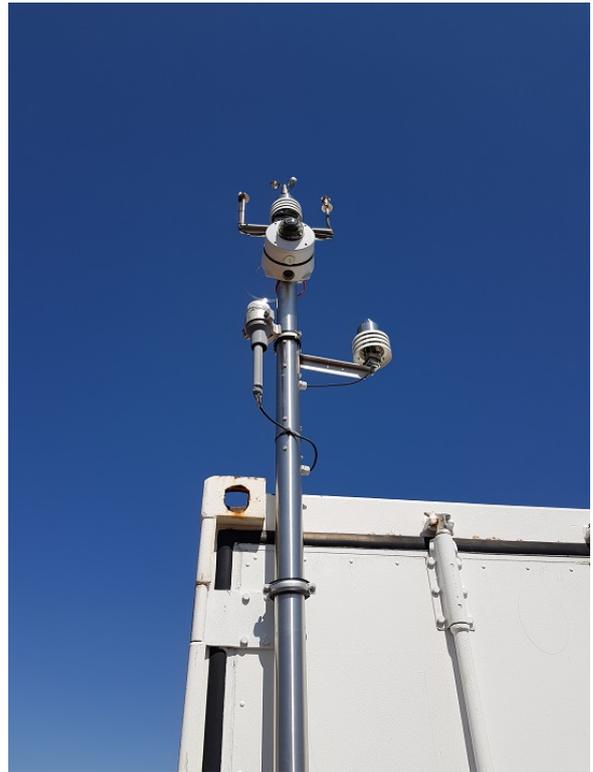
Figure 4. Weather station, GPS antenna, and webcam towards the dome, altogether mounted on a pole at the container, SMART–01–SUTH, by courtesy of J. Bernardo (SAAO)

Figure 5. Control building of USQ and telescope station SMART–02–KENT with dome, by courtesy of J. Herzog
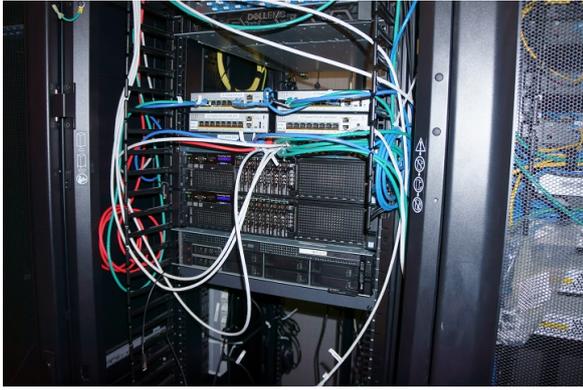
Figure 6. Computer rack, monitoring and control computers, hardware firewalls on top, SMART–02–KENT, by courtesy of H. Fiedler

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