6. How to optimize the sensor

After completing chapter 4, a first 3D image has been acquired successfully, which is, however, not perfect yet. The AT cameras offer many parameters, which can help to optimize the acquisition and improve the image quality. This chapter focuses on the most useful parameters and algorithms and explains their usage.

6.1. Optimize sensor speed

The sensors of AT are among the fastest triangulation sensors on the market. Hence, most users have specific demands for short cycle times which requires high scan rates.

6.1.1. AOI reduction

You can set a smaller AOI (Area Of Interest) to increase the sensor speed. A reduction in the sensor's height of the AOI will speed up the acquisition (When using a C5-1280, a reduction in the width can also increase the speed).

To do so, stop the acquisition, choose the *Rectangle Tool* and draw a rectangle around your object (with a small buffer). Make sure your whole target with the lowest and highest part is within the AOI. Maybe you have to move your target to verify all positions. Then press the *Set AOI* Button . The camera maximum frame rate will now be increased. To check the maximum frame rate go to *Acquisition Control* → *Acquisition Line Rate* → *Value*. *Acquisition Line Rate Enabled* needs to be set to *True*.
Hint: By holding *ctrl,* the display automatically covers the full width of the sensor.

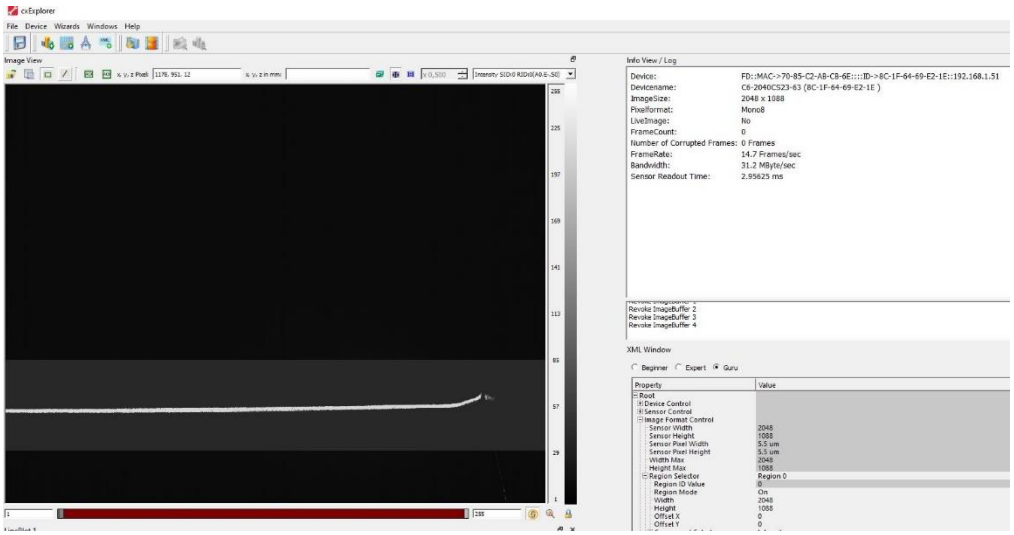


Figure 16: Set AOI

6.1.2. Region Search

In cases where the starting height of a flat object is unknown, the AOI-Search mode can be used. This mode allows the user to still set a small AOI around the laser line; In the beginning of each acquisition the laser line will be searched within the defined sensor area. This ensures a high scan rate within all of the measurement range in Z. Read the *AT Application Note: AOI-Search and –Tracking* for more details. (*Region Control* → *Region Search Selector)*

6.1.3. Region Tracking

The Region Tracking is the dynamic version of the static Region Search mode. It continuously tracks the position of the laser line and moves the AOI in the sensor according to the object movement. This ensures a high scan rate within all of the defined measurement range in Z and is recommended in applications where flat objects with a constant slope in the direction of movement must be inspected with high speed. Read the *AT Application Note: AOI-Search and –Tracking* for more details. (*Region Control → Region Tracking Selector)*

6.2. Optimize the laser line

Chapter *5.2 Parameterizing the camera* explains roughly how to get a reasonably good laser line image. In most cases, this step is crucial for the final precision of the measurements and requires some more effort to best set the underlying parameters.

6.2.1. Avoiding saturation

A more reliable and practical way to avoid laser line saturation is to check it with a maximum intensity image. To do so change the *Extraction Method* to *3D Maximum Intensity (MAX)*. Set the *Image Height* to a value where your whole target is visible and activate *Component Enable* for the *Reflectance* in *Component Selector*. Acquire a single image with the *Snapshot* button . When the *Max. value* of the currently shown data is 1023 (see Figure 17), there is at least one saturated pixel. Hence, a useful way to identify oversaturation is to set the *Min. value* of the shown data to 1022 to show only saturated pixels. A few saturated pixels are ok but make sure there are no larger connected oversaturated areas.

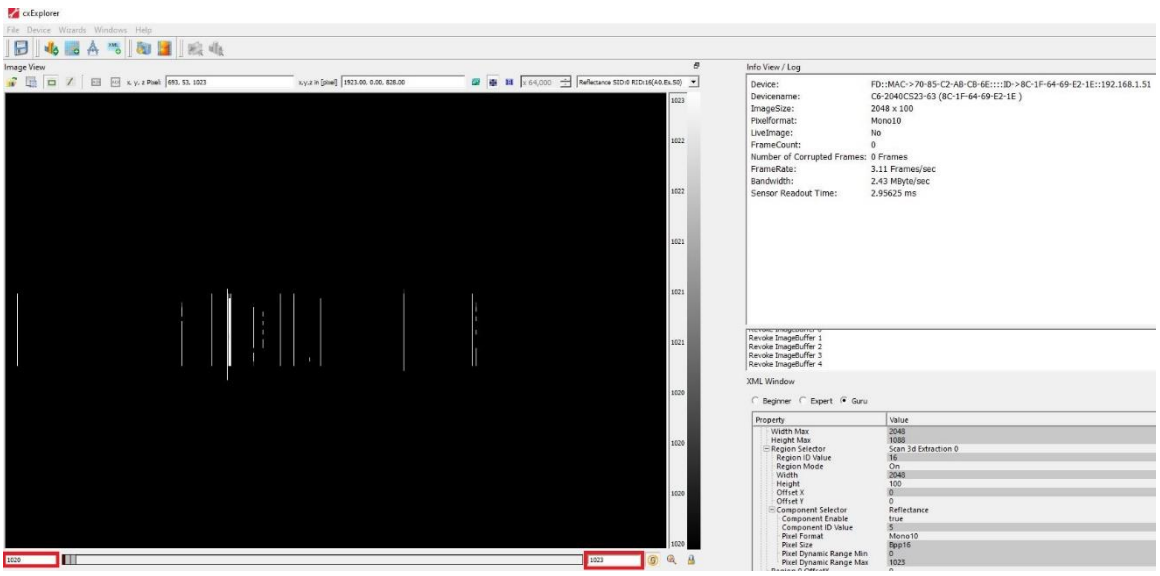


Figure 17: MAX algorithm to check for saturation

6.2.2. Increase dynamic range with multiple slope

An important feature to use to improve the range map quality is to use the multiple slope functionality. The Multiple Slope Mode is a function to increase the dynamic range of the sensor. It allows capturing very weak and very strong intensity signals (typically dark and bright or reflective and non-reflective surfaces) at the same time without image saturation, thus enhancing the precision of laser line detection.

In the example of the following screenshot, the laser line is just slightly above the AOI Threshold value of 120 on the left side while the right line is already saturated (see Figure 18).

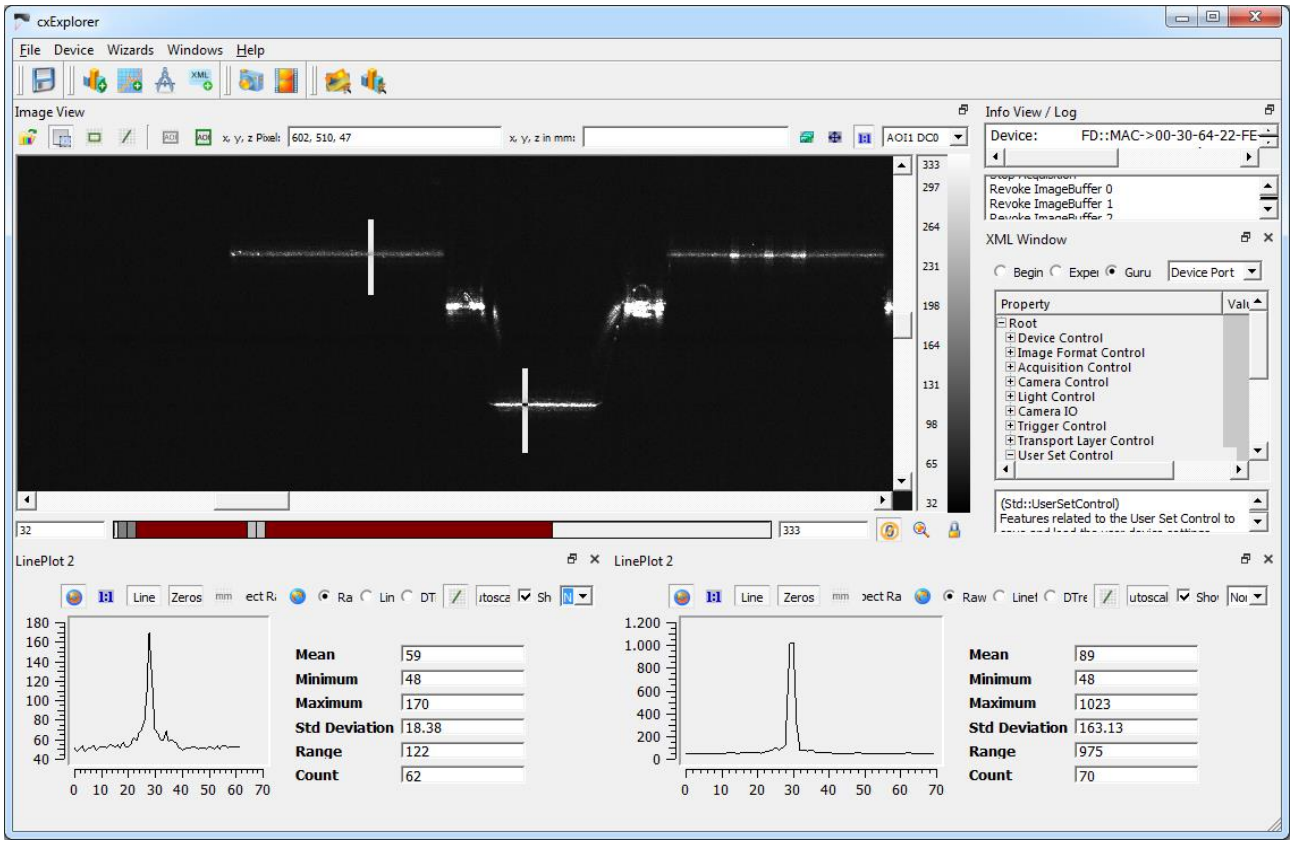


Figure 18: Different laser line intensities

There is a detailed step-by-step procedure in the AT Application Note: *The Multiple Slope*.

6.3. Optimize interpretation of the laser line

Equally important than a correct mapping of the projected laser line onto the sensor image is a well suited interpretation of the line. The AT camera offers a couple of different algorithms for the ideal determination of the range out of the sensor image. (*Scan 3d Control → Extraction Selector → Extraction Method)*

6.3.1. Choosing the right 3D sensor algorithm

The *Extraction Methods* specify how the centre of the laser line is determined. All modes are equally fast, thus the one that best suits the application should be selected. The operation mode can be chosen by setting the following parameter:

Scan3dExtractionMethod	Enumeration	RW	Expert	Selects the method for extracting 3D from the input sensor data. - *Threshold* (Value=0) - *MaximumIntensity* (Value=1) - *CenterOfGravity* (Value=2) - *FIRPeak* (Value=3)

Figure 19: 3D Acquisition Modes

The *MaximumIntensity algorithm* (**MAX**) determines the pixel yielding the highest intensity and assumes this as the line's central position. It does not provide any subpixeling, but can be nevertheless useful for inspecting objects with volume scatter.

Of higher precision is the *Threshold algorithm* (**TRSH**), which returns the left and right intersection of threshold value and intensity profile as well as the mean value between those. Consequently, the centre is determined with one subpixel of accuracy.

The *Centre Of Gravity* (**COG**) mode determines the positions with a precision determined by the used *Coordinate Scale*. It is more robust, precise and resilient than the two previous algorithms. When using the COG approach, the laser line width should cover at least 4 sensor pixels to allow for a meaningful detection.

The fourth *Extraction Method* is called *FIR-Peak* (**FIR**). This algorithm is based on a zero-detection on the first deviation of the signal and is even more robust against noisy signals. However, this algorithm only works good with non-overexposed laser lines. It provides precision determined by the used *Coordinate Scale*. The *Filter Mode* can be the algorithm of choice when used in combination with a multiple slope in order to ensure non-overexposed images. See the *AT AppNote - The FIR Filter* for more details.

Furthermore, the *Filter Mode* can be used in combination with the other algorithms (TRSH, MAX, COG) as a pre-processor for smoothing the sensor image. Therefore, the *Filter Mode* must be set to *On*.

Table 1: Advantages and Disadvantages of the different 3D algorithms

3D Algorithm	Advantages	Disadvantages
MAX	• Very robust against interference reflections	• Poor accuracy (no subpixeling) Poor results with saturated lase line
TRSH	• Useful when left/right position of laser line is needed	• Poor accuracy (1 subpixel)
COG	• Good accuracy for thick laser lines (> 10 pixel) • Ideal for geometry measurement	• Vulnerable to interference reflections
FIR-PEAK	• Good accuracy for narrow laser lines (< 10 pixel) • Robust against interference reflections • Also good with low laser line intensity • Ideal for surface and defect inspection	• Less accurate for thick laser lines (> 10 pixel) • No intensity image • Vulnerable to saturated laser line

6.3.2. Handle multiple laser lines

Sometimes the projected laser line is mapped on the sensor with multiple laser lines on top of each other (see **Error! Reference source not found.**), mostly caused by reflections or transparent objects. Normally the algorithm will choose the strongest peak automatically. In some use cases explicitly multiple laser lines are used to acquire objects. For these cases the C6 offers the possibility to use the *Multi Peak* functionality. (*Scan 3d Control → Mutli Peak Mode).*

Algorithm	Description
First	The first detected valid peak will be output. A peak is valid, when the algorithm found a rising edge over the specified threshold and the corresponding falling edge. The peak detection will be stopped after the first found peak.
Single	The Single mode is not available in FIRPeak mode. It will only output one Peak from the first rising edge to the last falling edge. Only one memory slot is needed and no peak detection is necessary.
Set First	The first four detected peaks will be saved and can be output individually. This mode is similar to the "First" mode, but no peak will be overwritten. With Multi Peak Enable individual peaks can be enabled. Internally all four peaks will need memory space but only the selected and enabled peaks will be output.

Using the Set First algorithm will allow to extract up to four peaks per column. The output of the camera will be a Multi Part Buffer containing the selected image data (Range, Reflectance, Scatter) for each level.

6.3.3. Validation of the COG results

When using the COG algorithm, the sensor offers the ability to validate the resulting height data. Using criteria related to the Gauss distribution area (sum of intensity values) and Gauss distribution width (laser line width), it is possible to suppress invalid height values.

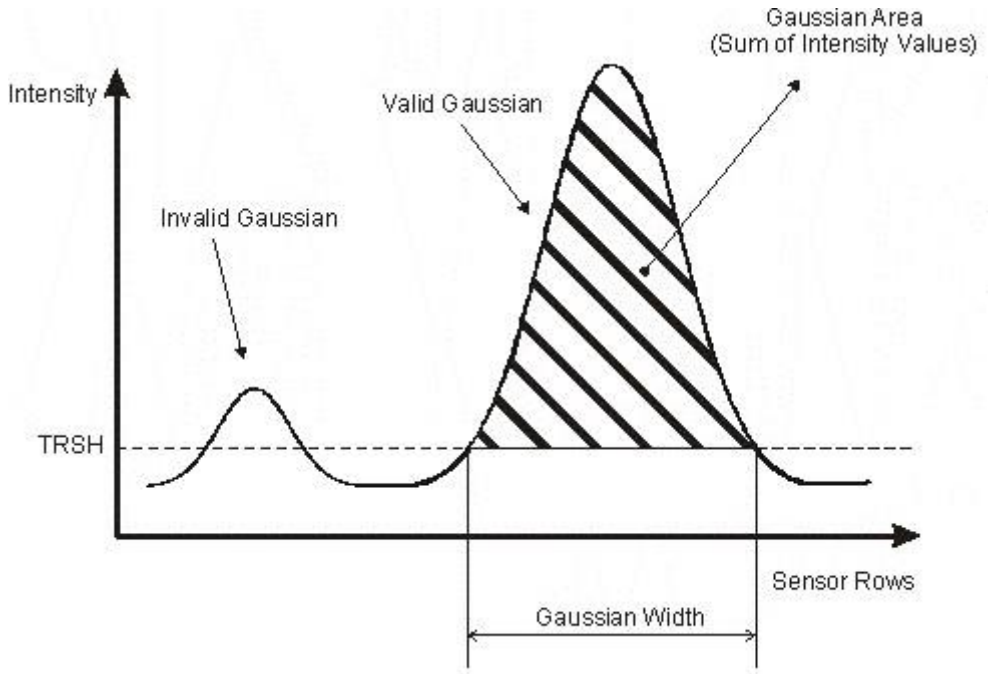


Figure 20: Gauss validation

6.4. Triggering

There are several ways to trigger an AT sensor. Which way to choose depends on the conditions in the machine and individual preferences.

6.4.1. Trigger Inputs

Profile triggering of the AT 3D devices can be performed via the RS-422 encoder interface or opto-coupled inputs IN1 and IN2 on the I/O panel (TTL, 5 or 24 V).

TriggerSelector	Enumeration	RW	Beginner	Selects the type of trigger to configure. - *AcquisitionStart* (Value=0): Selects a trigger that starts the Acquisition of one or many frames according to AcquisitionMode. - *FrameBurstStart* (Value=2): Selects a trigger starting the capture of the bursts of frames in an acquisition. AcquisitionBurstFrameCount controls the length of each burst unless a FrameBurstEnd trigger is active. The total number of frames captured is also conditioned by AcquisitionFrameCount if AcquisitionMode is MultiFrame. - *FrameStart* (Value=4): Selects a trigger starting the capture of one frame. - *LineStart* (Value=6): Selects a trigger starting the capture of one Line of a Frame (mainly used in line scan mode).
TriggerMode *[TriggerSelector]*	Enumeration	RW	Beginner	Controls if the selected trigger is active. - *Off* (Value=0): Disables the selected trigger. - *On* (Value=1): Enable the selected trigger.
TriggerSoftware *[TriggerSelector]*	Command	RW	Beginner	Generates an internal trigger. TriggerSource must be set to Software.
TriggerSource *[TriggerSelector]*	Enumeration	RW	Beginner	Specifies the internal signal or physical input Line to use as the trigger source. The selected trigger must have its TriggerMode set to On. - *Off* (Value=0) - *UserOutput0* (Value=2) - *UserOutput1* (Value=3) - *Counter0Start* (Value=4) - *Counter0End* (Value=5) - *SoftwareSignal0* (Value=6) - *SoftwareSignal1* (Value=7) - *Line0* (Value=8) - *Line1* (Value=9) - *Line2* (Value=10) - *Line3* (Value=11) - *Line4* (Value=12) - *Encoder0* (Value=16)
TriggerActivation *[TriggerSelector]*	Enumeration	RW	Beginner	Specifies the activation mode of the trigger. - *RisingEdge* (Value=1): Specifies that the trigger is considered valid on the rising edge of the source signal. - *FallingEdge* (Value=2): Specifies that the trigger is considered valid on the falling edge of the source signal. - *AnyEdge* (Value=3): Specifies that the trigger is considered valid on the falling or rising edge of the source signal.
TriggerDelay *[TriggerSelector]*	Float	RO	Expert	Specifies the delay in microseconds (us) to apply after the trigger reception before activating it.
TriggerDivider *[TriggerSelector]*	Integer	RO	Expert	Specifies a division factor for the incoming trigger pulses.
TriggerMultiplier *[TriggerSelector]*	Integer	RO	Expert	Specifies a multiplication factor for the incoming trigger pulses. It is used generally used in conjunction with TriggerDivider to control the ratio of triggers that are accepted.

Figure 21: Trigger Mode Settings

Both single lines and complete frames can be triggered externally by either choosing *LineStart* or *FrameStart* from the Trigger Selector and defining the *Trigger Source*. Triggers can be easily activated or deactivated using *Trigger Mode On/Off*.

For the *LineStart* either the IN1/2 or an external Encoder can be used. Please note that this implicitly prevents using an external frame trigger when the *LineStart* trigger is input on the digital I/O's. If both trigger types

should be provided externally, a rotary encoder is necessary. To fully exploit the available capabilities of the 3D cameras, a 24 V quadruple encoder is recommended, i.e. providing two pairs of differential outputs, signalling forward and backward movement. However, a single RS-422 pair can be used as well. The shield of the encoder should be connected to the input ground clamp.

Different selected Trigger events are used to synchronize the start of a frame acquisition - and optionally stop the acquisition - by an external hardware signal. For this purpose, the opto-coupled digital inputs on the I/O breakout board of the camera are utilized, which can be fed by either TTL or 24 V DC.

The following is an overview over the available Sequencer Modes ("Frame Trigger Controls"). Not all of them are suitable for all types of acquisition. To trigger images, the following options can be selected:

- **Start/Stop over camera input 1/2:** Using a combination of *FrameStart/Stop* or *AcquisitionStart/Stop* hardware triggers for *Line0* and *Line1* offers the possibility to trigger frames of individual amount of lines, defined by the timing of the *FrameStop* or *AcquisitionStop* trigger signal.
- **Trigger one frame over camera input 1 or 2:** A start signal is expected on camera input Line0 or Line1, triggering exactly one frame to be acquired. Therefore activate FrameStart trigger with Trigger Source Line0 or Line1
- **Gate over camera input:** After a HIGH level has been detected on *Line0* or *Line1*, images are continuously acquired until the voltage level is going back to LOW. When detecting the LOW level, the current frame is completed before sent to the host. When a fixed number of images is given, the acquisition stops after that number of images, even when HIGH signal is still present.
- **Start/Stop with instant transmission over camera input 1/2:** A signal is expected on camera *Line0*, starting the continuous acquisition of frames, while a signal on *Line1* will stop the acquisition. Both inputs trigger on detection of a rising edge (TTL). Upon reception of the stop signal, the current frame is immediately sent to the host. The frame will have the same size as its predecessors, invalid lines are however filled with random content. The actual number of valid lines can be determined either via Chunk data or the BUFFER_PART_INFO_DELIVERED_IMAGEHEIGHT. When a fixed number of images is given, the acquisition stops after that number of images, even when no stop signal is sensed.

6.4.2. Maximum Input Trigger Frequency

The maximum frequency the encoder input opto-coupler can handle for RS-422 at 5 V level is 15 MHz. Please be aware that incoming profile trigger signals can be divided internally. The divider field has a size of 32 bit. 24 V DC trigger signals must be connected to *Line0* and *Line1* instead of the RS-422 clamp row.

6.4.3. RS-422 Encoder Triggering

The trigger occurs on every edge of the RS-422 encoder signal, both on rising and falling edges. The trigger frequency can be reduced by means of a trigger divider (32 bit), e.g. a value of trigger divider equal to 2 means that every second edge will be used to generate a profile / line trigger. This is done by loading the value of trigger divider into an internal counter of the camera after starting the frame acquisition. For every incoming edge of the RS-422 encoder pulse, the internal counter is decreased by 1. As soon as the internal counter reaches zero, a profile/line trigger is generated.

Hint: To take into account that the camera interprets every edge of the signals. To register every edge use EncoderMode → High Resolution. To use only full quadrature phases use the Encoder Mode → Four Phase.

EncoderControl

Category that contains the quadrature Encoder Control features.

Name	Type	Access	Visibility	Description
EncoderSourceA	Enumeration	RW	Expert	Selects the signal which will be the source of the A input of the Encoder. - *Off* (Value=0): EncoderSourceA disabled. - *UserOutput0* (Value=2) - *UserOutput1* (Value=3) - *Counter0Start* (Value=4) - *Counter0End* (Value=5) - *SoftwareSignal0* (Value=6) - *SoftwareSignal1* (Value=7) - *Line0* (Value=8) - *Line1* (Value=9) - *Line2* (Value=10) - *Line3* (Value=11) - *Line4* (Value=12)
EncoderSourceB	Enumeration	RW	Expert	Selects the signal which will be the source of the B input of the Encoder. - *Off* (Value=0) - *UserOutput0* (Value=2) - *UserOutput1* (Value=3) - *Counter0Start* (Value=4) - *Counter0End* (Value=5) - *SoftwareSignal0* (Value=6) - *SoftwareSignal1* (Value=7) - *Line0* (Value=8) - *Line1* (Value=9) - *Line2* (Value=10) - *Line3* (Value=11) - *Line4* (Value=12)
EncoderMode	Enumeration	RW	Expert	Selects if the count of encoder uses FourPhase mode with jitter filtering or the HighResolution mode without jitter filtering. - *FourPhase* (Value=1): The counter increments or decrements 1 for every full quadrature cycle with jitter filtering. - *HighResolution* (Value=0): The counter increments or decrements every quadrature phase for high resolution counting, but without jitter filtering.
EncoderDivider	Integer	RW	Expert	Sets how many Encoder increment/decrements that are needed generate an Encoder output pulse signal.
EncoderOutputMode	Enumeration	RW	Expert	Selects the conditions for the Encoder interface to generate a valid Encoder output signal. - *Off* (Value=0): No output pulse are generated. - *PositionUp* (Value=1): Output pulses are generated at all new positions in the positive direction. If the encoder reverses no output pulse are generated until it has again passed the position where the reversal started. - *PositionDown* (Value=2): Output pulses are generated at all new positions in the negative direction. If the encoder reverses no output pulse are generated until it has again passed the position where the reversal started. - *DirectionUp* (Value=3): Output pulses are generated at all position increments in the positive direction while ignoring negative direction motion. - *DirectionDown* (Value=4): Output pulses are generated at all position increments in the negative direction while ignoring positive direction motion. - *Motion* (Value=5): Output pulses are generated at all motion increments in both directions.
EncoderResetSource	Enumeration	RW	Expert	Selects the signals that will be the source to reset the Encoder. - *Off* (Value=0): EncoderReset disabled. - *UserOutput0* (Value=2) - *UserOutput1* (Value=3) - *Counter0Start* (Value=4) - *Counter0End* (Value=5) - *SoftwareSignal0* (Value=6) - *SoftwareSignal1* (Value=7) - *Line0* (Value=8) - *Line1* (Value=9) - *Line2* (Value=10) - *Line3* (Value=11) - *Line4* (Value=12) - *AcquisitionStart* (Value=18)
EncoderResetActivation	Enumeration	RW	Expert	Selects the Activation mode of the Encoder Reset Source signal. - *LevelLow* (Value=0): Resets the Encoder as long as the selected signal level is Low. - *RisingEdge* (Value=1): Resets the Encoder on the Rising Edge of the signal. - *FallingEdge* (Value=2): Resets the Encoder on the Falling Edge of the signal. - *AnyEdge* (Value=3): Resets the Encoder on the Falling or rising Edge of the selected signal. - *LevelHigh* (Value=4): Resets the Encoder as long as the selected signal level is High.
EncoderReset	Command	RW	Expert	Does a software reset of the selected Encoder and starts it. The Encoder starts counting events immediately after the reset. EncoderReset can be used to reset the Encoder independently from the EncoderResetSource.
EncoderValue	Integer	RW	Expert	Reads or writes the current value of the position counter of the selected Encoder.
EncoderValueAtReset	Integer	RO	Expert	Reads the value of the of the position counter of the selected Encoder when it was reset by a signal or by an explicit EncoderReset command.

Figure 22: RS-422 Encoder Parameters

6.5. Calibration

6.5.1. Introduction

Many image processing applications require calibrations in order to be able to measure features. This applies to both, 2D and 3D applications. The Metric Tool of Common Vision Blox currently provides functionality for the calibration of 3D sensors. In detail, the calibration of laser triangulation systems can be determined (intrinsic calibration). Furthermore, all pre-calibrated 3D sensors can be transformed into a desired world coordinate system (extrinsic calibration).

Laser Triangulation

The principle of laser triangulation is shown in Figure 23.

A line laser emits light to provide a visible line on an object. The profile of the laser line is acquired by a camera that is mounted in a fixed angle to the laser. The shape of the object's surface will define the position where the laser line is captured in the camera sensor. From the distinct pixel positions of the laser line in the image a height profile can be calculated with relative height information. However, without knowing the exact positions and orientations of laser and camera is is not possible to refer these pixel positions to real metric coordinates. Therefore, it is necessary to previously calibrate the triangulation system with a calibration target with known coordinates.

By continuously moving the object under the laser-camera-system multiple profiles can be generated and accumulated in one height image. We call those images range maps.

The coordinate system of a point cloud created from a range map of a laser triangulation system is defined as follows:

laser triangulation setup	**range map**	**point cloud**
lateral position on laser line	number of sensor row	x-coordinate
position in the direction of movement	number of sensor column	y-coordinate
position in the direction of the laser projection	grey value	z-coordinate

The columns in the range map (x coordinate) correspond to the columns of the raw sensor image (u coordinate). The lines indicate the n'th profile in traverse direction (y direction) and the intensity value represents the v coordinate of the laser peak within the frame.

In order to get 3D world coordinates, the relationship between range map pixels and metric units have to be determined.

Therefore the relationship between pixel coordinates (in the sensor plane of camera) and coordinates of the laser plane, the so-called intrinsic parameters have to be estimated first.

Second, the relationship between laser plane and world coordinates, the so-called extrinsic parameters have to be determined.

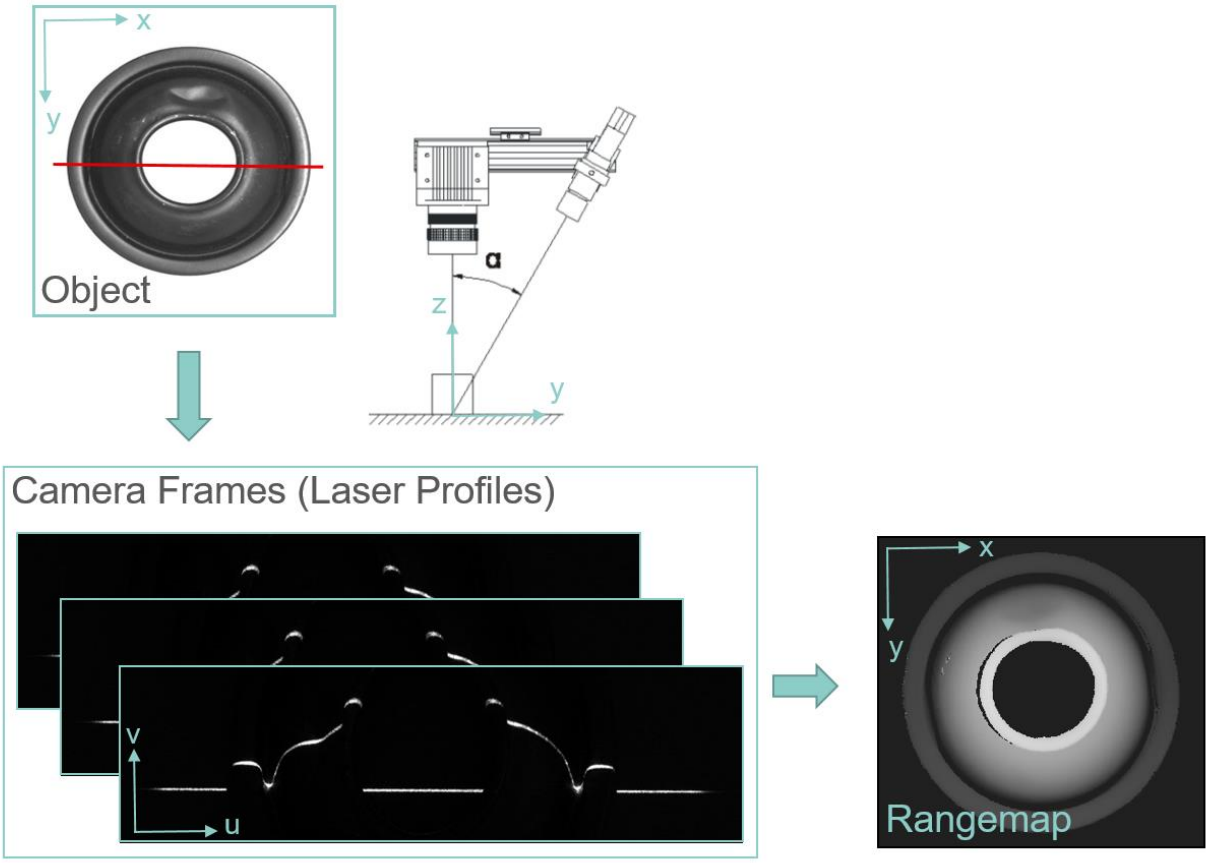


Figure 23: principle of laser triangulation

6.5.2. Metric conversion

The metric conversion can be divided into two parts: The intrinsic and the extrinsic calibration.

- The intrinsic calibration describes the relationship between camera pixel coordinates (sensor plane) and laser plane. The perspective projection (homography), the lens and the laser line distortion are classified as intrinsic parameters.
- The extrinsic parameters represent the transformation from the laser plane to world coordinates. They are described by a transformation matrix (scale and rotation) and a translation in all three directions (x, y and z).

Intrinsic calibration

In order to guarantee accurate coordinates all intrinsic calibration parameters should be estimated:

- perspective projection: homography (3x3 matrix)
- lens distortion (e.g. Brown-Conrad, cubic or polynomial)
- laser line distortion (2nd, 3rd, or 4th order polynomial)

The intrinsic calibration can be done with several calibration targets (like a zigzag target with one to n profiles, a trapeze with one to n profiles, etc...). If only the perspective projection and the lens distortion should be estimated a chessboard is an adequate calibration target, too. With the current CVB release only the homography and the extrinsic calibration parameters can be estimated using a diamond calibration target with the function `CVMAQS12CreateCalibrator()`. Note, that the complete intrinsic calibration will be implemented in a future release.

Extrinsic calibration

For the extrinsic calibration a transformation matrix (including three rotations and three scaling factors) and a translation vector is estimated. In CVB the extrinsic transformation parameters can be determined with a diamond calibration target with 12 reference points. The extrinsic calibration should only be applied if the range map is already calibrated by the intrinsic parameters, which possibly applies for compact sensors, where the distance and the angle between camera and laser line is fixed. In this case the intrinsic calibration has usually been done by the producer of the camera (e.g. Automation Technology, LMI Gocator). To calculate the extrinsic transformation parameters with a previously known intrinsic calibration CVB offers the function `CVMAQS12CalculateExtrinsic()`.

If the intrinsic parameters are not known, the function `CVMAQS12CreateCalibrator()` should be used. There, the extrinsic parameters plus the homography matrix is estimated. Note, that then the rotation around y (traverse direction), the scaling and translation in x and z are represented both by the homography matrix and the transformation matrix. As the homography is calculated in the first step, the rotation, translation and scaling mentioned before should be near zero (and one respectively) for the extrinsic calibration parameters.

6.5.3. Performing a Calibration with CVB

For the estimation of the calibration parameters, a suitable calibration target with precisely known dimensions is needed. The calibration target should be chosen considering which calibration parameters have to be estimated. For the intrinsic calibration e.g. a zigzag target or chessboards (not estimating the laser line distortion) are suitable. For the extrinsic calibration a diamond calibration target has been found to yield good results.

Currently, CVB only supports the diamond target (AQS12) for both, intrinsic and extrinsic calibration.

Estimation of intrinsic and extrinsic calibration parameters

For the CVB functions

- `CVMAQS12CreateCalibrator()`
- `CVMAQS12CreateCalibratorRect()`

a diamond calibration target with 12 reference points (see Section 6.5.4) is needed. The 3D world coordinates of the reference points have to be known precisely. Please pay attention to the pattern constraints.

Estimation of intrinsic calibration parameters

When calibrating the laser triangulation system with the AQS12 calibration target, it will always calculate both, the intrinsic AND the extrinsic calibration parameters. For future releases, a function for an intrinsic calibration only is planned.

Estimation of extrinsic calibration parameters

Following functions will calculate the extrinsic transformation parameters from a given range map of the AQS12 pattern.

- `CVMAQS12CalculateExtrinsicMatrix()`
- `CVMAQS12CalculateExtrinsicMatrixRect()`

Please note, that the range map should be pre-calibrated or the intrinsic calibration parameters already be known when using this function.

For a better understanding when to use which calibration, please refer to the 3D section in the Image Manager CVB documentation.

6.5.4. Calibration Target (AQS12)

Currently, CVB supports a diamond shaped calibration pattern (AQS12) for both, the intrinsic and extrinsic calibration. It has a distinct shape with 8 planes and 12 feature points resulting from the intersection points of these planes. The overall size of the target can vary, however, the proportions of the pattern are important for the internal algorithm, as well as the order of the points located on the pattern.

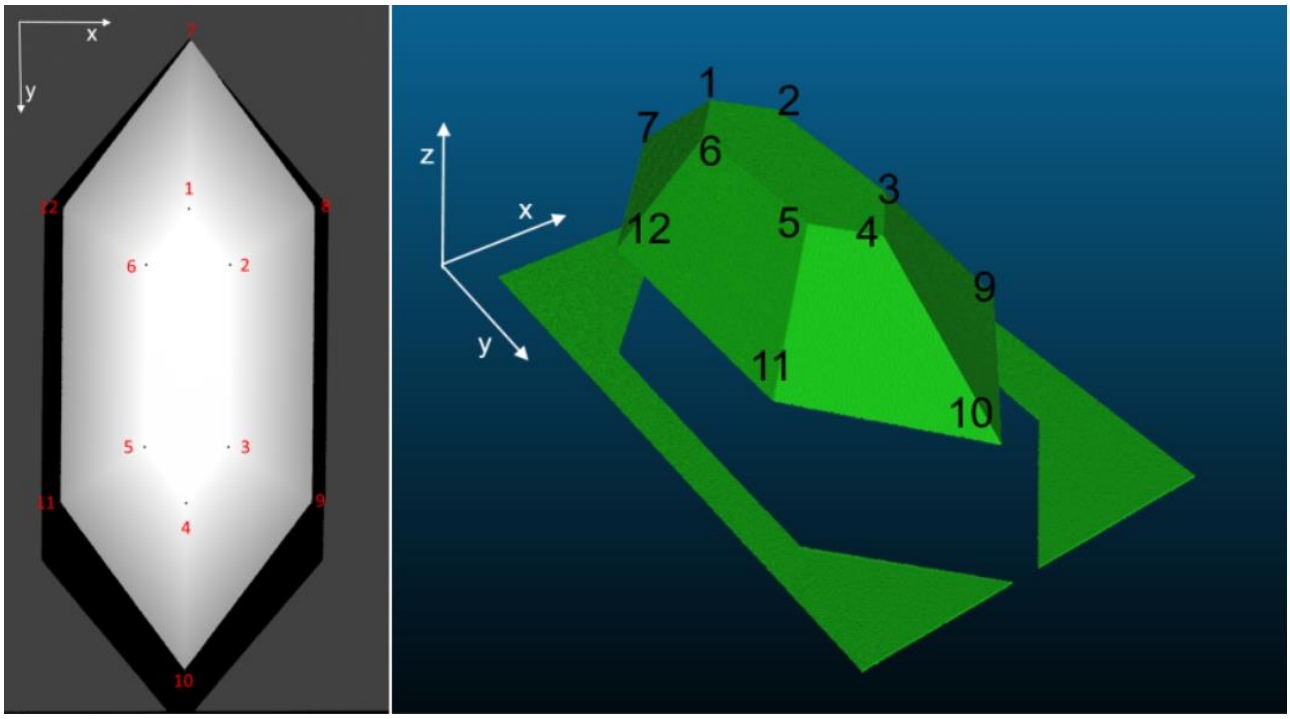


Figure 24: AQS12 point assignment

The dimensions of the calibration target should be similar to the example shown in the figures below. In any case it should meet the following requirements:

- The base plane has to contain enough area: The number of pixels on the base plane has to be (significantly) larger than the number of pixels on the roof.
- Points 1-6 and 7-12 respectively have to lie on the same plane. Base plane and roof have to be parallel.

- The shape of the object may not be changed, i.e. parallel lines must remain parallel, and the object has to be symmetric.
- Calibration points 1, 8 and 12 must have the same y values, same for 4, 9 and 11.
- In order to get accurate calibration results, the surfaces should be non-specular.
- Check, if the slopes of the calibration target can be acquired under the triangulation angle needed for your application.

Note, that the x-axis in the range map represents the x-axis of the camera frame. The y-axis is the traverse direction. The z-axis should be perpendicular to the base plane and represents the height of the object.

In addition the following specifications should be considered during the acquisition:

- The calibration target has to be moved at constant speed or synchronized with the camera by an encoder, so that the distances between successive profiles are always equal.
- The image used for the calibration should contain only points belonging to the calibration target. In case the acquired range map shows more than the pattern, use functions `CVMAQS12CreateCalibratorRect()` and `CVMAQS12CalculateExtrinsicMatrixRect()`.
- The axis on which the points 7, 1, 4 and 10 are located, should be (more or less) parallel to the motion direction.
- The z-axis of the calibration target should be perpendicular to the motion plane.

Example dimensions

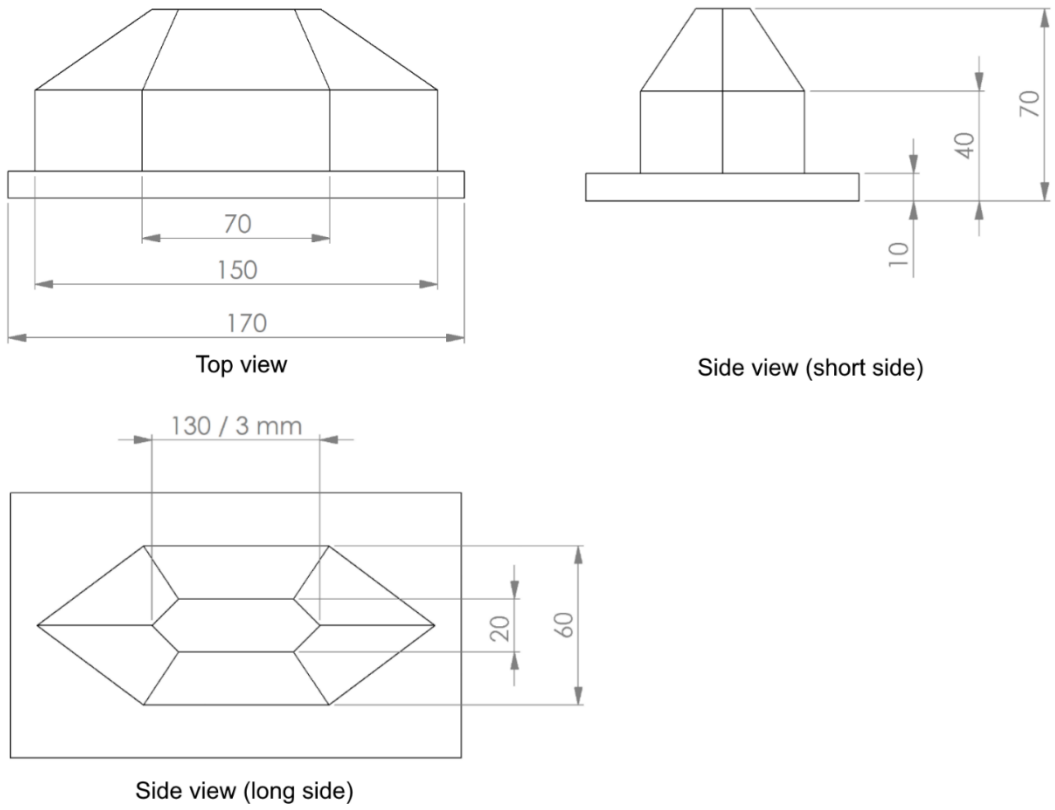


Figure 25: AQS12 example dimensions

The world coordinates of the reference points for the example shown in the figure above are listed in the table below:

Point	X [mm]	Y [mm]	Z [mm]
1	0	40	60
2	10	53.333	60
3	10	96.667	60
4	0	110	60
5	-10	96.667	60
6	-10	53.333	60
7	0	0	30
8	30	40	30
9	30	110	30
10	0	150	30
11	-30	110	30
12	-30	40	30
Height	60		

The first column indicates the x, second the y and third the z coordinate. Mind the order of the points (see Figure 24). The single value in the last line represents the height distance between y. If it is missing, the height of the base plane is supposed to be zero.

Note, that the vertical walls of the calibration target are not required. The calibration target may also have only the base and the top plane and 6 faces (see Figure 26).

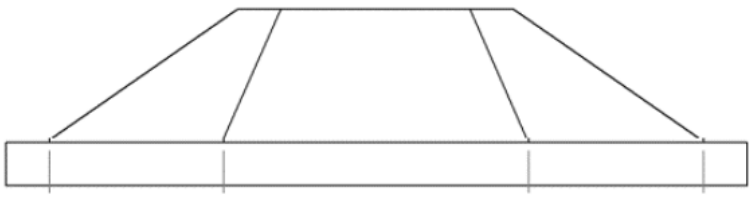


Figure 26: Alternative AQS12 shape

6.5.5. Calibration Checklist

From experience there are a lot of parameters and process steps to be considered for performing a calibration for C6 cameras. Therefor the following list should provide a guidance on avoiding errors during the calibration process.

1. Preparations

1. Conceptual design of a calibration target
   - target should have a cooperative surface characteristic (diffuse reflection, narrow laser line)
   - should cover entire measurement range in x and z
   - slopes must not be too steep
2. Determination of the exact dimensions of the calibration body with a different measurement system

2. Execution

1. Bring sensor into thermal equilibrium (housing and sensor should be stabilized after 1h of operation)
2. Adapt the camera parameters to acquire range maps of the calibration target with the best possible quality. See AT CVB Application Note for how to find the best settings.
3. Acquire a range map of the calibration target
4. Store used camera parameters (the following parameters are required for a correct point cloud reconstruction)
   - Width & Height
   - Position and dimension of the ROI (if Scan3dCoordinateMode = Sensor)
   - Scan3dCoordinateScale
   - RegionReverseY
5. Store intrinsic calibration from AT camera (e.g. with CXExplorer) in an .xml file
6. Use points from step 1.2 for the calibration
7. Calibrate application with either with the CVB CSMetric3D tutorial or programmatically
8. Interpret results (check residuals for excessive values)
9. Store calibration (intrinsic & extrinsic) in one .json file
10. Adapt the camera parameters for the final objects to be measured
11. Modify calibration file (.json) if any of the parameters from step 5 have changed
12. Acquire a range map of the final object under realistic conditions
13. Reconstruct calibrated 3D point cloud with range map and calibration file (.json)

6.6. Miscellaneous

6.6.1. Chunk Data

Additional information to the output channels which include the image data can be accessed using the chunk mode. The chunk data contains information about the states of triggers, timestamps, frame counters, I/O's, AOI sizes, valid image sizes, etc. and will be outputted in the end of each image frame or profile. More information about the chunk mode is available in the sensor manual.

For a more detailed description and a code example read this CVB user forum post:

https://forum.commonvisionblox.com/t/working-with-3d-cameras-of-automation-technology-in-cvb/532/17

6.6.2. Multi-Part

Since the introduction of GenICam Standard 3.0 AT is one of early adapter implementing the standard in the C6 camera series. As one of the major aspects from the new standard is the availability of Multi-Part. GenICam 1.2 did only allow to transmit single frames from cameras while Multi-Part now offers the possibility to transmit multiple images inside a single buffer. While the C5 needed to use the interlayesr format to transmit Range, Intensity and Scatter image inside one frame, the C6 using Multi-Part can now transmit all image parts as enclosed structure but in a single buffer.

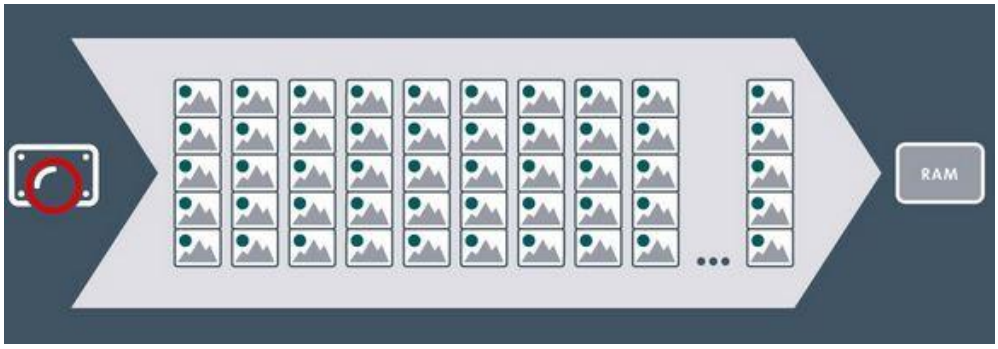
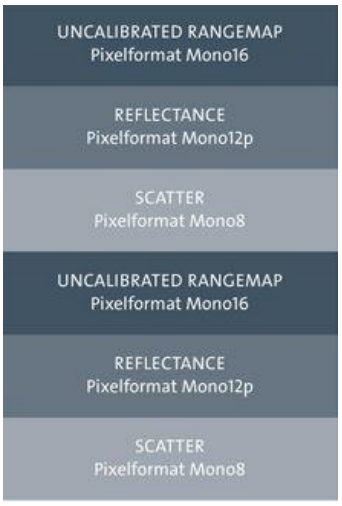


Figure 27: Camera transmitting multipart images. Each acquisition 5 images are generated and send to the host inside one Multi-Part buffer, while the host can directly split the buffer into single images.



Multi-Part is supported by cxExplorer and CVB. While there are still applications that require to use GenICam 1.2, the C6 offers the option for a fallback to still use multiple components without using Multi-Part. There is a detailed description inside the CVB Forum.

Figure 28: Example of a C6 Multi-Part buffer containing different image components.

6.6.3. Multi-Peak

Using the Multi-Part functionality in the C6 brings the option for additional features that were limited by the image transmition standard in the past. With Multi-Peak the C6 offers to extract multiple laser lines from the camera raw image. This feature is mainly used for translucent surfaces or systems where multiple laser lines are used. In the C6 now for each of maximum 4 laser lines an individual range, intensity and scatter image can be generated and transmitted using Multi-Part. To use the feature enable *Scan3dControl* → *MultiPeakMode* → *SetFirst* and activate each peak level using *MultiPeakSelector*.

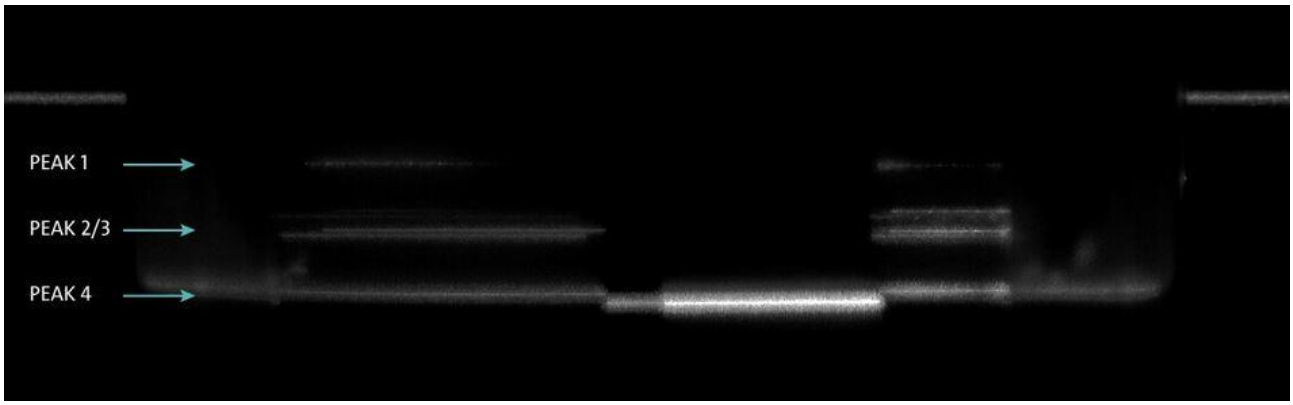


Figure 29: Multi-Peak feature shown on a translucent surface. The different layers of the translucent surface reflect the laser line partially. A surface from each layer can be extracted.

6.6.4. Multi-Region

Multi-Region allows to define multiple regions on the camera sensor and extract range, intensity and scatter images individual for each region. The data are than transmitted to the host using Multi-Part.

The key advantage is to increase the scanning speed for using for example a small region on top and bottom of the sensor instead of requiring to use a single large region.

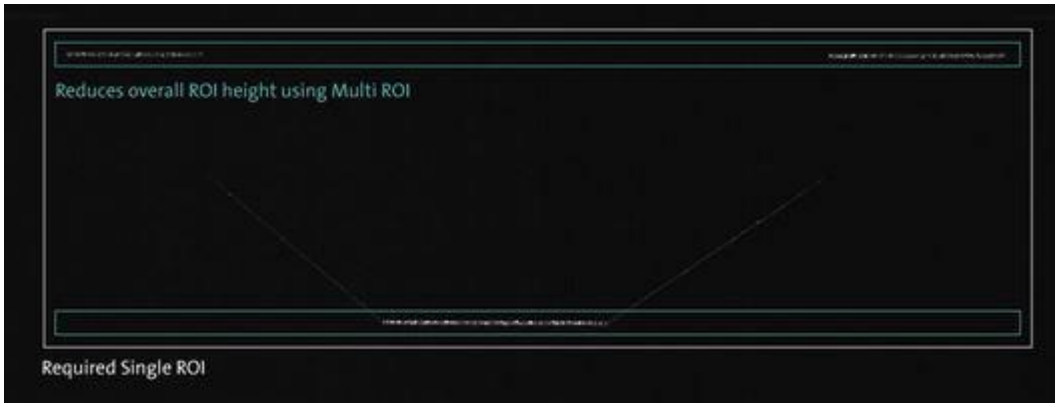
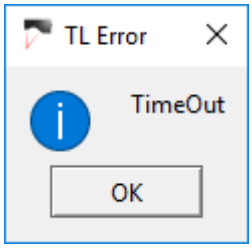


Figure 30: Multi-Region allows to acquire data from up to 4 different positions on the camera sensor. Using multiple regions instead of one large region significantly increases the acquisition speed of the sensor.

7. Troubleshooting

7.1. cxExplorer Timeout



When you get a TL Error - TimeOut message in the cxExplorer, most likely the *Sensor Frame Interval* is too high, thus the acquisition for all profiles takes too long. So try to decrease this value first.

If that is not the problem (e.g. because the acquisition might really take a long time), you can increase the cxExplorer acquisition timeout: (*File* → *Preferences* → *Device-Options* → *Acquisition Timeout*).

7.2. Overflow in image

When you notice an overflow in your rangemap image, the *Scan3dCoordinateScale* value might be too low. You can see the maximum subpixel value for your AOI height in the following table. There is a more detailed description about this on our CVB User Forum.

max. AOI height	max. subpixels (8Bit)	resolution (8Bit, Range 256)	max. subpixels (12Bit, Range 4096)	resolution (12Bit, Range 4096)	max. subpixels (16Bit, Range 65536)	resolution (16Bit, Range 65536)
4	6	0.015625	10	0.000977	14	0.000061
8	5	0.03125	9	0.001953	13	0.000122
16	4	0.0625	8	0.003906	12	0.000244
32	3	0.125	7	0.007813	11	0.000488
64	2	0.25	6	0.015625	10	0.000977
128	1	0.5	5	0.03125	9	0.001953
256	0	1	4	0.0625	8	0.003906
512	0	bit overflow	3	0.125	7	0.007813
1024	0	bit overflow	2	0.25	6	0.015625
2048	0	bit overflow	1	0.5	5	0.03125
4096	0	bit overflow	0	1	4	0.0625

7.3. Receiving black images in CVB

- Check if jumbo frames are activated in driver, NIC and intermediate switches.
- Check that color format in the driver is set to RAW.

7.4. Firmware update

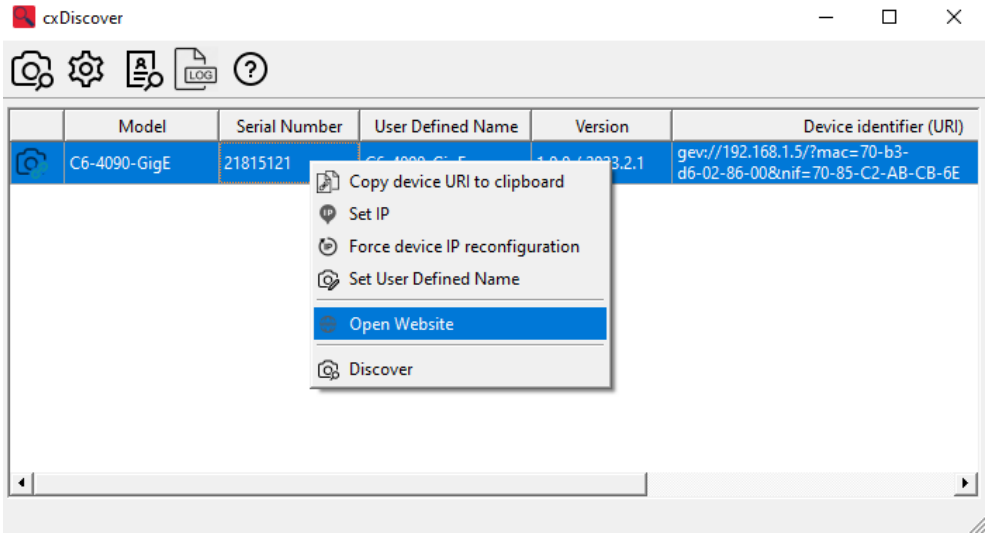
7.4.1. General

All AT 3D devices shipped by Stemmer Imaging are using the latest firmware version available at the time of delivery. In particular cases though, it might make sense to conduct a firmware update for a given camera later on. Reasons can be functionality upgrades, mitigation of erroneous behaviour or streamlining all devices in an engine to the same version.

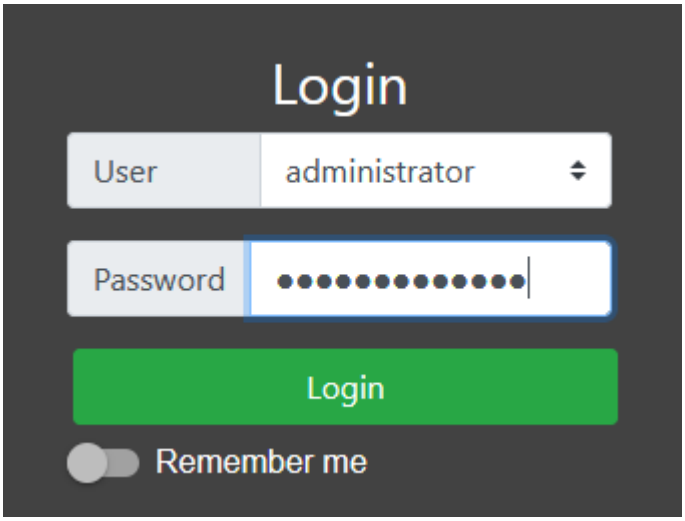
The cameras' firmware are generally field upgradable by a simple process. Stemmer Imaging also offers carrying out firmware updates as a service. If a customer decides to perform an update on his own, Stemmer Imaging can take no liability whatsoever that the device works correctly after the update.

7.4.2. Firmware Update using WEB Access

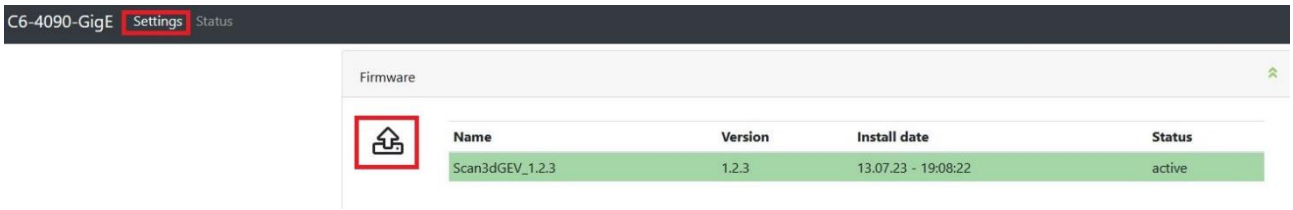
1. Prepare to have the camera connected and accessible and have the firmware file (.tar-files) ready to use
2. Enter the sensors IP-address in a webbrowser and enter the sensor web access or accessing via cxDiscover like bevor, and pressing luch webside button



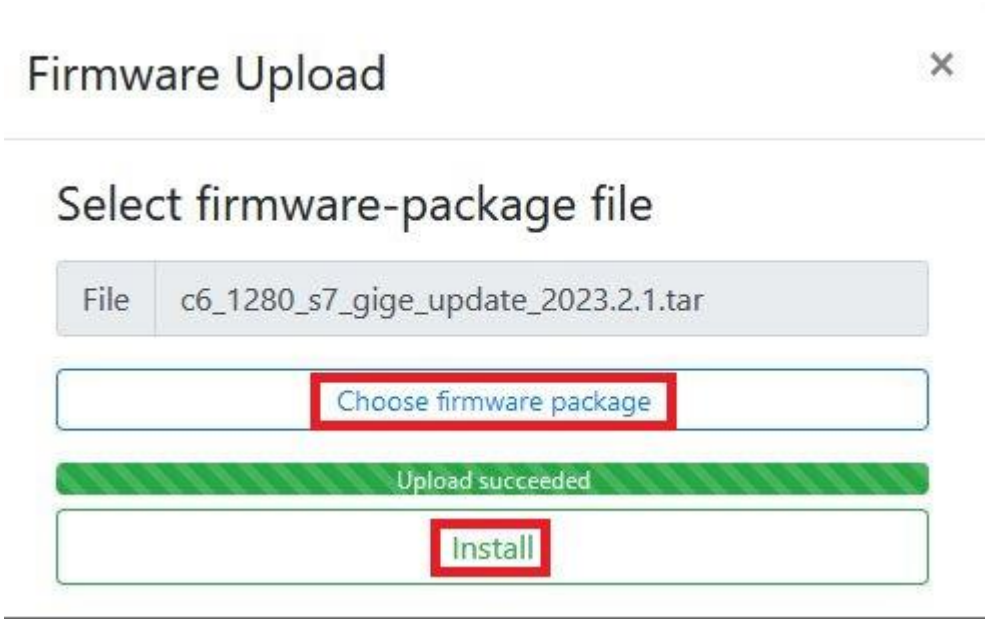
3. Set the user to administrator and enter the password "administrator" to log in.



4. Go to *Settings* and press the *Upload Firmware* button.



5. Choose the desired firmware and press install.



6. Do not disconnect the camera while the firmware update is running.
7. When the update is finished, reboot the camera.

7.5. Why do I lose or acquire too many profiles

Trigger Overrun: When the incoming trigger signals exceed the maximum scan rate of the current setup, the *Event LineMissed* will be triggered. Check if the camera maximum framerate is lower than the required framerate from the travelling speed and resolution.

Trigger Divider: The camera interprets every edge of the RS-422 encoder signal (rising **and** falling edge **and** every channel). Hence, the trigger frequency must be reduced by factor 4 in order to only use each trigger once when having A+,A-,B+,B- encoder signals. This can be done with the parameter *EncoderMode* (Encoder *Control* → *EncoderMode* →*Four Phase*). For further reducing the amount of detected signals use *EncoderDivider*.

Signal quality: Often, signals degrade through ESD noise nearby, defective cables, signal converter, etc. Please measure your trigger signals with an oscilloscope to ensure the I/O device receives clean signals. In general, differential signals are more robust compared to TTL signals. When using long-range cables RS422 signals are the preferred way to trigger profiles.

7.6. How long does it take to transmit a profile to an application?

Processing time between acquisition of a frame and queuing of a profile is < 10 µs. Additionally, a GigE Jumbo Packet takes about 72 µs transmission time from sender to the host. The time for packet re-assembly is depending on the GigEVision implementation and the image data properties, but can be assumed to be below the TX time.

7.7. Image artefacts (horizontal stripes)

Artefacts and horizontal stripes in the acquired images mostly indicate issues in the transmission of the data between camera and PC (network card).

Please note that the network interface card has to be Gigabit Ethernet capable. We discourage using onboard-interfaces and recommend Intel I350 Server Adapter models due to reliability reasons. As for the wiring, please use shielded Ethernet cables (at least CAT5E).

Also note that the maximum cable length depends on the wire quality and cable routing. An error free transmission can be expected for less than 30 meters in the absence of excess electro-magnetic interference (EMI) noise. The nominal length of 100 meters however usually requires also high quality cabling.

Please keep the following general things in mind:

- Firewalls and VPN drivers are also hooked in below the socket layer, thus they can potentially interfere with other filter drivers. Please shut them down for the NIC in question.
- Any other services on the network card take resources. To operate a GigE Vision device, nothing beyond the siFilterDriver and TCP/IP v4 is necessary. If possible, any other services, clients or protocols should be deactivated.

The cxExplorer and CVB offer a user friendly possibility to check for transmission issues coming from the Transport Layer. The following screenshot demonstrates how to check for corrupted frames or lost packages within the cxExplorer. Please read the *Network Configuration* chapter in our GenICam User Guide for more information.

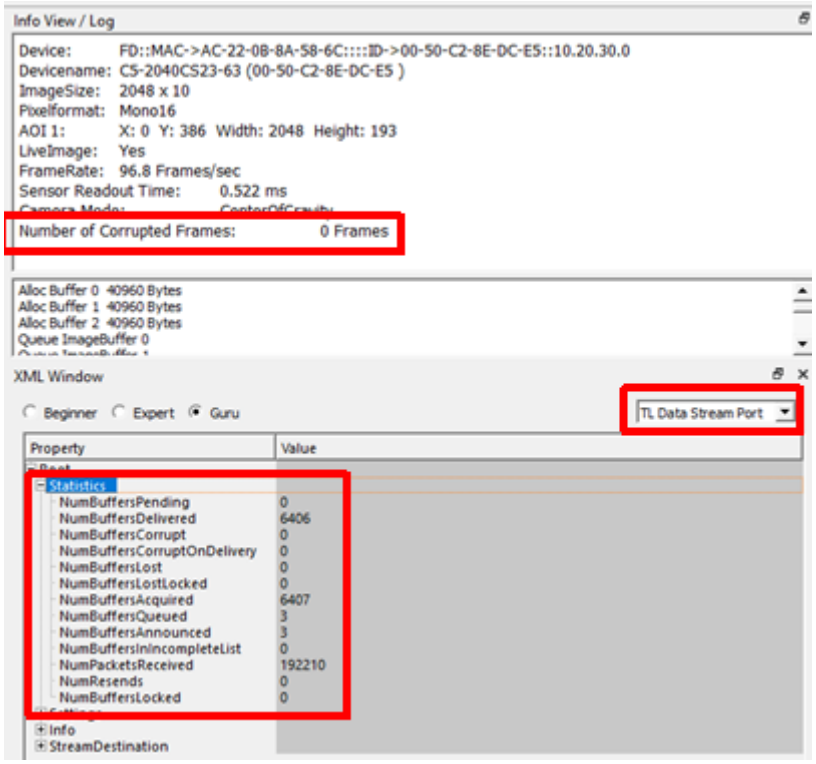


Figure 31: Transport Layer Data Stream Statistics

7.8. Triggering of multiple sensors in parallel

There are cases, in which a single source RS-422 signal has to be propagated to drive more than one camera, e.g. in multi sensor applications where all acquisitions must be synchronized. There are basically two ways to do this:

1. **Master-Slave connection**
   This is the solution that doesn't require additional hardware. One camera will be defined as the master camera and is fed by the encoder signal. It yields an *IntegrationActive* signal on its output and this output is connected to the input of all the slave cameras, using the TTL input as a line trigger. Please take a look into the official sensor manual for a schematic wiring of this principle.

   Be aware that this solution utilizes one of the digital Inputs of each slave camera and one of the digital outputs for the master camera.

2. **RS422 signal splitter**
   The cleanest and reliable solution to distribute RS422 signals to several consumers is the use of RS422 splitter devices, as offered by e.g. http://www.motrona.com.

8. Revision updates

Rev.	Date	By Who	Changes
1.0	30.08.2023	S.Pototzky	Initial Draft