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**GREGOR:
BTF3
Beam Tracker @ F3**

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1 Scope

To reduce coma and aberrations M2 had to be tilted, which resulted in a beam where the optical and mechanical axes are not aligned. This leads to a beam wobble at F3, which can be quite significant during the day. A manual centering is time consuming and a tedious task for observers. This document describes an automated system, which centers the beam in F3 by taking into account telescope elevation, azimuth, image rotation and mirror positioning.

2 Reference and applicable documents

BTF3	- Beam Tracker at F3
ICS	- Instrument Control System
GCS computer	- GREGOR Control System computer
AO	- Adaptive Optics
DCP	- Device Communication Protocol
“Quick help observation manual”	- GRE-KIS-MAN-0003_v002_QuickHelpObsMan.pdf
“BTF3 DCP commands list”	- Ref:

3 Overview

The Beam Tracker F3 interface (BTF3), allows to automatically center the beam at Focus 3 on the Adaptive Optics bench, before the Tip-Tilt and deformable mirrors.

The motion for the beam drift compensation is done with the M5 motorization (M5 is located in the coudé vacuum tube along the elevation axis). A webcam pointing at F3 produces an image of the beam. This image is evaluated by software, to locate the current beam position, to calculate the respective motorization compensation and to move the beam to the center of the hole.

When the beam is in the “Locked” zone, the motorization movement represents a drift of the order of an arc-second for the solar image. The AO Tip-Tilt actuator, when enabled, compensates this to guarantee a stable image position for the instruments. The small deviation should also be compensated by telescope pointing, to keep Tip-Tilt’s dynamic range...

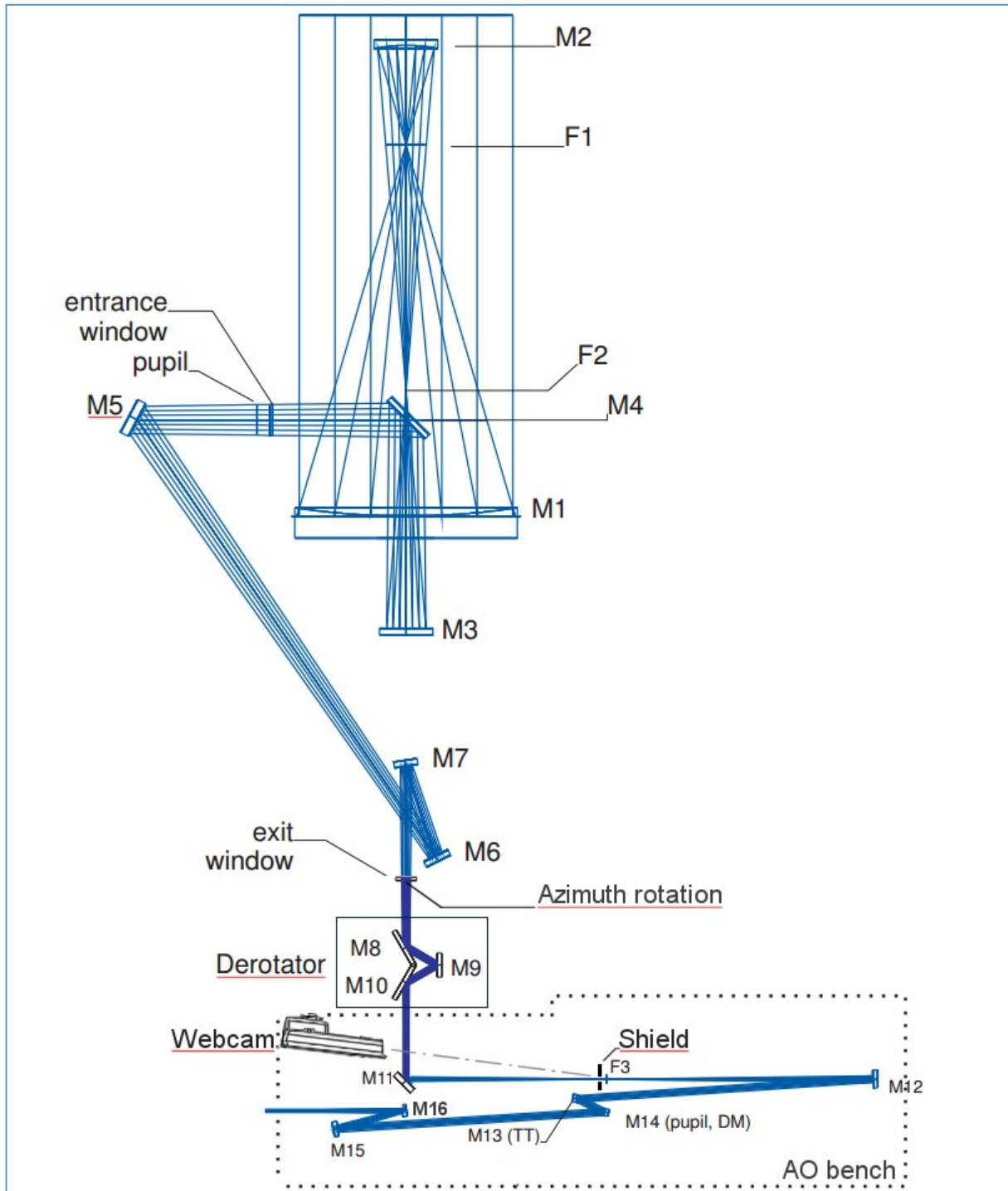


Figure 1 - BTF3 Opto-mechanics schematic

4 Mechanical and optical components

The next paragraphs describe the different parts involved in the automation.

4.1 M5 motorization

The M5 motorization, composed by 2 motors for tip-tilt, is used to move and re-center the beam at F3. The manual operation is not really intuitive because both axes have to be moved from the M2M3control interface with Up/Down steps in each axis, to make the beam converge at the desired center position. The beam misalignment introduces an image drift with respect to the center of the F3 hole during the day; this forces the use of the “try/error/success” method, to move and finally get the beam to the right place. Because the misalignment may occur in less than 15 minutes, the observers needed to constantly monitor the beam alignment, which wasted time and was inconvenient during observations. The auto-centering process provides an unsupervised way to move the M5 motorization, through DCP commands sent to the M2M3control interface.

The step sizes of the M5-1 and M5-2 motors are different and are taken into account for the calculation of the M5 movements, after evaluation of the necessary shifts. The scale values for the motors have been stored in the configuration file.

4.2 Telescope azimuth axis

Tracking the Sun during the day from East to West (negative azimuth values to positive values, passing the South at 0°) with an alt-azimuth telescope, such as GREGOR, means that a rotation of the beam has to be taken into account, to be able to compensate the beam wobble correctly. The query of the Azimuth position is done through a DCP command in each loop, to obtain the current angle in the software. Because of the mechanics and AO bench orientation, an azimuth offset angle has been stored in the BTF3 configuration file, for calculation of the angle for the motor compensation.

4.3 Derotator

This motorized optical device consisting of 3 mirrors allows the observer to get a solar image with a fixed orientation during the day. The default tracking position is not aligned to any special astronomical solar angle, but it is also possible to introduce an offset for a desired orientation of the image (e.g. spectrograph slit north-south).

The software has to know if the Derotator is in the optical path and its current position. This is also done through DCP commands (for status and position).

A rotation of 1 degree of the Derotator produces a 2 degrees image rotation. Equally, it is important to remember that one of the image axes is flipped.

Similarly as for the Azimuth axis, a Derotator reference offset angle has been determined during the tuning of the system and stored in the configuration file for software calculation to compensate the introduction of the Derotator optics with respect to the AO bench orientation.

4.4 Webcam

On the AO bench, near the M11 motorization, an AXIS Q1604 Network Camera was installed and images the F3 filter wheel to get an image of the beam. The camera view angle with respect to the F3 plane is negligible and is not taken into account for the calculation.

The IP address of the camera is 192.168.90.139 and the stream is available from any browser. The image is retrieved by the BTF3 software from the URL:

<http://192.168.90.139/jpg/image.jpg>

The image size is: 1280 x 960 Pixels (1.23 MPixels) (4:3) (24 BitsPerPixel)

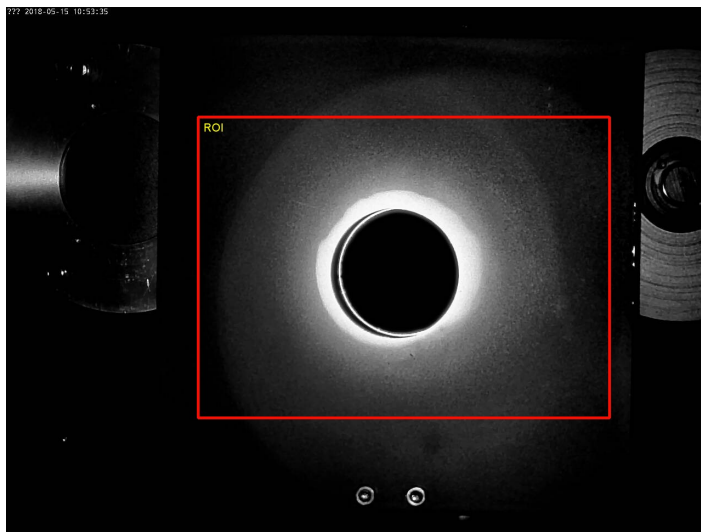


Figure 2 - raw webcam image. The red rectangle shows the ROI.

The BTF3 software only shows the region of interest (ROI) defined in the configuration file and reduces the resolution to 8 bits.

It is highly recommended to keep the camera configuration as is. Any modification of its settings could drastically affect the beam tracking capability.

4.5 F3 shield

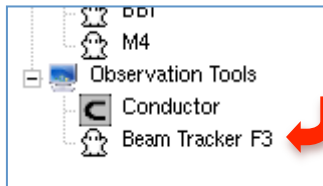
A black coated metal plate with a circular hole has been mounted just before the F3 filter wheel to generate a clear contrast to visualize beam misalignments. The position of the screen and more concretely for centering the hole with respect to the filter wheel center can be adjusted manually with 2 fine adjustment screws (x, y).

The screen provides a flat surface to avoid visual artifacts in the picture and to simplify the image analysis. A mask zone around the hole center is defined in the configuration file for the beam centering calculation with the MaskDiscRadius parameter.

5 Software

The Beam Tracker interface is written in Labview 15-64bits for Linux, and working in a CentOS 7 environment.

As the other GREGOR control system programs, the interface has to run on the GCS computer and is then also used via the remote panel on the Flight Stations, where some maintenance functionalities are not visible. In both cases, the interface is launched with the ICS menu, under the “Observation Tools” selection group.



Please, read the “Quick Help Observation Manual” information paragraph about the “Remote panels” operation.

5.1 Take center reference

This operation has to be done only if the webcam orientation is changed or the F3 shield is moved. It can only be executed from the main interface (at the GCS computer).

This position is necessary for the software to determine where the beam has to be centered to. The procedure should be performed with the telescope tracking, the free aperture in the Calibration Unit, light entering the AO bench, and following these steps:

- 1 If necessary, STOP the beam tracking with the “Control” button.
- 2 With the M11M16F3 interface move the F3 filter wheel to the “74 arcsec” aperture.
- 3 Check the “Calib.” checkbox, in the left side panel extension.
- 4 Click on Start and Stop with the “Control” button, to obtain a new image from the “webcam” picture.
- 5 Click somewhere inside the “74 arcsec” hole (the black disc zone).
- 6 Click on the “Take center reference” button.
- 7 Uncheck the “Calib.” checkbox.

The program will compute the center of the hole and store the coordinates in the configuration file. The reference should be close to this value (x,y,radius): (LastReference = "368;281;84")

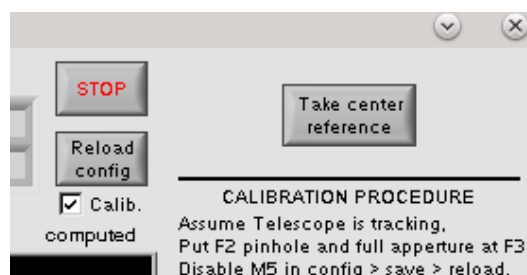


Figure 3 - Take center reference

5.2 Steps inside the program for a loop

On GCS this process takes a couple of seconds.

Description:

- Grab the image from the webcam.
- Show “webcam” image in window (on the left side).
- Threshold the image to discriminate the beam (white) from background (black).
- If desired, save the images to the “images” folder.
- Search for the beam close to the hole.
- If not found, search for the beam outside the hole with a radar method, i.e. check rays in different angles around the center until the beam is found.
- If not found, set the “Beam error” LED to “ON”, wait and start a new loop.
- If found, detect the border coordinates of the beam in 5° steps and store them in an array.
- Calculate the centers of circles defined by taking 3 points separated by ~120 deg along the borders of the array and iterate this for all points on the border.
- Find the median of all centers found by the 3 point fit and then apply a margin to identify dots close to the real beam center.
- Median filtering of the resulting array to get the beam center and radius.
- Draw and show the “computed” image in the window (on the right) with hole center disc (yellow), beam center dot (red), beam borders dots (green), beam circle line (blue).
- Calculate the compensation vector in pixels.
- Read the M5 motorization, Azimuth and Derotator positions, and its status.
- Calculate rotations for the vector, as a function of all needed angles and positions.
- Scaling and maximum motor step filtering for M5 motorization.
- Send the DCP command of relative movement to M5 motorization.
- Read and show the new position of motors.
- If the beam center is inside the “locked threshold” value range, the “Locked” blue LED is set to “ON” and positions are stored in a log file, in the “report” folder.
The loop is restarted after the “loop time” value (in seconds).

5.3 Front panel



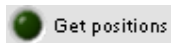
Figure 4 - front panel

5.4 Interface

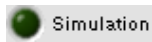
The following part gives the descriptions of the front panel indicators and controls:



“DCP” connection indicator is green if the connection is established with the DCP server; the interface is ready to receive commands. If red; a connection error is detected. If blinking red/green, some other instance of the program is already running; please close this instance and open the first one from the task bar.



The “Get positions” LED indicates when the program is reading the positions of M5, Azimuth and Derotator.



The “Simulation” LED is also a control button to put the interface into a test mode. If set to ON, the webcam images are read from the disk instead of the web.

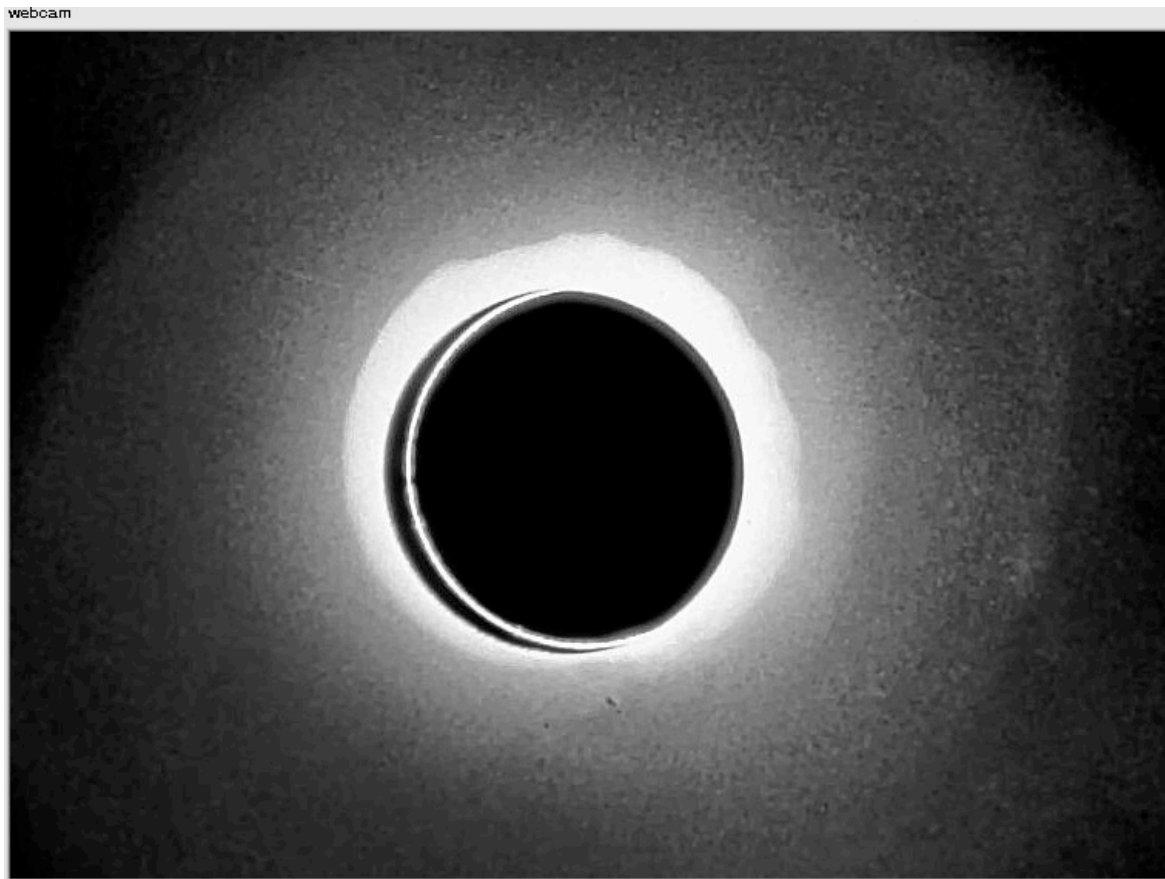
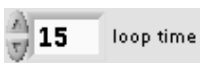


Figure 5 - webcam picture

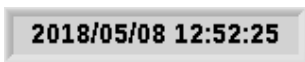
“webcam” picture indicator shows the last downloaded image from the F3 webcam.



The “Control” button (ON/OFF) to start/stop beam tracking. Depending on the beam distance from the hole center, the software may need a few loop steps to converge upon start, to reach the locked zone (yellow disc).



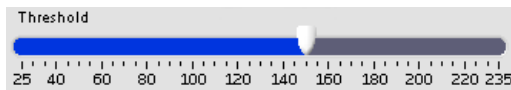
“Loop time” is the delay between two calculations of the Beam Tracker when the beam is inside the locked position. When the beam is not locked, the time is fixed to 5 seconds to accelerate the positioning of the beam to the hole center. $15 \leq \text{Loop time} \leq 180$



“Date/time” indicator. If the time is frozen, the interface may be stopped or also frozen.



Loop step indicator; the yellow LED moves when a new loop is started.



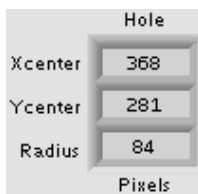
“Threshold” is a control to set the black/white level of the “computed” webcam image. Experience shows that it is necessary in some cases to modify the level to get a better beam definition and shape for analysis.



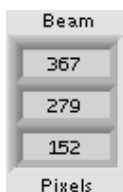
The “BEAM ERROR” indicator shows the state of the beam. If it is not detected, the indicator lights up and no motor movement is executed. This should occur for example when the beam tracking is ON and the M1 shutter or the AO bench cover is closed, the Calibration Unit/Derotorator is blocking the beam, M5/M11 is out of field or clouds appear... Please verify all these points in case of issues.



The “imgSave” control can be set to ON to save the webcam image on the disk. In normal mode it is convenient to set it OFF to avoid filling the disk with unwanted pictures. It can be useful in some special cases to get a few images for post analysis. The “LST” image prefix stands for the last webcam picture, “RAW” for ROI shown on the left side and “THR” for threshold image.



“Hole” indicates the (x, y) center position of the hole and radius. It is the target position for the Beam Tracker. (Units: pixels)



“Beam” indicator shows the result of the calculation of the current “computed” image beam position and radius. The center may be outside of the image, but taken into account for compensation. (Units: pixels)

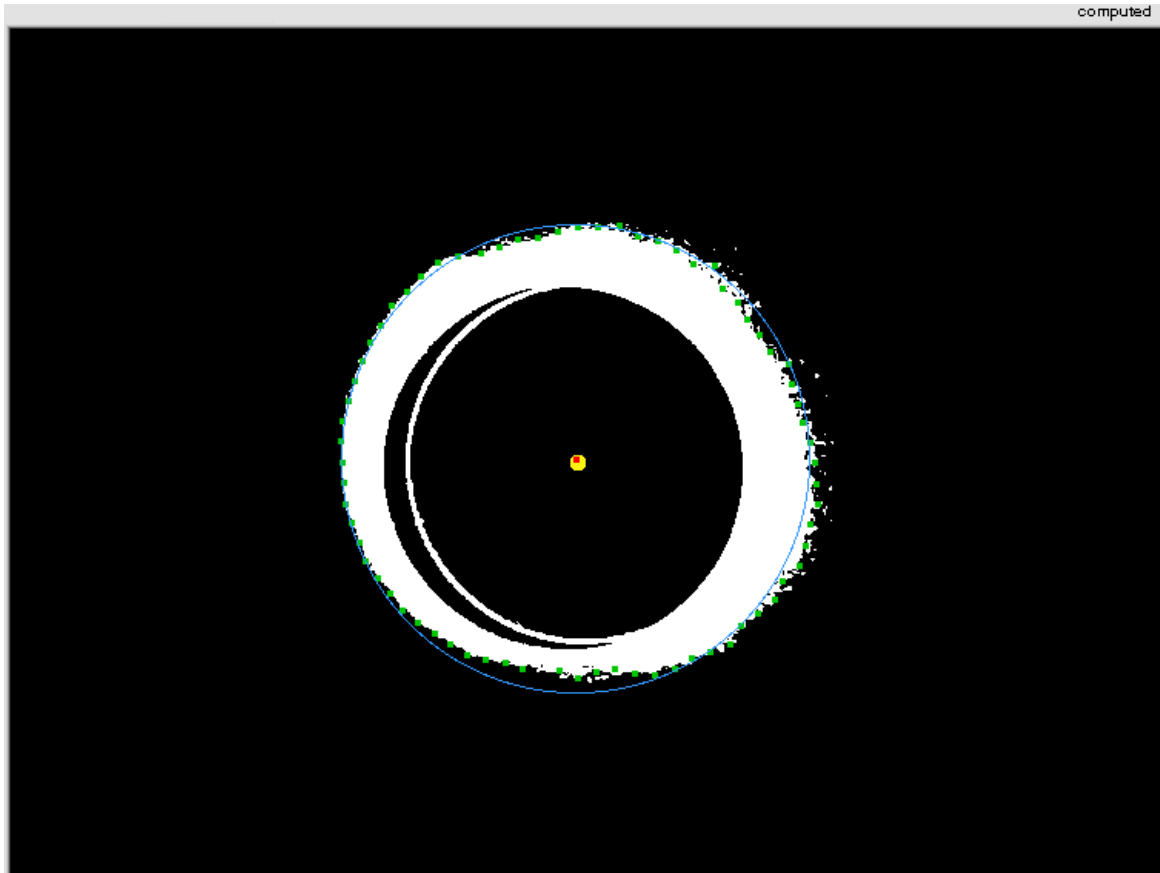


Figure 6 - computed image

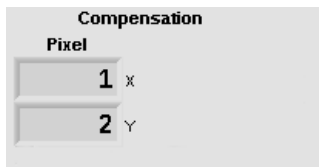
The “computed” image indicator shows the result of webcam image threshold in white, beam borders in green and calculations for beam center position in red. The yellow disc represents the hole center position, the blue circle is the estimated beam border.

Last Position	
40675	M5-1
32781	M5-2
-23.7859	Azimuth
0.46999	DER

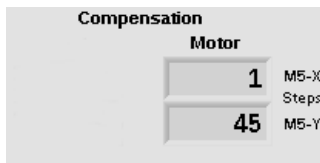
The “Last position” indicator shows the last M5, Azimuth and Derotator positions used for computation. They are renewed at every tracking loop, depending on the “time loop” parameter. (M5 units: motor steps / Azimuth and DER angle units: degrees)



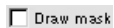
In front of the DER last position, an “in” LED indicator shows if the Derotator is inserted in the beam path. This indicator is only visible when the interface “Control” is started.



“Pixel Compensation” shows the desired movement vector for the beam. The start position is the current computed beam position and the end position is the hole center position. Positive X and Y are respectively to right and down. In this example, the beam has to be moved 1 pixel to the right and 2 pixels down. (Units: pixels)



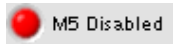
From the “Pixel Compensation” vector the program computes the “Motor Compensation” for the M5 axes, taking into account the Azimuth, Derotator, offsets positions, motor scales and steps limitation. (Units: motor steps)



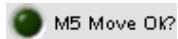
The “Draw mask” option box allows to show the zone of the hole that is masked for the beam analysis. Beam borders inside of this zone are omitted for the beam center calculation.



“BEAM LOCKED” indicator ON shows that the beam reached the hole center position. The threshold value (expressed in pixels), is defined in the configuration file. (LockedThreshold = 5).



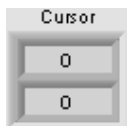
“M5 disabled” indicator LED becomes red if the M5 actuation is disabled. This can be done through the configuration file with “M5_disabled = 1” and will keep the beam compensation inactive. This option can be used for testing purposes. In normal mode, the LED has to be OFF by setting “M5_disabled = 0”.



The “M5 move Ok?” indicator LED shows if the motorization moved correctly after compensation. In case of “Pixel Compensation” (X=0,Y=0) when the beam is locked, no move is necessary, so this indicator will stay OFF.



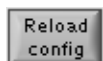
“Config error” indicator LED shows if there is some error or missing parameter in the configuration file. If it is red, please verify the parameters and correct them.



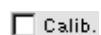
This “Cursor” indicator shows the last (x,y) cursor position when “computed” image is clicked, for information and calibration mode.



This button is disabled on the remote panel interface at Flight Stations. When pressed on the GCS computer, the application will close...: Firstly, the button turns to grey as “disabled”, then the application closes after about 5 seconds.



This button will reload the configuration file parameters in the interface. Therefore it is not necessary to restart the interface after a parameter modification; just click on this button.



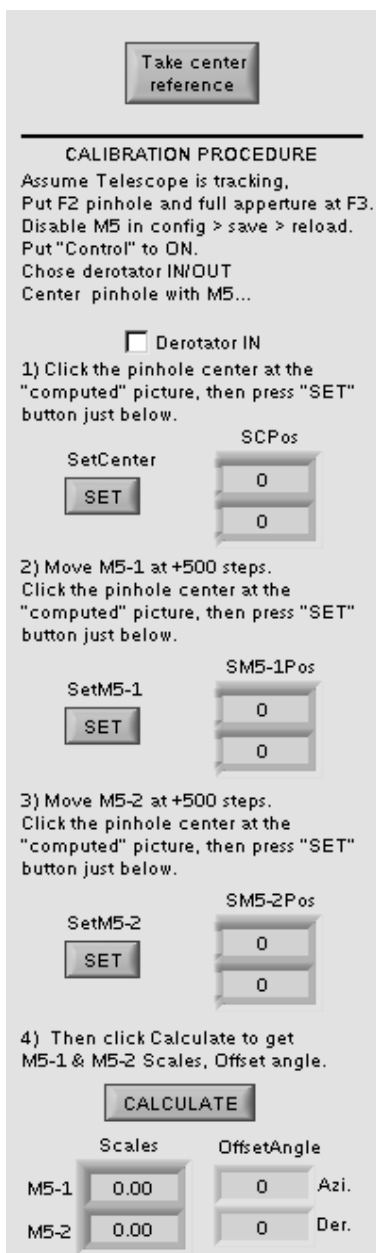
The “Calib.” check box allows extending the interface front panel to show new buttons and indicators to calibrate and find motorization parameters. This only works on the GCS computer. In normal use, please keep this box unchecked.



On Flight Stations, use this button to normally close the interface remote panel. On the GCS computer, never use this button to shut down the interface, but click the “STOP” button instead (as it may quit without closing the application ports correctly, preventing to restart the interface at the first time).

Extended front panel

To find the relation between pixels and motor steps for M5, a calibration procedure is included in this extended panel.



For “Take center reference”, please read paragraph (5.1).

Please follow the Calibration Procedure instructions to get the motorization scales relation. As the unit is motor step per pixel, it is easy to find the compensation scale parameters for each M5 axis and to store them in the configuration file.

The goal is to move each motor axis to determine how many pixels (as vector) correspond to a defined motor steps value, to establish the proper scale factor.

“OffsetAngle” for Azimuth and Derotator offsets was found before the use of this procedure; they are just for information and are subject to further tests to be validated.

Figure 7 - Calibration

5.5 Configuration file

This paragraph describes the “BTF3_config.ini” configuration file that is read at startup or by pushing the “Reload config” button. Any unjustified modification can compromise the Beam Tracker execution and has to be done with care. Please, report any change to the author.

[Network]

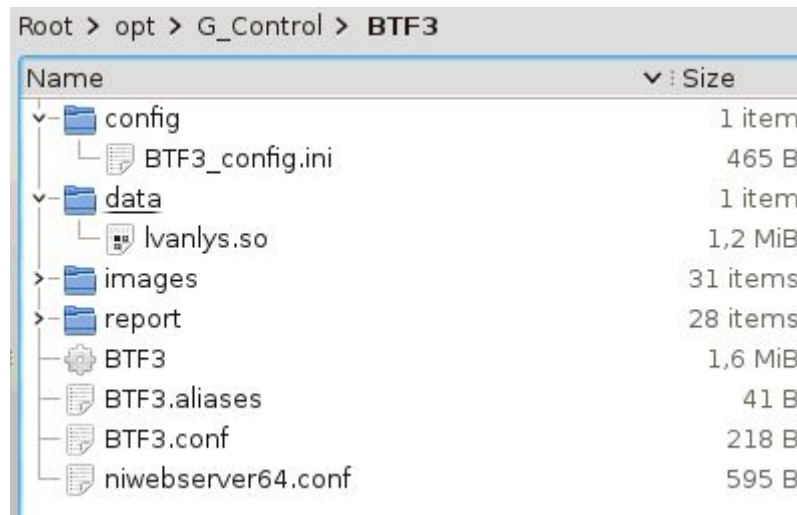
BTF3ClientName = BTF3	<i>DCP interface name</i>
GreCoServerIP = localhost	<i>DCP server address</i>
GreCoServerPort = 2001	<i>DCP server port</i>
GreCoServerTimeOut = 1000	<i>Server Time-Out value (ms)</i>
GreCoClientTimeOut = 1000	<i>Client Time-Out value (ms)</i>

[General]

F3imageAddress = "192.168.90.139/jpg/image.jpg"	<i>Webcam image URL</i>
ROI = 350;200;750;550	<i>Region of interest of the image</i>
MaskDiscRadius = 135	<i>Hole mask for calculation</i>
LoopTime = 15	<i>Time (sec) between 2 calculations</i>
Offset_M5 = 0	<i>Offset for M5 orientation angle</i>
Offset_Azimuth = 150	<i>Offset for Azimuth angle</i>
Offset_DER = 120	<i>Offset for Derotator angle</i>
PixelToMotorStepFactorX = 10	<i>M5-1 scaling</i>
PixelToMotorStepFactorY = 20	<i>M5-2 scaling</i>
LockedThreshold = 5	<i>Pixels to center “locked” zone</i>
M5_disabled = 0	<i>M5 disabled (1) / Enabled (0)</i>
MaxMotorStep = 1000	<i>Maximum motor steps</i>
LastReference = "368;278;70"	<i>Hole center last reference</i>

5.6 Installation

The Labview executable, after compilation, should be transferred and installed at the GCS Computer in the “/opt/G_Control/BTF3/” directory. The “lvanlys.so” is a Labview Linux DLL that has to be in the “data” folder at the BTF3 application level. Here is the folder structure after installation:



BTF3.aliases, BTF3.conf and niwebserver64.conf are files generated during compilation; they must remain with the executable BTF3 file.

The BTF3.conf file has to be modified, in order to use the correct fonts, decimal point and webserver configuration, as this:

[BTF3]

```
appFont="misc-liberation sans" 11
dialogFont="misc-liberation sans" 11
systemFont="misc-liberation sans" 11
useLocaleDecimalPt=False
WebServer.Enabled=True
WebServer.TcpAccess="c+*"
xwmShellRect.Title=0x4+0+23
```

6 Communication

6.1 DCP commands

BTF3 INTERFACE – DCP Commands

DCP device name: BTF3

command	parameter	format	description
set nop	none	none	communication test
set soft ctrl	a	BINARY/TEXT On=1 Off=0	Tracking ON/OFF
set soft loop	t	UINT16	Loop time setting in seconds $15 \leq t \leq 180$

command	answer	format	description
get status	a b c	BINARY On=1 Off=0	a: Tracking control status b: Locked status c: Beam error status
get position hole	x y	INT32	x: coordinate of hole in pixels y: coordinate of hole in pixels
get position beam	x y r	INT32	x: coordinate of beam in pixels y: coordinate of beam in pixels r: radius of beam in pixels

Command protocol

The BTF3 interface respects the DCP protocol rules / Text parameters are not case sensitive.

6.2 Script examples

As an example, currently in use in the “Find Sun Center” Conductor script procedure, a method to automatically stop and later restart the Beam Tracker. Here are the command lines and descriptions to insert into a script:

....

.... *Script does something....*

....

Retrieve the status of the BTF3; Tracking or not:

1000 BTF3 get status

Execute the Conductor command to parse the result of the previous command that have 3 parameters as binary value (0/1): [tracking] [locked] [beam error] at memories 80, 81, 82. (Be sure these memories are not used by the other script functions; if so, choose differently):

0001 Conductor distribute 80

Stop the Beam Tracking:

1000 BTF3 set soft ctrl off

....

.... *Script does something....*

....

Restore the previous state of the Beam Tracker:

1000 BTF3 set soft ctrl peek80

The state of the Beam Tracker remains the same after, as before execution.

7 Reports

As described in the “*Steps inside the program for a loop*” paragraph 5.2, the generated report files log the telescope activity, device positions and behavior during the day. The reports are automatically saved into the “report” folder of the BTF3, including the date in the file name; ex: “20180510-btf3-locked-data.txt”.

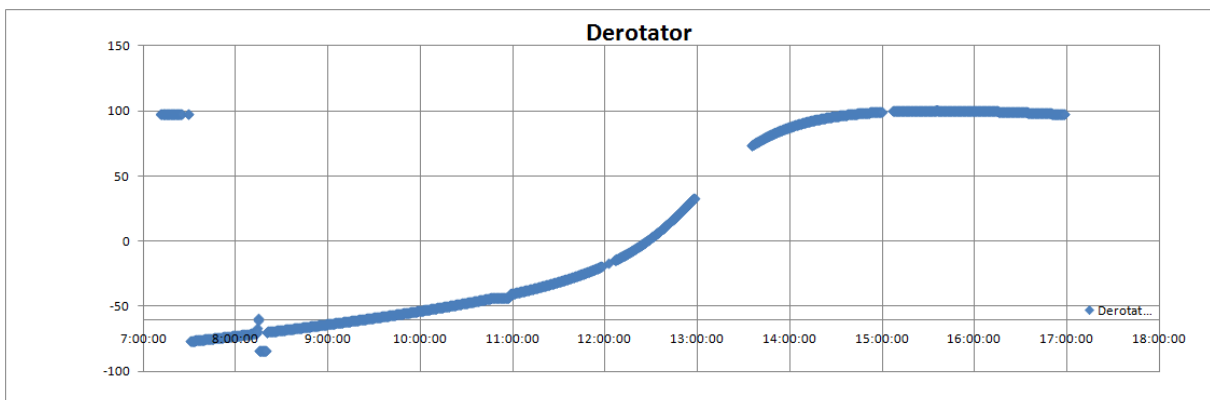
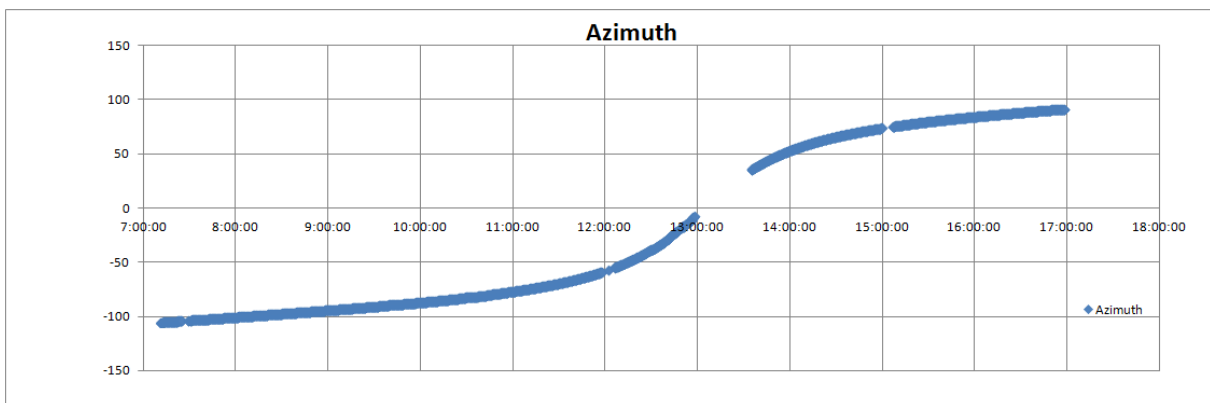
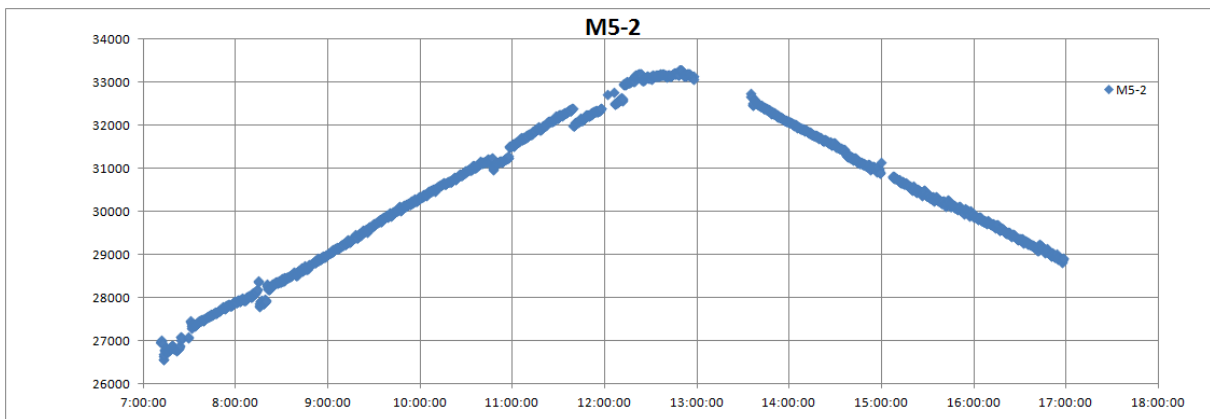
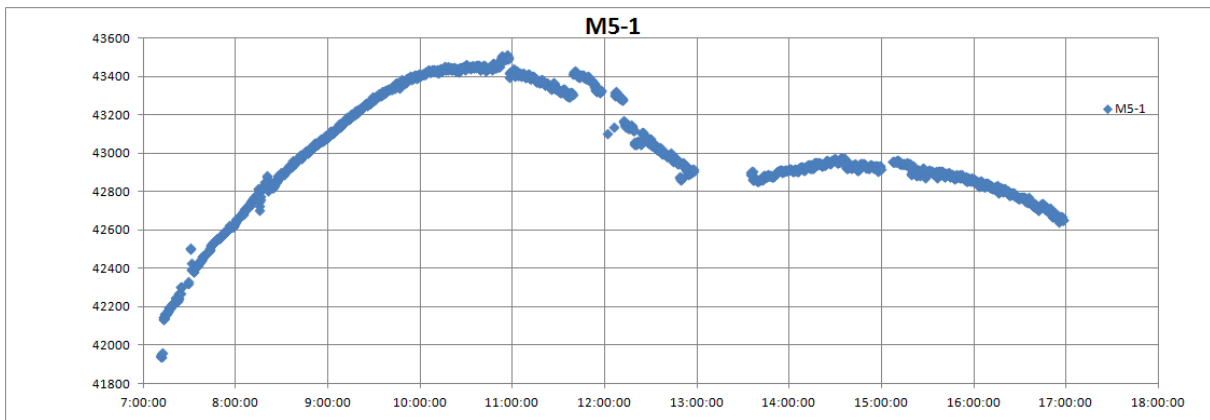
“i/o” stands for “*inserted/out of path*” of Derotator (0 => out of path / 1=> inserted).

Here is a partial example of data samples collected on May, 10th of 2018:

<i>Date</i>	<i>Time</i>	<i>M5-1</i>	<i>M5-2</i>	<i>Azimuth</i>	<i>i/o</i>	<i>Derotator</i>
2018/05/10	07:24:01	42304	27083	-103.292900	1	98.088810
2018/05/10	07:24:06	42304	27083	-103.284260	1	98.088810
2018/05/10	07:24:21	42303	27058	-103.257180	1	98.088820
2018/05/10	07:28:51	42323	27059	-102.779220	1	98.088810
2018/05/10	07:28:57	42334	27094	-102.768450	1	98.088810
2018/05/10	07:30:13	42502	27425	-102.633740	1	-76.384700
2018/05/10	07:30:18	42507	27464	-102.624790	1	-76.373960
2018/05/10	07:30:48	42430	27382	-102.571670	1	-76.306680
2018/05/10	07:31:08	42396	27291	-102.536520	1	-76.261510
2018/05/10	07:31:13	42395	27331	-102.527520	1	-76.250090
2018/05/10	07:31:29	42395	27356	-102.499160	1	-76.214020
2018/05/10	07:31:43	42395	27356	-102.472660	1	-76.180220
...						

BEAM TRACKER @ F3

GRAPHICAL EXAMPLE OF COLLECTED DATA OVER THE DAY



8 Acknowledgment

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