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# INTRODUCTION

This document analyses the “FPU Verification Process Flow Chart”, below, and breaks it into smaller tasks, which are described in detail.

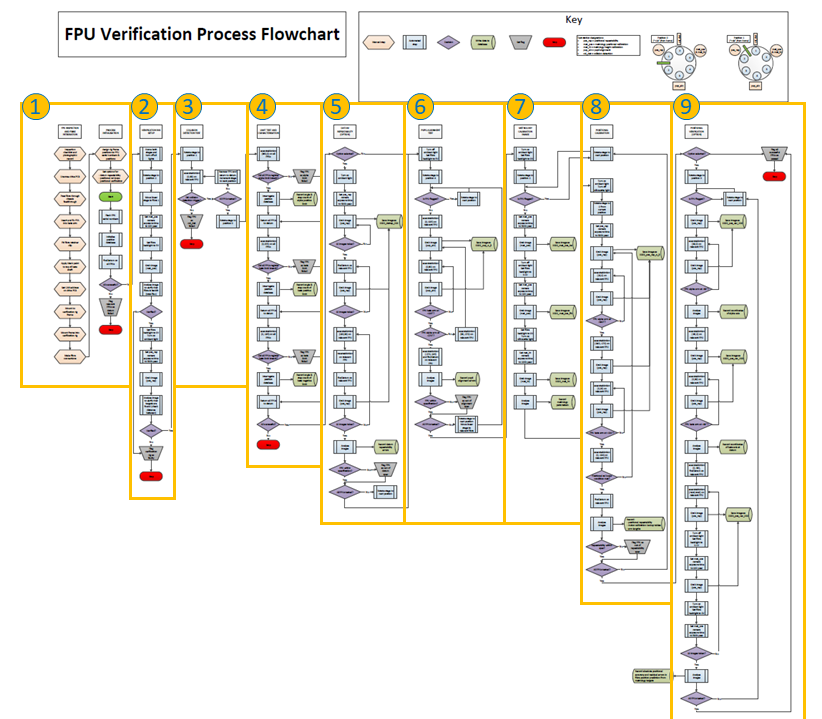


Figure 1: FPU Verification Process Flowchart

# PREREQUISITES

The following things need to be completed before the tests can be carried out.

* Software to control each camera, take exposures and save the images to a file.
* Metrology camera distortion calibrated using a rectangular pattern of dots. This process generates a set of distortion coefficients which can be used to rectify each camera image.
  + Primary plan: calibration the cameras with Holger’s software
  + Backup plan: calibrate the cameras with openCV library functions.
* Software to control the Thorlabs turntable.
* Software to control the linear stage.
* Software to control the lamps.
* FPU control parameters (minimum and maximum speed and acceleration) agreed.
* The turntable, linear stage, lights and cameras have all been tested and verified to work.  
  There should a self-test procedure which verifies all the components are responding.

# Verification process specification

## General rules

* When moving the rotary stage, the last successful operation from all FPUs must have been a findDatum. The only exception to this is prior to running the Collision Detection Test.
* Images taken should not be deleted or overwritten.
* Where red dots are indicated ● the intention is that the test will stop with an error and the operator will take immediate action. In all other cases, unless otherwise stated, it should be assumed that errors are handled by the software and the process should continue.
* Where a process is manual (i.e. not controlled by software), it is stated in *italics*

## Initialisation

Purpose – this is the process where a user loads FPUs into the verification rig, flashes the electronics with the correct serial number and ensures that the FPU is responding to commands by running a findDatum operation.

*For each fibre positioner received*

*Note the unique serial number assigned to that fibre positioner (etched onto chassis)*

*If FPU position is not at or very close to datum then*

*Manually initialise FPU to the point where it can be automatically datumed*

*Fix to a position on the verification rig frame*

*Assign a CAD ID commensurate with that position*

*Make an association between the position and serial number in the verification software interface*

For each of 6 FPUs

Reprogram the onboard firmware with the correct version

Flash the FPU PCB with the correct serial number

Initialise the FPU position database with (-180,0)

Initialise the FPU verification database

Find datum for all FPUs simultaneously.

If all FPUs successful

Start the automated verification tests (as below) 🡪

Else

For each failed FPU

Flag FPU as FAILED\_TO\_INITIALISE

Stop with an error – FPU or electronics failure ●.

*If any FPUs have failed*

*If datum is confirmed non-functional*

*Remove FPU from verification rig*

*Choose a new FPU to fill this slot*

*Update the serial number to turntable slot to CAN bus mapping*

*Else*

*Manually correct the non-datum issue*

*Flag FPU for retest and leave it on the rig*

*Restart the initialisation process until all FPUs can be datumed and the automated tests can begin.*

## Verification rig setup

Purpose – this is a self-check of the verification rig critical functions, whereby sample images are taken from all test stations and the image analysis functions are run to verify that the images resulting are as expected.

Home the turntable and the linear stage

Turn off all lights

Move rotary stage to PUPIL\_ALN\_POSN\_1 *(4.2)*

Move linear stage to PUPIL\_ALN\_LINPOS\_1 *(4.3)*

Configure pup\_aln camera with PUPIL\_ALN\_EXPOSURE *(4.5)*

Configure lighting for pupil alignment test (ambient/silhouette off, backlight 5V) *(4.4)*

Take image with pup\_aln camera *(4.5)*

Pass image to pupil alignment image analysis script *(5.5)*

Pass coordinates to pupil alignment parameter script *(6.3)*

If error returned then

Stop with an error – pupil alignment equipment failure ●

Move rotary stage to METROLOGY\_CAL\_POSN\_1 *(4.2)*

Configure met\_cal camera with METROLOGY\_CAL\_TARGET\_EXPOSURE *(4.5)*

Configure lighting for metrology calibration target image (backlight/silhouette off, ambient on) *(4.4)*

Take image with met\_cal camera *(4.5)*

Pass image to metrology calibration target image analysis script *(5.2)*

If error returned then

Stop with an error – metrology calibration equipment failure ●

Move rotary stage to METROLOGY\_HT\_POSN\_1 *(4.2)*

Configure met\_ht camera with METROLOGY\_HT\_TARGET\_EXPOSURE *(4.5)*

Configure lighting for metrology height image (backlight/ambient off, silhouette on) *(4.4)*

Take image with met\_ht camera *(4.5)*

Pass image to metrology height image analysis script *(5.4)*

If error returned then

Stop with an error – metrology height equipment failure ●

Move rotary stage to POS\_REP\_POSN\_1 *(4.2)*

Configure pos\_rep camera for POSITION\_REP\_EXPOSURE *(4.5)*

Configure lighting for positional repeatability test (silhouette/backlight off, ambient on) *(4.4)*

Take image with pos\_rep camera *(4.5)*

Pass image to positional repeatability image analysis script *(5.1)*

If error returned then

Stop with an error – positional repeatability equipment failure ●

Home the turntable and the linear stage

Turn off all lights

## Collision detection

Purpose – to functionally test the collision detection circuit using a soft contact with the beta arm. This will give confidence that the system is functioning without putting the FPU at risk of unnecessary damage.

Configurable constants

* **COLLISION\_DET\_POSN\_N –** the rotary stage angle at which each FPU should touch the soft contact, given the FPU is at COLLISION\_DET\_FPU\_POS
* **COLLISION\_DET\_FPU\_POS –** the alpha/beta angles at which the FPU can touch the soft contact when running through the COLLISION\_DET\_POSN\_N

For each of 6 FPUs

Move rotary stage to 10 degrees negative of COLLISION\_DET\_POSN\_N *(4.2)*

Configure and execute waveform to bring FPU to COLLISION\_DET\_FPU\_POS

Move rotary stage to 10 degrees positive of COLLISION\_DET\_POSN\_N *(4.2)*

If FPU registers collision Then

Flag FPU as COLLISION\_DET\_OK

Run reverseMotion

Run findDatum

Else

Flag FPU as COLLISION\_DET\_FAIL

Stop with an error – FPU collision detection circuit non-functional ●

## Limit characterisation

Purpose – to determine where the end stop limits of the FPU are with respect to the datum position. This will enable the software safety limits to be set for each FPU. This will be achieved by safely activating the limit switch of each stage in both directions.

For the beta arm, this means driving to a position slightly beyond the expected position of the end stop switch in both positive and negative directions. Both tests will require the software to successfully handle exceptions from the FPU driver and then for the beta stop recovery process to be followed.

For the alpha arm, the datum position represents the limit in the negative direction. The positive limit will be found by driving to a positive slightly beyond the expected position of the datum switch. This will require the software to successful handle an exception from the FPU driver and then for the alpha limit breach recovery process to be followed.

Configurable constants



## Pupil alignment

Purpose - to determine precession of the FPU optical axis as it rotates through 16 positions representing all combinations of the major compass directions on both alpha and beta arms. A high-power LED backlights the fibre, which is projected onto a screen via fold mirrors and imaged by a camera. Software finds the centre of the projected spot in the image and, from this, the errors in the chassis, alpha and beta axes can be derived.

Configurable constants

* **PUPIL\_ALN\_POSN\_N** – the rotary stage angle required to place each FPU under the first pupil alignment fold mirror
* **PUPIL\_ALN\_LINPOS\_N** – the linear stage position required to illuminate each FPU fibre
* **PUPIL\_ALN\_PASS** – the maximum total deviation in arcmin from the calibrated centre point which represents an acceptable FPU
* **PUPIL\_ALN\_EXPOSURE** – the exposure time in microseconds for a correctly exposed image

Configure pup\_aln camera with PUPIL\_ALN\_EXPOSURE *(4.5)*

Configure lighting for pupil alignment test (ambient/silhouette off, backlight 5V) *(4.4)*

For each of 6 FPUs

Move rotary stage to PUPIL\_ALN\_POSN\_N *(4.2)*

Move linear stage to PUPIL\_ALN\_LINPOS\_N *(4.3)*

Configure and execute waveform (+10, -170)

For 4 iterations

Take image with pup\_aln camera *(4.5)*

For 3 iterations

Configure and execute waveform (0,90)

Take image with pup\_aln camera *(4.5)*

If Not the final iteration Then configure and execute waveform (90,-270)

Configure and execute waveform (-279,-279)

Run findDatum

For 16 saved images

Pass image to pupil alignment image analysis script *(5.5)*

Pass coordinates to pupil alignment parameter script *(6.3)*

If returned value is below PUPIL\_ALN\_PASS then

Flag FPU as PUPIL\_ALN\_OK

Return axis errors to output file

Else

Flag FPU as PUPIL\_ALN\_FAIL

Return axis errors to output file

## Metrology calibration

Purpose – to determine the static relationship between the metrology targets and the fibre aperture for each FPU, allowing the MOONS metrology position to use the targets to infer the position of the fibre. The required parameters are the distance between the fibre aperture and targets in microns, to a precision of +/- 1 microns. An image will be taken of the FPU with an ambient LED illuminating the targets. A second image will be taken with the fibre backlit. Software will find the positions of the targets using a centre of mass technique, then the position of the fibre using a centroiding algorithm.

Configurable constants

* **METROLOGY\_CAL\_POSN\_N** - the rotary stage angle required to place each FPU under the metrology calibration camera
* **METROLOGY\_CAL\_TARGET\_EXPOSURE** – the exposure time in microseconds for a correctly exposed image of the illuminated targets
* **METROLOGY\_CAL\_FIBRE\_EXPOSURE** – the exposure time in microseconds for a correctly exposed image of the backlit fibre

For each of 6 FPUs

Move rotary stage to METROLOGY\_CAL\_POSN\_N *(4.2)*

Configure met\_cal camera with METROLOGY\_CAL\_TARGET\_EXPOSURE *(4.5)*

Configure lighting for metrology calibration target image (backlight/silhouette off, ambient on) *(4.4)*

Take image with met\_cal camera *(4.5)*

Pass image to metrology calibration target image analysis script *(5.2)*

Configure met\_cal camera with METROLOGY\_CAL\_FIBRE\_EXPOSURE *(4.5)*

Configure lighting for metrology calibration fibre image (ambient/silhouette off, backlight 0.1V) *(4.4)*

Take image with met\_cal camera *(4.5)*

Pass image to metrology calibration fibre image analysis script *(5.3)*

Pass coordinates to metrology target calibration parameter script *(6.1)*

Return metrology calibration distances to output file

## Metrology height

Purpose – to determine the height of the metrology targets above the beta arm surface, allowing a correction to be made within the MOONS metrology software pipeline. An LED lights a white surface behind the beta arm such that the arm and targets are silhouetted and the edges can be clearly defined. The silhouette is imaged by a camera and software finds the surface of the beta arm, then the surfaces of the targets, and calculates the height.

Configurable constants

* **METROLOGY\_HT\_POSN\_N** - the rotary stage angle required to place each FPU in front of the metrology height camera
* **METROLOGY\_HT\_TARGET\_EXPOSURE** – the exposure time in microseconds for a correctly exposed image of the illuminated targets

Configure met\_ht camera with METROLOGY\_HT\_TARGET\_EXPOSURE *(4.5)*

Configure lighting for metrology height image (backlight/ambient off, silhouette on) *(4.4)*

For each of 6 FPUs

Move rotary stage to METROLOGY\_HT\_POSN\_N *(4.1)*

Take image with met\_ht camera *(4.5)*

Pass image to metrology height image analysis script *(5.4)*

## Datum repeatability

Purpose – to determine the repeatability of the FPU datum position under repeated datum operations, both with and without a prior FPU motion. An ambient LED illuminates the metrology targets and a camera images the targets after each FPU datum. Software finds the target coordinates using a centre of mass technique, then calculates the deviation from the starting position. The maximum single error found represents the repeatability as defined by the contract.

Configurable constants

* **POS\_REP\_POSN\_N** – the rotary stage angle required to place each FPU under the positional repeatability camera
* **DATUM\_REP\_ITERATIONS** – the number of datum operations made for each test
* **DATUM\_REP\_PASS** – the maximum single deviation in microns from the baseline position which represents an acceptable FPU
* **DATUM\_REP\_EXPOSURE** – the exposure time in microseconds for a correctly exposed image

Configure pos\_rep camera for DATUM\_REP\_EXPOSURE *(4.5)*

Configure lighting for positional repeatability test (silhouette/backlight off, ambient on) *(4.4)*

For each of 6 FPUs

Move rotary stage to POS\_REP\_POSN\_N *(4.2)*

For 10 iterations (baseline)

Take image with pos\_rep camera *(4.5)*

Pass image to positional repeatability image analysis script *(5.1)*

For DATUM\_REP\_ITERATIONS iterations (datum)

Run findDatum on FPU

Take image with pos\_rep camera *(4.5)*

Pass image to positional repeatability image analysis script *(5.1)*

For DATUM\_REP\_ITERATIONS iterations (move-then-datum)

Configure and execute waveform (+30,+30)

Run reverseMotion

Run findDatum on FPU

Take image with pos\_rep camera *(4.5)*

Pass image to positional repeatability image analysis script *(5.1)*

Pass coordinates to datum repeatability parameter script *(6.3)*

If returned value is below DATUM\_REP\_PASS then

Flag FPU as DATUM\_REP\_OK

Return average and maximum values to output file

Else

Flag FPU as DATUM\_REP\_FAIL

Return all measured coordinates to output file

## Positional repeatability and gearbox calibration

Purpose - to run each FPU stage through a sequence of equally spaced movements, then back, and repeats several times. An ambient LED illuminates the metrology targets and a camera images the targets after each movement. Software finds the target coordinates using a centre of mass technique, then calculates the deviation from the nominal position, as well as the spread of points at that nominal position. From the spread of points at each nominal position, the positional repeatability can be derived, which represents a pass/fail parameter. Also, the error from the nominal position can be converted into a circumferential and radial error, the former of which can be converted into a function which can correct the FPUs movement to improve absolute accuracy, given an acceptable repeatability.

Configurable constants

* **POS\_REP\_POSN\_N** – the rotary stage angle required to place each FPU under the positional repeatability camera
* **POSITION\_REP\_PASS** – the maximum deviation from an average position of a grouping of measured points at a given nominal position which represents an acceptable FPU
* **POSITION\_REP\_EXPOSURE** – the exposure time in microseconds for a correctly exposed image
* **POSITION\_REP\_INCREMENTS** – the number of movements made within each positive sweep from the starting position
* **POSITION\_REP\_ITERATIONS** – the number of times each FPU sweeps back and forth

Configure pos\_rep camera for POSITION\_REP\_EXPOSURE *(4.5)*

Configure lighting for positional repeatability test (silhouette/backlight off, ambient on) *(4.4)*

For each of 6 FPUs

If DATUM\_REP\_FAIL or PUPIL\_ALN\_FAIL then

Skip FPU

Move rotary stage to POS\_REP\_POSN\_N *(4.2)*

Configure and execute waveform (+10, -170)

Take image with pos\_rep camera *(4.5)*

For POSITION\_REP\_ITERATIONS iterations

For POSITION\_REP\_INCREMENTS iterations

Configure and execute waveform (+ [320 / POSITION\_REP\_ INCREMENTS], 0)

Take image with pos\_rep camera *(4.5)*

For POSITION\_REP\_ INCREMENTS iterations

Configure and execute waveform (- [320 / POSITION\_REP\_ INCREMENTS], 0)

Take image with pos\_rep camera *(4.5)*

For POSITION\_REP\_ INCREMENTS iterations

Configure and execute waveform (0, + [320 / POSITION\_REP\_ INCREMENTS])

Take image with pos\_rep camera *(4.5)*

For POSITION\_REP\_ INCREMENTS iterations

Configure and execute waveform (0, - [320 / POSITION\_REP\_ INCREMENTS])

Take image with pos\_rep camera *(4.5)*

For all images

Pass image to positional repeatability image analysis script *(5.1)*

Pass coordinates to motor calibration parameter script *(6.3)*

If returned value is below POSITION\_REP\_PASS then

Flag FPU as POSITION\_REP\_OK

Return maximum repeatability value to output file

Return motor calibration tables to output file

Else

Flag FPU as POSITION\_REP\_FAIL

Return all repeatability values to output file

## Positional verification

Purpose – to verify that the gearbox calibrations derived in the previous step result in absolute accuracy within specification.

* **POS\_REP\_POSN\_N** – the rotary stage angle required to place each FPU under the positional repeatability camera
* **POSITION\_VER\_PASS** – the maximum deviation from an average position of a grouping of measured points at a given nominal position which represents an acceptable FPU
* **POSITION\_VER\_EXPOSURE** – the exposure time in microseconds for a correctly exposed image
* **POSITION\_VER\_ITERATIONS** – the number of random positions where real position is tested against nominal position

Configure pos\_rep camera for POSITION\_VER\_EXPOSURE *(4.5)*

Configure lighting for positional repeatability test (silhouette/backlight off, ambient on) *(4.4)*

For each of 6 FPUs

If DATUM\_REP\_FAIL or PUPIL\_ALN\_FAIL or POSITION\_REP\_FAIL then

Skip FPU

Move rotary stage to POS\_REP\_POSN\_N *(4.2)*

Apply gearbox correction function *(6.5)*

Configure and execute waveform (10, -170)

Take image with pos\_rep camera *(4.5)*

For 7 iterations

Configure and execute waveform (45,0)

Take image with pos\_rep camera *(4.5)*

For POSITION\_VER\_ITERATIONS iterations

Configure and execute waveform (random, random)

Take image with pos\_rep camera *(4.5)*

For all images

Pass image to positional repeatability image analysis script *(5.1)*

Pass coordinates to positional accuracy parameter script *(6.6)*

If returned value is below POSITION\_VER\_PASS then

Flag FPU as POSITION\_VER\_OK

Return maximum accuracy value to output file

Else

Flag FPU as POSITION\_REP\_FAIL

Return all repeatability values to output file

# Hardware control specification

## FPU control

* See FPU protocol 2 documentation

## Rotary stage

* Purpose – the rotary stage rotates the verification frame such that FPUs can be positioned under various test stations.
* Rotary stage - Thorlabs NR360S/M - <https://www.thorlabs.de/thorproduct.cfm?partnumber=NR360S/M>
* Controller - Thorlabs BSC201 – <https://www.thorlabs.de/thorproduct.cfm?partnumber=BSC201>
* Required operations
  + Home
  + Forward absolute movement
  + Reverse absolute movement
* Adjustable parameters
  + Speed

## Linear stage

* Purpose – the linear stage moves a backlight LED and focussing lens assembly such that light is shone into one of the 6 fibre patch cables coupled with the FPU fibres. This allows imaging of the fibre centre and back projection of the fibre aperture such that pupil alignment can be measured.
* Linear stage - Thorlabs MTS50/M-Z8 - <https://www.thorlabs.de/newgrouppage9.cfm?objectgroup_id=3002&pn=MTS50/M-Z8#3006>
* Controller - Thorlabs BSC201 – <https://www.thorlabs.de/thorproduct.cfm?partnumber=BSC201>
* Required operations
  + Home
  + Forward absolute movement
  + Reverse absolute movement
* Adjustable parameters
  + Speed

## Lamps and control DAQ

* Purpose – three LED lamps allow different setups of ambient and directional illumination within the verification enclosure, as well as backlighting of the fibres.
* Ambient illumination - Thorlabs LED cluster LIU365A - <https://www.thorlabs.de/newgrouppage9.cfm?objectgroup_id=2853>
* Metrology target silhouetting - Thorlabs LED cluster LIU365A - <https://www.thorlabs.de/newgrouppage9.cfm?objectgroup_id=2853>
* Fibre backlight - Thorlabs mounted LED MCWHLP1 - <https://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=2692>
* LED driver – Thorlabs LEDD1B - <https://www.thorlabs.de/newgrouppage9.cfm?objectgroup_id=2616>
* DAQ - RedLab1208LS - <https://www.meilhaus.org/downloadserver/redlab/manual/RedLab%201208LS_en.pdf>
* Required operations
  + On-off for ambient illumination and target silhouetting lamps
  + Voltage control (0-5V) for fibre backlight

## Camera control

* Purpose – four cameras take images of the FPU and fibre projection during the various tests
* Positional repeatability – Basler ace acA3800-10gm GigE - <https://www.edmundoptics.com/p/Basler-ace-acA3800-10gm-Monochrome-GigE-Camera/32412/>
* Metrology calibration – Basler ace acA3800-10gm GigE - <https://www.edmundoptics.com/p/Basler-ace-acA3800-10gm-Monochrome-GigE-Camera/32412/>
* Metrology height – Basler ace acA3800-10gm GigE - <https://www.edmundoptics.com/p/Basler-ace-acA3800-10gm-Monochrome-GigE-Camera/32412/>
* Pupil alignment – Basler ace acA1920-40gm GigE - <https://www.edmundoptics.com/p/basler-ace-aca1920-40gm-monochrome-gige-camera/3429/>
* Required operations
  + Connect to camera and load configuration using given parameters
  + Save image from a single camera given its IP address
* Adjustable parameters
  + Exposure time

# Image analysis specification

## Find metrology targets from pos-rep camera

* Purpose – to find coordinates for the metrology targets in real space using the pos-rep camera. Used in the following tests:
  + Datum repeatability
  + Positional repeatability
* Inputs
  + 8bit bitmap image from pos-rep camera
* Return
  + XY coordinates in real space of centres of large target and small target
  + Quality metric of target detection
* Configurable constants
  + POSREP\_SMALL\_TARGET\_DIA\_LOWER\_THRESH
  + POSREP\_SMALL\_TARGET\_DIA\_UPPER\_THRESH
  + POSREP\_LARGE\_TARGET\_DIA\_LOWER\_THRESH
  + POSREP\_LARGE\_TARGET\_DIA\_UPPER\_THRESH
  + POSREP\_TARGET\_CIRCULARITY\_THRESH
  + POSREP\_THRESHOLD\_VAL
  + POSREP\_PLATESCALE
  + POSREP\_DISTORTION\_MATRIX
* Potential errors
  + Contaminated image from stray reflections leading to false positive detections
  + Unable to find one or both targets due to shadows/noise/contamination
* Algorithm
  + Process image (distortion correction and threshold)
  + Find contours
  + Filter contours on size and circularity to detect targets and reject contamination
  + Find centre of targeted contours using Centre of Mass

## Find metrology targets from met-cal camera

* Purpose – to find coordinates for the metrology targets in real space using the met-cal camera. Used in the following tests:
  + Metrology calibration
* Inputs
  + 8bit bitmap image from met-cal camera
* Return
  + XY coordinates in real space of centres of large target and small target
  + Quality metric of target detection
* Configurable constants
  + METCAL\_SMALL\_TARGET\_DIA\_LOWER\_THRESH
  + METCAL\_SMALL\_TARGET\_DIA\_UPPER\_THRESH
  + METCAL\_LARGE\_TARGET\_DIA\_LOWER\_THRESH
  + METCAL\_LARGE\_TARGET\_DIA\_UPPER\_THRESH
  + METCAL\_TARGET\_CIRCULARITY\_THRESH
  + METCAL\_THRESHOLD\_VAL
  + METCAL\_PLATESCALE
* Potential errors
  + Positioning error in FPU or rotary stage leads to part of target being out of FoV
* Algorithm
  + Process target image (threshold)
  + Find contours
  + Filter contours on size and circularity to detect targets and reject contamination
  + Find centre of targeted contours using Centre of Mass

## Find backlit fibre from met-cal camera

* Purpose – to find coordinates for the metrology targets in real space using the met-cal camera. Used in the following tests:
  + Metrology calibration
* Inputs
  + 8bit bitmap image from met-cal camera
* Return
  + XY coordinates in real space of centres of backlit fibre
  + Quality metric of target detection
* Configurable constants
  + METCAL\_FIND\_GAUSSIAN\_BOX\_SIZE
  + METCAL\_PLATESCALE
* Potential errors
  + Overexposed fibre image leads to inability to run Gaussian fit
* Algorithm
  + Find fibre location (find maxima)
  + Find Gaussian fit around point

## Find metrology target heights from met-ht camera

* Purpose – to measure the height of the metrology targets above the beta arm surface to allow correction for elongation in the metrology system
* Inputs
  + 8bit bitmap image from met-ht camera
* Return
  + Height in microns of large target and small target above beta arm top surface
  + Quality metric of edge detection
* Configurable constants
  + METHT\_NOISE\_THRESH
  + METHT\_THRESHOLD\_VAL
  + METHT\_PLATESCALE
* Potential errors
  + Image out of focus so edges not clearly defined
  + Targets not clearly protruding
  + Noise in image from stray reflections
* Algorithm
  + Process image (convert, blur and threshold)
  + Check image noise
  + Find side of beta arm
  + At fixed offsets from arm side, find transition pixel representing top edge of arm and targets
  + Fit line through arm points
  + Find normal from line to target points
  + Average normals to give target height

## Find projected spot from pup-aln camera

* Purpose – to measure misalignment of the projected axis from a backlit fibre as the FPU rotates and thus determine the angular errors in each of the three mechanism axes
* Inputs
  + 8bit bitmap image from pup-aln camera
* Return
  + XY coordinates in real space of centre of projected spot
* Configurable constants
  + PUPIL\_CIRCULARITY\_THRESH
  + PUPIL\_THRESHOLD\_VAL
  + PUPIL\_DISTORTION\_MATRIX
  + PUPIL\_PLATESCALE
* Potential errors
  + Signal-to-noise too low due to upstream light loss or leakage through enclosure
  + Image contamination
  + Non-flat projection leading to bias in centre of mass
* Algorithm
  + Process image (distortion correct, convert, de-noise and threshold)
  + Find contours
  + Filter contours on size and circularity to detect targets and reject contamination
  + Find centre of targeted contour using Centre of Mass

# Performance parameter calculations

## Metrology target calibration

* Input
  + Coordinates of small target, large target and fibre aperture in real space
* Return
  + Distance between metrology targets and fibre aperture in microns

## Metrology height characterisation

* Input
  + Heights of small target and large target above beta arm
* Return
  + In tolerance (pass/fail) – heights are within acceptable tolerances
  + Heights – in microns for input to metrology system correction algorithm

## Pupil alignment

* Input
  + Coordinates of projected fibre aperture for given alpha/beta angles in real space
* Return
  + Pupil alignment (pass/fail) – maximum error in arcmin for total system
  + Pupil alignment breakdown – error magnitude/direction in arcmin for chassis, alpha and beta axes

## Datum repeatability

* Input
  + Coordinates of both metrology targets for given datum datasets in real space
* Return
  + Datum repeatability (pass/fail) – maximum error of datum error in microns
  + Datum repeatability – all values in microns for comparable points (for diagnostics)
* Algorithm
  + Average all baseline coordinates
  + For each datum coordinate
    - Subtract baseline coordinate from datum coordinate to give ‘error – datum only’
  + For each move-then-datum coordinate
    - Subtract baseline coordinate from move-then-datum coordinate to give ‘error – move-then-datum’
  + Find average and maximum ‘error – datum only’ values
  + Find average and maximum ‘error – move-then-datum’ values

## Gearbox correction calibration

* Input
  + Coordinates of both metrology targets for given alpha/beta angles in real space
* Return
  + Positional repeatability (pass/fail) – maximum error in microns for comparable points
  + Positional repeatability - all values in microns for comparable points (for diagnostics)
  + Alpha gearbox lookup table – step correction values for given angles to flatten circumferential error as best as possible
  + Beta gearbox lookup table – step correction values for given angles to flatten circumferential error as best as possible

## Positional accuracy

* Input
  + Coordinates of both metrology targets for given alpha/beta angles in real space
  + Coordinates of both metrology targets for given alpha/beta angles in nominal space
* Return
  + Positional accuracy (pass/fail) – maximum error of real position against nominal position in microns