A Mirror Alignment Control System for H.E.S.S. Phase II

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***Abstract*. The H.E.S.S. experiment in Namibia, which currently consists of four Cherenkov telescopes, will be extended in phase II by a fifth, larger telescope. This new telescope with its 890 mirrors poses new challenges on the design of the Mirror Alignment Control System. Important features of the new developed design are, apart from the scalability for future experiments, the possibility to do a fast realignment of a subgroup of mirrors, the fully robotic operation and the protection of the system from nearby lightning strikes. The overall design of the mirror alignment control system, its current implementation and possible modifications that would be needed to adapt it for a future Cherenkov telescope observatory are presented.**

I. Introduction

H.E.S.S. phase II, the expansion of the current H.E.S.S. experiment by a fifth, larger telescope, is currently under construction in Namibia. The reflector will consist of 890 mirror tiles. Each mirror tile will be supported at three points, with two points movable by a motor driven actuator. With this construction, the orientation of the mirror tile can be adjusted. The system that controls the adjustment of the mirrors will be described here. The procedure of the alignment was adapted from the system that is in use for the current H.E.S.S. telescopes and is described in detail in [1]. The basic layout and main components can be seen in Figure 1. For the initial alignment, the telescope is pointed at a star. A CCD camera takes pictures of the reflections of the starlight on the lid of the photomultiplier camera in the focal plane. A transformation matrix is calculated, that can translate between the position of a reflection in the focal plane and the position of the actuator of a mirror tile. With this transformation matrix, all mirror tiles can be aligned to point to the center of the photomultiplier camera.

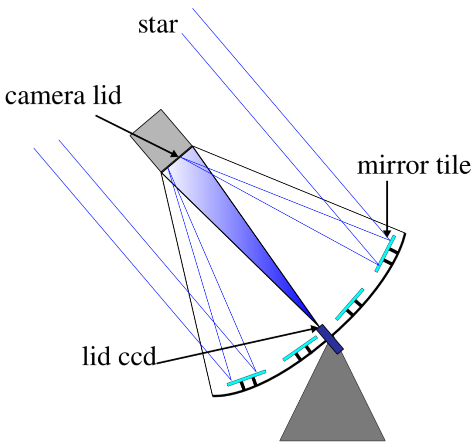

Fig. 1. Basic components and layout of the mirror alignment system (figure and procedure are based on [1]). Starlight is reflected by the individual mirror tiles of the reflector onto the PMT camera lid. A CCD camera takes pictures of these reflections, so called 'mirror spots'.

II. Mechanics and electronics

The motors that move the actuators are DC motors originally used for in-car applications like electrically operated window regulators by the automotive industry. Information about the movement of a motor can be deduced from the hall signal that is emitted by a hall sensor close to the motor axis. Since a worm drive with a 1/210 ratio is also included in the motor, each turning of the actuator axis can be divided into 210 steps or, if the raising and the falling edge of the hall signal are recognized separately, into 420 steps. This resolution translates into a linear displacement of $\sim$2.4μm per hall count and an angular resolution of 2.2arcsec which is $\sim 1/100$ of the pixel size of the PMT camera.

The layout of the system that will be used to analyze the hall pulses, control the movement of the motors and provide the communication means to control the system remotely, can be seen in Figure 2. The main components are a workstation in the control building, a switch and a power supply at a central position on the dish and 25 panel control boxes, each located at a central position of the corresponding panel. A panel control box contains a panel controller board, a bus system and seven motor controller boards.

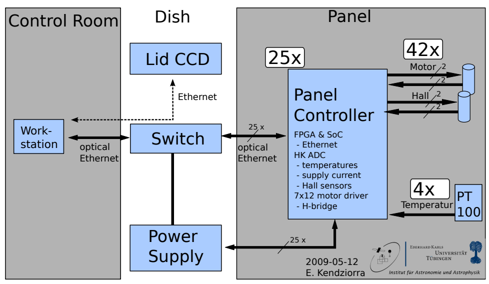

Fig. 2. H.E.S.S. 2 Mirror Alignment Block Diagram

Since the H.E.S.S. phase II telescope has a larger number of mirror tiles than current H.E.S.S. telescopes, it is desirable to align the individual tiles faster than in H.E.S.S. I, where only one mirror could be moved at a time, and possibly also allow several mirror tiles to be moved at a time without optical feedback. Therefore, and following the configuration of the mirror support dish structure, the alignment system is divided into 25 identical panels. Each panel can operate independently and communicates with the control software on the central server (outside the dish) via a simple TCP/IP based protocol. This Ethernet connection is physically realized with optical fibers, and media converters on each panel controller, at a switch on the dish, and on the ground. This was necessary to protect the electronic components from induced currents of nearby lightning hits, a problem that is more serious in the H.E.S.S. phase II telescope than it is for the four current telescopes, due to its larger height and the absence of large lightning protection masts for H.E.S.S. phase II.

The custom electronics components (motor boards, bus system, panel-controller board) have been designed at the IAAT. The actuators were designed by the MPI-K in Heidelberg and commissioned by the Astronomical Institute of the Cracow University.

Fig. 3. Main electronics for one panel. A bus system connects the seven motor controller boards in the box. One of these boards is shown in the front.

III. Software

The Ethernet connectivity of each panel controller is provided by a System-on-Chip (SoC), a FPGA based commercial board (Suzaku-S, see [3]). On the Mircoblaze soft processor core, a CPU architecture implemented as a FPGA hardware design, an embedded operating system (uClinux, see [4]) provides a full TCP/IP stack to the panel control daemon which is written in C and already in large parts working and tested. The daemon includes a hardware driver in userspace, a construction that can be achieved due to the absence of a Memory Management Unit (MMU) in the Microblaze CPU.

Programmed onto the same FPGA, along with the CPU and other components, is a custom FPGA hardware design, which was developed in Tübingen, that controls the movement of up to 84 motors via signals to the motor drivers (H-bridges) on the motor driver boards (this board can be seen in Figure 3). The hall signals coming from the motors are than multiplexed, converted into digital signals and analyzed. Based on this analysis the FPGA hardware design is able to drive the motors a defined range of hall counts and will in the future also be able to stop the motors if the time between two hall counts gets too large, which would indicate a malfunction of the motor. Other additional functionality like stopping the motors in case of overheating or a too large power consumption will be implemented in the near future.

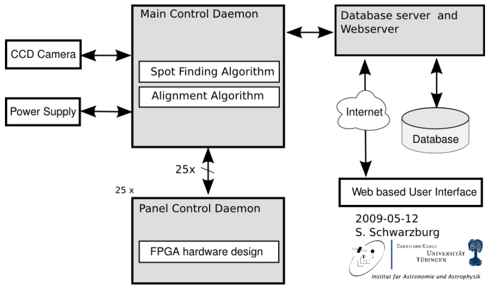

Fig. 4. Software components of the Mirror Alignment Control System

Apart from the FPGA hardware design on the panel controller and the software on the SoC which mainly provides an Ethernet based interface to the custom VHDL hardware design, there are also several other software components involved. A web based user interface is currently being implemented which will allow to start and stop the mainly automatic alignment procedure. The server side of the interface application also acts as a database manager that will store all the alignment related information like actuator position, a history of the movements, images of the reflections of the mirror tiles as well as a maintenance record of the mechanical components.

The software of the alignment system running on the central server is developed in Python with *scipy/numpy* being the basis of the spot finding algorithm and the *django* web framework for the object-relation mapper (ORM) and the web interface. Several components of the alignment system have been tested so far. One of the critical parts of the alignment is the accuracy with which the hall counts get detected and counted. This was extensively tested in different kinds of test cycles.

Fig. 5. Test setup to measure the accuracy during the long term tests.

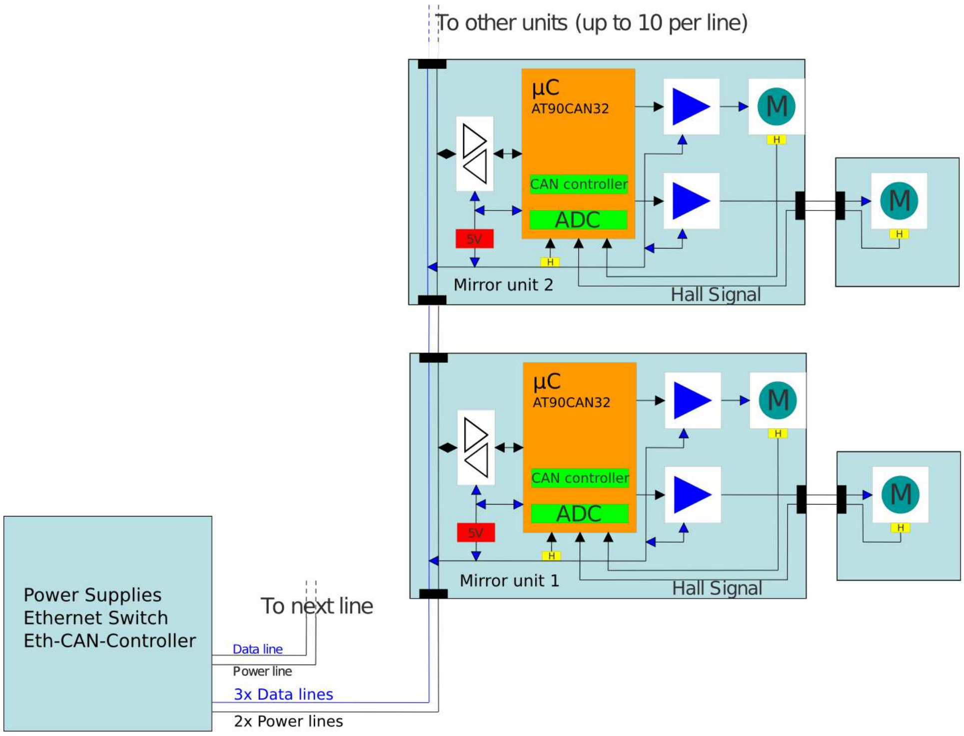

Fig. 6. Possible design of the CTA active mirror control system. Only parts on the telescope are shown. Starting from a central position in the dish, Ethernet to CAN converters are connected to several CAN busses, the actual number depends on the telescope design. Ten mirror units are connected to each CAN bus, each containing an Atmel microcontroller as the central control component.

An initial test was to compare the number of hall counts detected by the alignment system with a manual count of the signal that was recorded with an oscilloscope. No deviation could be measured in several of these test. This was done with hall count numbers of the order of 100. When going to larger numbers of hall pulses (e.g. 100000), a manual comparison is no longer possible, therefore a different kind of test setup was used (see Figure 5). In this setup, the actuator was moved a certain number of steps in one direction and then the same amount of steps in the other direction. This cycle was repeated a few hundred times before the difference between the start position and the end position was measured with an analogue dial gauge. The overall number of these cycles was chosen to be much larger than the estimated number of movements in the lifetime of the H.E.S.S. experiment. A conservative estimation on the number of movements in the lifetime could be one cycle per motor and month, independently of the need to make a realignment, to prevent the mechanical parts from corroding. In total 4400 cycles were performed which corresponds to 10 years of operation with 36 cycles per month, a factor 36 more than the expected number of movements in 10 years.
The results of 9 measurements were a deviation of $0 \pm 10\mu$m in six and $10\pm10\mu$m in 3 measurements (10μm correspond to $\sim$4 hall counts). This shows that both the durability of the hardware as well as the accuracy of the electronic hall count detection and motor drive system is well suited for the H.E.S.S. phase II telescope.

IV. TOWARDS A POSSIBLE CTA ACTIVE MIRROR CONTROL

Developments are currently ongoing to design a prototype possible for application in the planned array of Cherenkov telescopes (CTA).
Current design guidelines foresee the ability to realign the mirrors during an observation (Active Mirror Control, AMC) in case the chosen mounts are not stiff enough to allow a single mirror position for all zenith angles. Although the mirror alignment system for H.E.S.S. phase II is easily extendable for other telescopes, this requirement makes it necessary to further decentralize the analysis of the hall signals and the motor control so that more motors can be moved at a time.
A design currently under investigation can be seen in Figure 6.
In this design each mirror has its own control electronics, composed of a motor driver for each motor and a microcontroller (Atmel AT90CAN32) that already includes an 10bit ADC and a Controller Area Network (CAN) controller. The electronic components are placed in a watertight box, possibly vented by a valve of sintered bronze as it is used in the H.E.S.S. phase II design, together with one of the motors. The other motor is placed in a separate box, with the two boxes forming a mirror control unit.
Apart from the microcontroller, an additional CAN transceiver would be needed to allow one mirror control unit to communicate with the other units and also via a CAN-to-Ethernet converter at a central position in the

dish to communicate with a remote control software.
To allow for a simpler cabling procedure, the two power wires and three CAN bus wires will be combined in a single five-wire cable. Since all mirrors should be movable at a time and because the power cable diameter should not exceed a certain value, not more than 10 mirror units will be chained up on a single CAN bus.
Similar to the design for H.E.S.S. phase II, a temperature sensor as well as an additional hall sensor to measure the power consumption of the motors will be included in the motor box.
The current design does not foresee an optical feedback of the mirror position, therefore a calibration of the positioning must be done during the initial alignment. From these calibration values, a look-up table will be created, that connects the zenith angle of the telescope with the necessary movement of the motors. With this tables an active alignment of all mirrors of the telescope can be achieved whenever the telescope has moved over certain zenith angle thresholds. The exact threshold values have to be defined when more properties of the mirror support structure are known. Assuming an actuator and motor combination similar to H.E.S.S. phase II, the system will have an accuracy of $\sim$ 2.4 μm of the actuator, but with a larger separation of the actuators ($\sim$1m) than in H.E.S.S. phase II and therefore an angular resolution of a mirror spot of $\sim$1.3arcsec. More information about the development of mirrors for CTA can be found in [2].
A displacement of 1mm of an actuator, the maximum displacement foreseen in the current design guidelines for the CTA prototype, takes $\sim$3.5sec, given that there are two motors per mirror and normally both motors will be moved, less than 10sec would be needed to realign the telescope.

REFERENCES

[1] R. Cornils, et al., *The optical system of the H.E.S.S. imaging atmospheric Cherenkov telescopes Part II: mirror alignment and point spread function*, Astropart.Phys. 20 (2003) 129-143
[2] M. Doro, et al., *Technologies of mirrors facets for the telescopes of the CTA observatory*, in this volume
[3] *Atmark Techno* http://www.atmark-techno.com/en/products/suzaku/suzaku-s
[4] *uClinux* http://www.uclinux.org/