FACT: Towards Robotic Operation of an Imaging Air Cherenkov Telescope

A. BILAND[1], H. ANDERHUB[1], M. BACKES[2], V. BOCCONE[3], I. BRAUN[1], T. BRETZ[1], J. BUSS[2], F. CADOUX[3], V. COMMICHAU[1], L. DJAMBAZOV[1], D. DORNER[5], S. EINECKE[2], D. EISENACHER[5], A. GENDOTTI[1], O. GRIMM[1], H. VON GUNTEN[1], C. HALLER[1], D. HILDEBRAND[1], U. HORISBERGER[1], B. HUBER[1a], K.-S. KIM[1b], M. L. KNOETIG[1], J.-H. KÖHNE[2], T. KRÄHENBÜHL[1], B. KRUMM[2], M. LEE[1b], E. LORENZ[1c], W. LUSTERMANN[1], E. LYARD[3], K. MANNHEIM[5], M. MEHARGA[3], K. MEIER[5], T. MONTARULI[3], D. NEISE[2], F. NESSI-TEDALDI[1], A.-K. OVERKEMPING[2], A. PARAVAC[5], F. PAUSS[1], D. RENKER[1d], W. RHODE[2], M. RIBORDY[4], U. RÖSER[1], J.-P. STUCKI[1], J. SCHNEIDER[1], T. STEINBRING[5], F. TEMME[2], J. THAELE[2], S. TOBLER[1], G. VIERTEL[1], P. VOGLER[1], R. WALTER[3], K. WARDA[2], Q. WEITZEL[1], M. ZÄNGLEIN[5] (FACT COLLABORATION)

[1] *ETH Zurich, Switzerland – Institute for Particle Physics, Schafmattstr. 20, 8093 Zurich*
[2] *Technische Universität Dortmund, Germany – Experimental Physics 5, Otto-Hahn-Str. 4, 44221 Dortmund*
[3] *University of Geneva, Switzerland – ISDC, Chemin d'Ecogia 16, 1290 Versoix – DPNC, Quai Ernest-Ansermet 24, 1211 Geneva*
[4] *EPF Lausanne, Switzerland – Laboratory for High Energy Physics, 1015 Lausanne*
[5] *Universität Würzburg, Germany – Institute for Theoretical Physics and Astrophysics, Emil-Fischer-Str. 31, 97074 Würzburg*
[a] *Also at: University of Zurich, Physik-Institut, 8057 Zurich, Switzerland*
[b] *Also at: Kyungpook National University, Center for High Energy Physics, 702-701 Daegu, Korea*
[c] *Also at: Max-Planck-Institut für Physik, D-80805 Munich, Germany*
[d] *Also at: Technische Universität München, D-85748 Garching, Germany*

biland@phys.ethz.ch

Abstract: The First G-APD Cherenkov Telescope (FACT) became operational at La Palma in October 2011. Since summer 2012, due to very smooth and stable operation, it is the first telescope of its kind that is routinely operated from remote, without the need for a data-taking crew on site. In addition, many standard tasks of operation are executed automatically without the need for manual interaction. Based on the experience gained so far, some alterations to improve the safety of the system are under development to allow robotic operation in the future. We present the setup and precautions used to implement remote operations and the experience gained so far, as well as the work towards robotic operation.

Keywords: FACT, IACT, remote operation, robotic operation

1 Introduction

So far, all Imaging Air Cherenkov Telescopes use Photomultiplier tubes to measure the dim flashes of Cherenkov light emitted by air-showers induced by high energy cosmic-ray particles or gamma-rays. The First G-APD Cherenkov Telescope (FACT) investigates the feasibility of using solid state photosensors (Avalanche Photo Diodes operated in Geiger-mode: G-APD aka SiPM) for future cameras. A complete camera consisting of 1440 pixels was designed, constructed and installed in the refurbished HEGRA CT3 telescope, having a mirror area of ≈ 9.5 m^2, at the canary Island La Palma next to the two huge MAGIC telescopes [1, 2].

The G-APDs are type Hamamatsu MPPC S10362-33-50C, equipped with solid light concentrators. The electronics is based on the DRS4 chip and read via standard Ethernet. The physics trigger uses analogue sums of nine neighbouring pixels forming a trigger-patch, and the complete camera is read out in case one patch has a signal above a programmable threshold. The complete trigger and data-acquisition electronics is integrated in the camera body.

The power supplies for the electronics as well as bias voltage for the G-APDs are located in a container next to the telescope, housing also the control cabinet for the drive systems, the computers for data-acquisition, control, onsite data-analysis and communication as well as working space for an onsite shift crew.

There are several individual processes to operate the telescope, mainly drive control, slow control, trigger control, bias control and daq control, all steered by a central control. All the communications between these systems uses the DIM environment[3], allowing also easy integration of different user interfaces. Currently there exists a command-line interface, a full graphical interface allowing also full debugging of the system, and a reduced graphical interface for standard operations that can be run from smartphones.

Power is delivered from the MAGIC system, including a large UPS and a diesel generator in case of extended power outages. Internet is based on the system delivered by the ORM (Observatorio Roque de los Muchachos).

2 Early Operation and Identified Problems

The FACT camera was mounted in October 2011, and few hours after cabling the first airshowers were successfully recorded (under fullmoon conditions). While it was planned to bring the camera back to the laboratory for some upgrade work after few months of experience gained, the system is working so reliable since the first minute that this upgrade was canceled and FACT is taking data since then almost every night.

Very few problems have been encountered so far, mainly when powering on the camera. It can happen that some components do not correctly boot, but all these problems can be solved by a reset command or a power cycling of the camera electronics.

During operation, it can happen that some communications get lost. All these can be identified within very short time, and a simple reconnect command was always sufficient to restore operation.

Few incidences needed a manual interaction when a FACT crew was still on site:
– Once the drive system behaved erratically and it was necessary to park the telescope manually. This was traced to a cable in the control cabinet of the drive system being damaged and was repaired within two days.
– Recently, the electronics of the drive system started to suffer from very high temperatures in the container. We are going to install a cooling system. – A fuse inside the camera housing protecting the electronics did blow. The cause might have been a DRS4 not correctly initializing and therefore consuming far too much power. In the mean time, additional monitoring is installed to prevent such an incident. Being a prototype, some necessary changes in the basic design during construction resulted in a crowded system not allowing easy maintenance of the electronics inside the camera housing. Nevertheless, a procedure was developed at site and the damage repaired within few days.
– The electronics controlling the Bias supply lost its firmware for unknown reasons and was replaced by a spare board.
– One of the boards delivering Bias voltages did break and was replaced by a spare board.
– After almost two years of operation, the water pump for cooling the camera electronics needed a major maintenance.

Beyond these, the only manual interactions ever necessary were refilling of cooling water, greasing the hinges of the camera lid and replacing a broken disk in a RAID array. Recently, we suffered for few nights from overheating of the electronics of the drive system and are improving its cooling.

The stability and reliability of the system allows to operate FACT since spring 2012 from remote, without the need of a shift-crew permanently at La Palma. Currently, we are working on minor auxiliary system improvements to allow robotic operation in near future. Of course, the system cannot be left fully unattended, and we have an agreement with the MAGIC collaboration to get some help from the onsite crew in case of emergencies. But the need for help shall be limited to exceptional cases.

3 Personnel safety

By far the most important aspect of operation of a system without onsite crew is to care for safety of people who could be near to the telescope. Therefore, the telescope is fully fenced without a gate. The only possibility to enter is through the container, having one door outside and one inside of the gate. The container is locked, with the MAGIC crew having access to the key in case emergency access is needed. If work has to be performed at the telescope structure, a large switch disables the power to the drive system.

A infrared CCD can monitor the area. If it is too dark, a infrared illumination can be activated, but this has to be limited to emergencies since it does affect datataking.

4 Remote operation

Not only for remote, but also for onsite operation it is a good strategy that major hardware components shall protect themself against malfunctioning. Section 6 will explain in detail how this is implemented for the major subsystems.

This leaves as key difference between onsite and remote operation that it is not possible to press buttons on e.g. front panels of power supplies or switching power off and on. Fortunately the AGILENT [4] power supplies used can be fully controlled via Ethernet, needing no modifications. Minor systems like the lid control were upgraded with simple Ethernet connectivity based on Arduino [5] boards. In addition, we want to be able to power cycle each component via its 220V connection. Therefore, we installed Ethernet controllable power switches (GUDE 8012 [6]), and did configure all computers to boot at power up. For security reasons, all Ethernet connections are limited to a internal network, with the only connection from outside via two redundant gateway computers.

This leaves a major vulnerability: if both gateway computers are stuck, there is no possibity to access the power switch to reboot them. Therefore, the computers are connected to a power switch GUDE 8090 [6] that is not only accessible via the internal network, but also via sending a SMS message from a cellular phone via GSM. This allows to power cycle all components necessary for Internet communication from remote, independent of the Internet.

Since more than one year we operate FACT from remote without a major hardware problem. During this time, we upgraded the software to identify and cure every incident we encountered so far. In addition, all operations except the safety relevant parts like unlocking the drive system are now executed via scripts, configuration files and database entries. This reduces the duty of the remote shifter more and more to a simple monitoring task.

5 Robotic Operation

The step from remote to robotic operation is mainly to ensure that the system is able to operate on its own and can handle all the known or foreseeable malfunctions. Save operation shall have priority over extended datataking, so in case of an unexpected problem the system should put itself into a save state (i.e. at least parking the telescope and switching off the bias voltage of the G-APDs) and inform the collaboration by e.g. sending an e-mail, SMS or automatic phone calls. The most dangerous situation is the telescope not in the park position when the sun rises, since we could concentrate more than 10 kW solar power onto an area of few cm^2 on the camera.

We are currently testing the operation software and ensuring the system to behave correctly under all known conditions. Some minor auxiliary systems still need to be adapted. When this is done, we will send a crew to La Palma to manually trigger all expected malfunctions and check if the system reacts correctly.

6 Major Subsystems

In this section we describe how the major subsystems are implemented and protected. For simplicity, the descriptions concentrate mainly on the topology and do not necessarily represent the detailed implementation. Due to usage of off the shelf components and a historically grown system, some tasks are more complicated than necessary and could be simplified in a future implementation. We plan to have all systems ready for robotic operations by late 2013.

We describe here only the safety related tasks and leave out the normal dataflow and the datataking procedures working on top of it.

6.1 Electronics Power

A schematic of the camera power and safety setup is shown in figure 1.

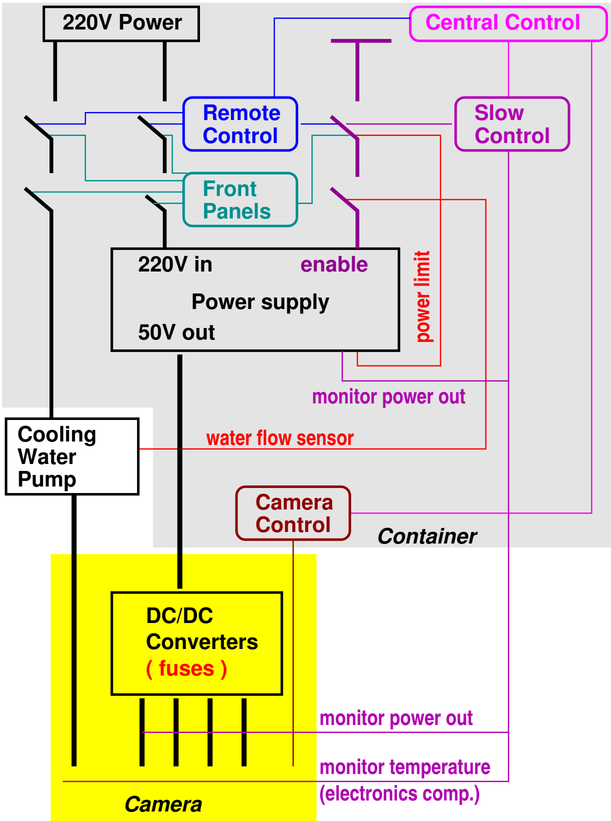

Figure 1: Schematics of the electronics power control. See 6.1 for explanations.

The key component is the central power supply delivering 50V to the electronics integrated in the camera body. While the operation power consumption is less than 500W, the high density of the electronics still asks for continuous cooling. We use a water cooling, and whenever the water flow stops, the power supply is automatically disabled. Without making hardware shortcuts it is therefore not possible to deliver power to the camera without operational water cooling.

In addition, the power supply is configured with an internal power limit. Unfortunately, due to high spikes in power consumption during booting of the system, this limit has to be set rather high. Therefore, we are monitoring the delivered power, and the slow control system shall disable the power supply when the delivery is above a predefined limit for several seconds. The slow control system monitors the power output of the DC/DC converters inside the camera housing (as a last resort, these are equipped with fuses) delivering the power to the individual electronics boards. It also measures the temperature inside the electronics compartment of the camera. If these are above predefined limits, the power supply will be disabled. Such disable states can be reset via the front panel or from remote control via Ethernet when the cause of the problem has been resolved.

The 220V power for the cooling pump can be switched from a front panel or the remote control concurrently, e.g. it is possible to switch the power off locally and switch it on again from remote.

For the power supply, it is also possible to switch the 220V concurrently from local or remote, but there is the additional possibility to switch it off locally without the possibility for remote activation. This allows to ensure the power is off in case of a crew working onsite on the camera.

What is summarized in the figure as camera control includes trigger control and data acquisition. All control task communicate with the central control.

6.2 Bias Power

In addition to the power for the electronics, there is also the need to deliver the bias power to the G-APDs (fig.2). Ensuring the correct voltage setting is the task of the Bias control. It does also monitor the total power delivered and shall set the voltage to zero in case of too high power consumption.

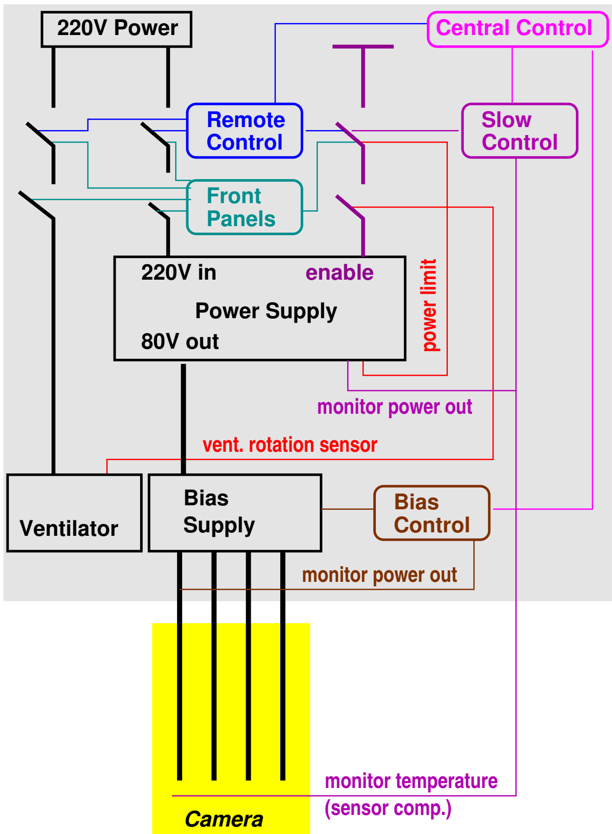

Figure 2: Schematics of the Bias power control. See 6.2 for explanations.

The control of the power supply delivering 80V is configured the same way as described in the previous section. The only difference is there is no water cooling but a ventilator that is necessary to cool the bias supply. To ensure the blades are turning, we have glued small permanent magnets on the blades and read hall sensors positioned on top of them. In case some of the blades do not turn, the power supply is disabled and it is not possible to overrule that from remote. The ventilators can also be switched on and off concurrently from local or remote, and a dedicated local power switch exists but shall only but used in case somebody is working directly at the bias supply onsite.

The slow control system is monitoring the total power delivered by the power supply and the temperature in the sensor compartment of the camera. It shall disable the power if the values are above a predefined limit.

6.3 Drive System

The drive system can be locally operated with a joystick and the power can be switched on and off from a large manual switch, The joystick also includes an emergency button to break the power to the motors of the drive system.

Normal operation (Fig 3), nevertheless, are done via the drive control sending commands to the drive electronics and reading the shaft encoders to know the orientation of the telescope. While the drive control is responsible to park the telescope before the sun rises, there is an additional brightness monitor and and a sunrise-timer that will send a 'park' command and disable the drive control before there is danger to the telescope. The drive control cannot overrule these conditions itself. A dedicated command from the remote control is needed to enable the drive control again.

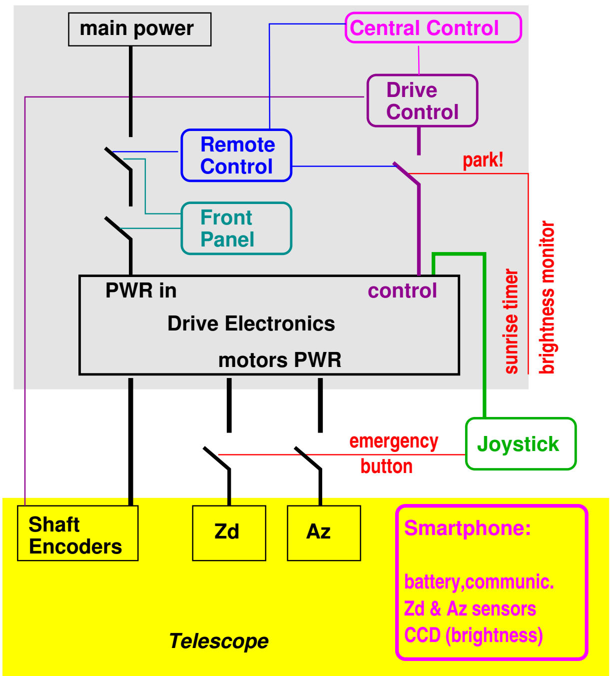

Figure 3: Schematics of the drive system control. See 6.3 for explanations.

In addition to the main manual power switch that cannot be overruled from remote, there is the default power switch that can be used from local or remote concurrently.

Ensuring the parking of the telescope is the most crucial part of robotic operation. But there is a major problem that it might not be possible to check the pointing of the telescope from remote for several reasons like:

– Due to a major power problem it is not possible to access the shaft encoders or the computers reading the shaft encoders.
– A local Ethernet problem or a Internet problem to La Palma prevents accessing the computers reading the shaft encoders.
– All computers are down and connection cannot be established in due time.

In case of a power or network failure, most probably also the installed webcam cannot be used to check the orientation of the telescope. Therefore, we are currently investigating a fully independent system, that needs to have its own power, independent communication and sensors to approximately read the zenith and azimuth position of the telescope. Most probably this can be reached by implementing a standard smartphone in the telescope structure: the batteries ensure independent power for several hours, it knows the actual time, B-field sensor and inclinometer measure the orientation, and by definition it can use GSM for communication. Additionally, the integrated CCD camera might be used as a brightness sensor or used to take pictures of the environment. This smartphone can then be queried from remote, or independently send alerts if the telescope is not parked in due time. It is then possible to park the telescope manually before it can be damaged.

6.4 Documentation

When operating a robotic telescope, it can not be expected that information is flowing from one shift crew to the other. In addition, if problems are rare theire solution tend to get forgotten. Therefore, it is even more crucial than for normal telescopes to have a well and up to date documentation available on site as well as accessible from remote places. We must have online versions on the computers on site and mirrored to several machines at the institutes and laptops of the users as well as a printed version in the container.

7 Conclusion

FACT is working very reliable since being switched on the first time in October 2011. The majority of the few hardware related problems encountered so far did not need any local interaction but can be solved by software, allowing to operate the system from remote. Based on the experience of more than one year remote operation, handling of problems was more and more automatized, and the operation of the telescope reduces to monitoring and identifying bugs in the control software. This will eventually lead to a fully robotic operation, only needing help from onsite personnel in case of severe emergencies.

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References

[1] H. Anderhub et al. (FACT Collaboration), JINST **8** P06008 (2013), arXiv:1304.1710.
[2] T. Bretz (FACT Collaboration), these proc., ID 683.
[3] http://dim.web.cern.ch
[4] http://www.home.agilent.com
[5] http://www.arduino.cc/
[6] http://www.gude.info/power-distribution.html