



**the Power of Machine Vision**

## **Solution Guide II-A**

**Image Acquisition**

# 9.0

# Overview

Obviously, the acquisition of images is a task to be solved in all machine vision applications. Unfortunately, this task mainly consists of interacting with special, non-standardized hardware in form of image acquisition devices, i.e., cameras or frame grabber boards. To let you concentrate on the actual machine vision problem, HALCON already provides interfaces performing this interaction for a large number of image acquisition devices (see [section 1](#) on page 5).

Within your HALCON application, the task of image acquisition is thus reduced to a few lines of code, i.e., a few operator calls, as can be seen in [section 2](#) on page 6. What's more, this simplicity is not achieved at the cost of limiting the available functionality: Using HALCON, you can acquire images from various configurations of frame grabbers and cameras (see [section 3](#) on page 8) in different timing modes (see [section 5](#) on page 18).

The example programs that are presented in this Solution Guide can be found in the specified subdirectories of the directory %HALCONROOT%. Note that most programs are preconfigured to work with a certain HALCON acquisition interface; in this case, the name of the program contains the name of the interface. To use the program with another image acquisition device, please adapt the parts which open the connection to the device. More example programs for the different HALCON acquisition interfaces can be found in the subdirectory hdevelop\Image\Acquisition of the directory %HALCONROOT%\examples.

Please refer to the Programmer's Guide, [chapter 7](#) on page 71 and [chapter 18](#) on page 155, for information about how to compile and link the C++ and C example programs; among other things, they describe how to use the example UNIX makefiles which can be found in the subdirectories c and cpp of the directory %HALCONROOT%\examples. Under Windows, you can use Visual Studio workspaces containing the examples, which can be found in the subdirectory win parallel to the source files.

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## The Art of Image Acquisition, Version 9.0.1

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More information about HALCON can be found at: <http://www.halcon.com/>

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# 1 The Philosophy Behind the HALCON Acquisition Interfaces

From the point of view of a user developing software for a machine vision application, the acquisition of images is only a prelude to the actual machine vision task. Of course it is important that images are acquired at the correct moment or rate, and that the camera and the frame grabber are configured suitably, but these tasks seem to be elementary, or at least independent of the used image acquisition device.

The reality, however, looks different. Image acquisition devices differ widely regarding the provided functionality, and even if their functionality is similar, the SDKs (*software development kit*) provided by the manufacturers do not follow any standard so far. Therefore, switching to a different image acquisition device probably requires to rewrite the image acquisition part of the application.

HALCON's answer to this problem are its *image acquisition interfaces* (IAI) which are provided to currently more than 50 frame grabbers and hundreds of industrial cameras (analog, Camera Link, USB 2.0, IEEE 1394, and GigE) in form of *dynamically loadable libraries* (Windows: DLLs; UNIX: shared libraries). HALCON image acquisition interfaces bridge the gap between the individual image acquisition devices and the HALCON library, which is independent of the used image acquisition device, computer platform, and programming language (see figure 1). In other words, they

- provide a standardized interface to the HALCON user in form of 11 HALCON operators, and
- encapsulate details specific to the frame grabber or camera, i.e., the interaction with the SDK provided by the device manufacturer.

Therefore, if you decide to switch to a different image acquisition device, all you need to do is to install the corresponding driver and SDK provided by the manufacturer and to use different parameter values when calling the HALCON operators; the operators themselves stay the same.

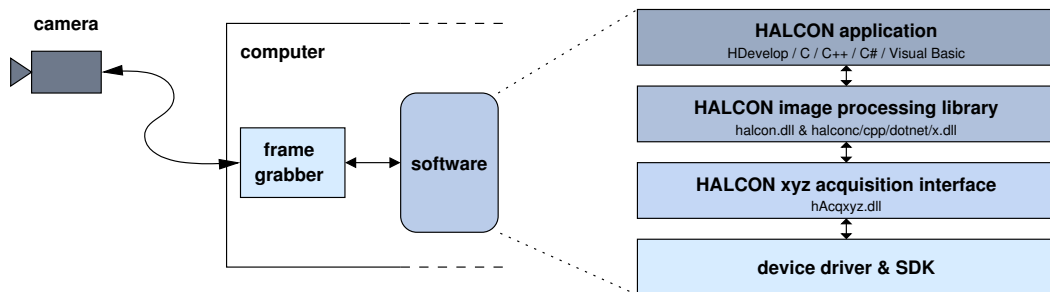


Figure 1: From the camera to a HALCON application.

In fact, the elementary tasks of image acquisition are covered by two HALCON operators:

- `open_framegrabber` connects to the image acquisition device and sets general parameters, e.g., the type of the used camera or the port the camera is connected to, then
- `grab_image` (or `grab_image_async`, see section 5.1 on page 18 for the difference) grabs images.

If an image acquisition device provides additional functionality, e.g., on-board modification of the image signal, special grabbing modes, or digital output lines, it is available via the operator `set_framegrabber_param` (see section 4 on page 14).

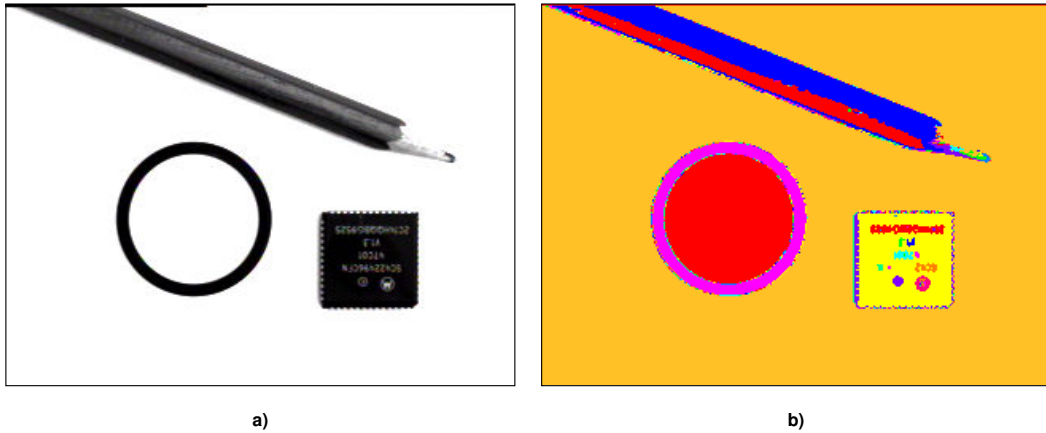


Figure 2: a) Acquired image; b) processed image (automatic segmentation).

Note, that for some image acquisition devices the full functionality is not available within HALCON; please refer to the corresponding online documentation which can be found in the directory `%HALCONROOT%\doc\html\manuals` or via the HALCON folder in the Windows start menu (if you installed the documentation). The latest information can be found under <http://www.halcon.com/image-acquisition>.

If the image acquisition device you want to use is not (yet) supported by HALCON, you can nevertheless use it together with HALCON. Please refer to [section 6.1](#) on page 32 for more details.

Please note that with HALCON 8.0 our terminology has changed: Since digital cameras which are connected by USB 2.0, IEEE 1394 or GigE are not really based on a actual frame grabber board, we no longer use the term HALCON frame grabber interface. Instead, we use the term *HALCON acquisition interface*, and the term *image acquisition device* is used as a substitute for either a frame grabber board or a digital camera. For backwards compatibility reasons, the names of the HALCON operators have been unchanged, thus, the operator names [open\\_framegrabber](#), [info\\_framegrabber](#), and [close\\_framegrabber](#) may sound a little bit old-fashioned.

## 2 A First Example

In this section we start with a simple image acquisition task, which uses the image acquisition device in its default configuration and the standard grabbing mode. The grabbed images are then segmented. To follow the example actively, start the HDevelop program `examples\solution_guide\image_acquisition\first_example_acquisition_falcon.dev`, then press Run once to initialize the application. Note that the program is preconfigured for the HALCON acquisition interface FALCON; to use it with a different acquisition interface, please adapt the parts which open the connection.

### Step 1: Connect to the frame grabber

```
open_framegrabber (AcqName, 1, 1, 0, 0, 0, 0, 'default', -1, 'gray', -1, \
                  'false', 'ntsc', 'default', -1, -1, AcqHandle)
```

When opening the connection to your image acquisition device using the operator `open_framegrabber`, the main parameter is the `Name` of the corresponding HALCON acquisition interface. As a result, you obtain a so-called *handle* (`AcqHandle`), by which you can access the image acquisition device, e.g., in calls to the operator `grab_image`.

In the example, default values are used for most other parameters ('default' or -1); [section 4.1](#) on page 14 takes a closer look at this topic. How to connect to more complex frame grabber and camera configurations is described in [section 3](#).

### Step 2: Grab an image

```
grab_image (Image, AcqHandle)
```

After successfully connecting to your image acquisition device you can grab images by calling the operator `grab_image` with the corresponding handle `AcqHandle`. More advanced modes of grabbing images are described in [section 5](#) on page 18.

### Step 3: Grab and process images in a loop

```
while (Button # 1)
  grab_image (Image, AcqHandle)
  auto_threshold (Image, Regions, 4)
  connection (Regions, ConnectedRegions)
  get_mposition (WindowHandleButton, Row, Column, Button)
endwhile
```

In the example, the grabbed images are then automatically segmented using the operator `auto_threshold` (see [figure 2](#)). This is done in a loop which can be exited by clicking into a window with the left mouse button.

### 3 Connecting to Your Image Acquisition Device

In this section, we show how to connect to different configurations of frame grabber(s) and camera(s), ranging from the simple case of one camera connected to one frame grabber board to more complex ones, e.g., multiple synchronized cameras connected to one or more boards.

#### 3.1 Opening a Connection to a Specified Configuration

With the operator `open_framegrabber` you open a connection to an image acquisition device. This connection is described by four parameters (see figure 3): First, you select an acquisition interface with the parameter `Name`. The parameter `Device` specifies the actual board or camera; depending on the acquisition interface, this parameter can contain a string describing the board or simply a number (in form of a string!).

Often, the camera can be connected to the frame grabber at different ports, whose number can be selected via the parameter `Port` (in rare cases `LineIn`). The parameter `CameraType` describes the connected camera: For analog cameras, this parameter usually specifies the used signal norm, e.g., `'ntsc'`. For digital cameras, this parameter typically specifies the camera model; more complex acquisition interfaces use this parameter to select a camera configuration file.

As a result, `open_framegrabber` returns a *handle* for the opened connection in the parameter `AcqHandle`. Note that if you use HALCON's COM or C++ interface and call the operator via the classes `HFramegrabberX` or `HFramegrabber`, no handle is returned because the instance of the class itself acts as your handle.

With HDevelop's Image Acquisition Assistant you can easily connect to your image acquisition device

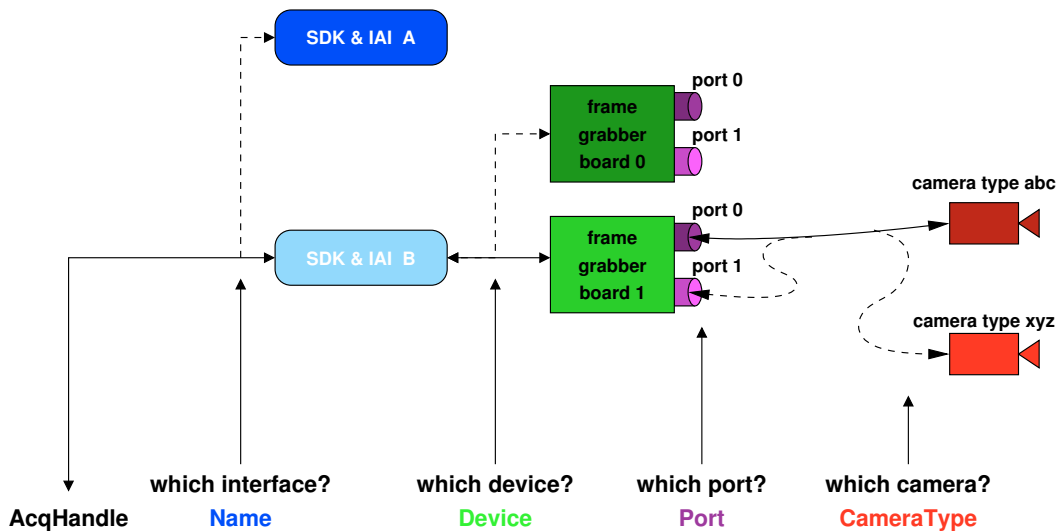


Figure 3: Describing a connection with the parameters of `open_framegrabber` .



and choose suitable parameters (for details see the HDevelop User's Guide, [section 6.1](#) on page 160), which is very useful to setup your vision system (illumination, focus, field of view).

## 3.2 Connecting to Multiple Boards and Cameras

Most HALCON acquisition interfaces allow to use multiple frame grabber boards and cameras. However, there is more than one way to connect cameras and boards and to access these configurations from within HALCON. Below, we describe the different configurations; please check the online documentation of the HALCON interface for your image acquisition device (see %HALCONROOT%\doc\html\manuals, the HALCON folder in the Windows start menu, or <http://www.halcon.com/image-acquisition>) which configurations it supports.

### 3.2.1 Single Camera

[Figure 4a](#) shows the simplest configuration: a single camera connected to a single board, accessible via a single handle. Some frame grabbers, especially digital ones, only support this configuration; as described in the following section, you can nevertheless use multiple cameras with such frame grabbers by connecting each one to an individual board. Note that this configuration is the typical one in case of digital cameras connected by USB 2.0, IEEE 1394, or GigE.

### 3.2.2 Multiple Boards

[Figure 4b](#) shows a configuration with multiple cameras, each connected to a separate board. In this case you call the operator `open_framegrabber` once for each connection as in the HDevelop example program `examples\solution_guide\image_acquisition\multiple_boards_px.dev`. Note that the program is preconfigured for the HALCON PX interface; to use it with a different frame grabber, please adapt the parts which open the connection.

```
open_framegrabber (AcqName, 1, 1, 0, 0, 0, 0, 'default', -1, 'default', -1, \
                  'default', 'default', Board0, -1, -1, AcqHandle0)
open_framegrabber (AcqName, 1, 1, 0, 0, 0, 0, 'default', -1, 'default', -1, \
                  'default', 'default', Board1, -1, -1, AcqHandle1)
```

In this example, the two calls differ only in the value for the parameter `Device` ('0' and '1'); of course, you can use different values for other parameters as well, and even connect to different image acquisition interfaces.

To grab images from the two cameras, you simply call the operator `grab_image` once with the two handles returned by the two calls to `open_framegrabber`:

```
grab_image (Image0, AcqHandle0)
grab_image (Image1, AcqHandle1)
```

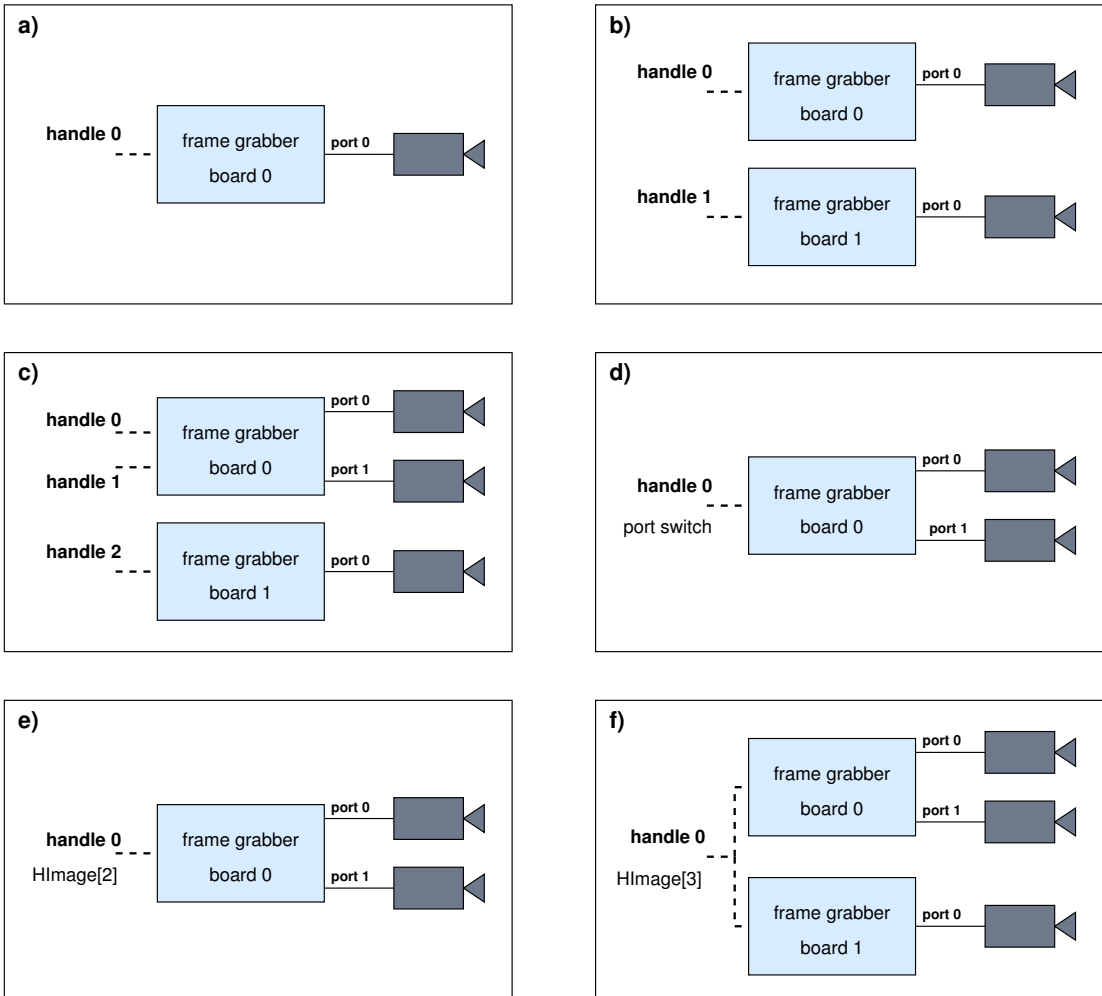


Figure 4: a) single board with single camera; b) multiple boards with one camera each; c) multiple boards with one or more cameras; d) single board with multiple cameras and port switching; e) single board with multiple cameras and simultaneous grabbing; f) simultaneous grabbing with multiple boards and cameras.

### 3.2.3 Multiple Handles Per Board

Many frame grabbers provide multiple input ports and thus allow to connect more than one camera to the board. Depending on the HALCON acquisition interface, this configuration is accessed in different ways which are described in this and the following sections.

The standard HALCON method to connect to the cameras is depicted in [figure 4c](#): Each connection gets its own handle, i.e., `open_framegrabber` is called once for each camera with different values for the parameter `Port`, like in the HDevelop example program `examples\solution_guide\image_acquisition\multiple_ports_px.dev` (preconfigured for the HALCON PX interface, please

adapt the parts which open the connection for your own frame grabber):

```
open_framegrabber (AcqName, 1, 1, 0, 0, 0, 0, 'default', -1, 'default', -1, \
                  'default', 'default', 'default', Port0, -1, AcqHandle0)
open_framegrabber (AcqName, 1, 1, 0, 0, 0, 0, 'default', -1, 'default', -1, \
                  'default', 'default', 'default', Port1, -1, AcqHandle1)
grab_image (Image0, AcqHandle0)
grab_image (Image1, AcqHandle1)
```

As [figure 4c](#) shows, you can also use multiple boards with multiple connected cameras.

### 3.2.4 Port Switching

Some image acquisition interfaces do not access the cameras via multiple handles, but by switching the input port dynamically (see [figure 4d](#)). Therefore, `open_framegrabber` is called only once, like in the HDevelop example program `examples\solution_guide\image_acquisition\port_switching_inspecta.dev` (preconfigured for the HALCON INSPECTA interface, please adapt the parts which open the connection for your own frame grabber):

```
open_framegrabber (AcqName, 1, 1, 0, 0, 0, 0, 'default', -1, 'default', -1, \
                  'default', MyCamType, 'default', 0, -1, AcqHandle)
```

Between grabbing images you switch ports using the operator `set_framegrabber_param` (see [section 4.2](#) on page 15 for more information about this operator):

```
set_framegrabber_param (AcqHandle, 'port', Port0)
grab_image (Image0, AcqHandle)
set_framegrabber_param (AcqHandle, 'port', Port1)
grab_image (Image1, AcqHandle)
```

Note that port switching only works for compatible (similar) cameras because `open_framegrabber` is only called once, i.e., the same set of parameters values is used for all cameras. In contrast, when using multiple handles as described above, you can specify different parameter values for the individual cameras (with some board-specific limitations).

### 3.2.5 Simultaneous Grabbing

In the configurations described above, images were grabbed from the individual cameras by multiple calls to the operator `grab_image`. In contrast, some acquisition interfaces allow to grab images from multiple cameras with a single call to `grab_image`, which then returns a multi-channel image (see [figure 4e](#); [appendix A.1](#) on page 41 contains more information about multi-channel images). This mode is called *simultaneous grabbing* (or *parallel grabbing*); like port switching, it only works for compatible (similar) cameras. For example, you can use this mode to grab synchronized images from a stereo camera system.

In this mode, `open_framegrabber` is called only once, as can be seen in the HDevelop example program `examples\solution_guide\image_acquisition\simultaneous_grabbing_inspecta.dev`

(preconfigured for the HALCON INSPECTA interface, please adapt the parts which open the connection for your own frame grabber):

```
open_framegrabber (AcqName, 1, 1, 0, 0, 0, 0, 'default', -1, 'default', -1, \
                  'default', MyCamType, 'default', 0, -1, AcqHandle)
```

You can check the number of returned images (channels) using the operator `count_channels`

```
grab_image (SimulImages, AcqHandle)
count_channels (SimulImages, num_channels)
```

and extract the individual images, e.g., using `decompose2`, `decompose3` etc., depending on the number of images:

```
if (num_channels = 2)
    decompose2 (SimulImages, Image0, Image1)
```

Alternatively, you can convert the multi-channel image into an image array using `image_to_channels` and then select the individual images via `select_obj`.

Note that some acquisition interfaces allow simultaneous grabbing also for multiple boards (see [figure 4f](#)). Please refer to [section 5.3.2](#) on page 31 for additional information.

### 3.3 Requesting Information About the Image Acquisition Interface

As mentioned already, the individual HALCON acquisition interfaces are described in detail on HTML pages which can be found in the directory `%HALCONROOT%\doc\html\manuals` or in the HALCON folder in the Windows start menu (if you installed the documentation). Another way to access information about an image acquisition interface is to use the operator `info_framegrabber`.

In the HDevelop example program `examples\solution_guide\image_acquisition\info_framegrabber_falcon.dev` (preconfigured for the HALCON FALCON interface, please adapt the interface name for your own image acquisition device) this operator is called multiple times to query the version number of the interface, the available devices, port numbers, camera types, and the default values for all parameters of `open_framegrabber`; the result, i.e., the values displayed in the HDevelop Variable Windows, is depicted in [figure 5](#).

```
info_framegrabber (AcqName, 'general', GeneralInfo, GeneralValue)
info_framegrabber (AcqName, 'revision', RevisionInfo, RevisionValue)
info_framegrabber (AcqName, 'info_boards', BoardsInfo, BoardsValue)
info_framegrabber (AcqName, 'port', PortsInfo, PortsValue)
info_framegrabber (AcqName, 'camera_type', CamTypeInfo, CamTypeValue)
info_framegrabber (AcqName, 'defaults', DefaultsInfo, DefaultsValue)
```

The operator `info_framegrabber` can be called before actually connecting to a image acquisition device with `open_framegrabber`. The only condition is that the HALCON acquisition interface and the device driver and SDK have been installed.

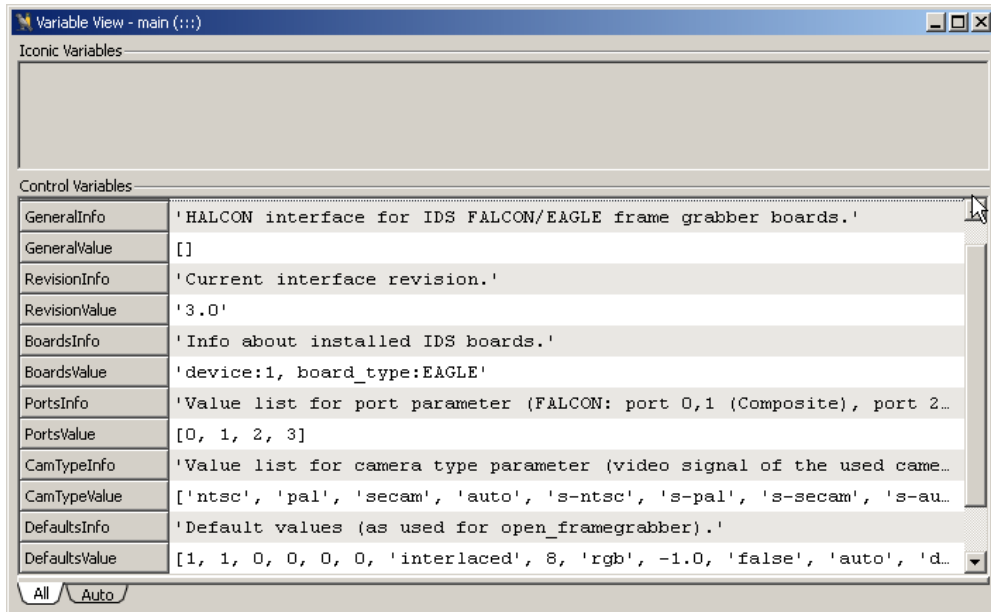


Figure 5: An example result of the operator `info_framegrabber`.

## 4 Configuring the Acquisition

As explained in [section 1](#) on page 5, the intention of HALCON's acquisition interfaces is to provide the user with a common interface for many different image acquisition devices. This interface is kept as simple as possible; as shown, you can connect to your frame grabber or camera and grab a first image using only two operators.

However, HALCON's second goal is to make the full functionality of an image acquisition device available to the user. As image acquisition devices differ widely regarding the provided functionality, this is a difficult task to realize within a simple, common interface. HALCON solves this problem by dividing the task of configuring an image acquisition device connection into two parts: Those parameters which are common to most acquisition interfaces (therefore called *general parameters*) are set when calling the operator `open_framegrabber`. In contrast, the functionality which is not generally available can be configured by setting so-called *special parameters* using the operator `set_framegrabber_param`.

### 4.1 General Parameters

When opening a connection via `open_framegrabber`, you can specify the following general parameters:

<code>HorizontalResolution,</code> <code>VerticalResolution</code>	spatial resolution of the transferred image in relation to the original size (see <a href="#">appendix B.1</a> on page 44)
<code>ImageWidth, ImageHeight,</code> <code>StartRow, StartColumn</code>	size and upper left corner of the transferred image in relation to the original size (see <a href="#">appendix B.1</a> on page 44)
<code>Field</code>	grabbing mode for analog cameras, e.g., interlaced-scan, progressive-scan, field grabbing (see <a href="#">appendix B.2</a> on page 45)
<code>BitsPerChannel, ColorSpace</code>	data contained in a pixel (number of bits, number of channels, color encoding, see <a href="#">appendix B.3</a> on page 48)
<code>Generic</code>	generic parameter with device-specific meaning
<code>ExternalTrigger</code>	hooking the acquisition of images to an external trigger signal (see also <a href="#">section 5.2</a> on page 28)
<code>CameraType, Device, Port,</code> <code>LineIn</code>	configuration of frame grabber(s) and camera(s) from which images are to be acquired (see <a href="#">section 3.1</a> on page 8)

In [section 3.1](#) on page 8, we already encountered the parameters describing the frame grabber / camera configuration. Most of the other parameters of `open_framegrabber` specify the image format; they are described in more detail in [appendix B](#) on page 44. The parameter `ExternalTrigger` activates a special grabbing mode which is described in detail in [section 5.2](#) on page 28.

Note that when calling `open_framegrabber` you must specify values for all parameters, even if your acquisition interface does not support some of them or uses values specified in a camera configuration file instead. To alleviate this task, the HALCON acquisition interfaces provide suitable default values which are used if you specify 'default' or -1 for string or numeric parameters, respectively. The actually used default values can be queried using the operator `info_framegrabber` as shown in [section 3.3](#) on page 12.

After connecting to a frame grabber or camera, you can query the current value of general parameters using the operator `get_framegrabber_param`; some interfaces even allow to modify general parameters dynamically. Please refer to [section 4.3](#) on page 17 for more information about these topics.

## 4.2 Special Parameters

Even the functionality that is not generally available for all image acquisition devices can be accessed and configured with a general mechanism: by setting corresponding special parameters via the operator `set_framegrabber_param`. Typical parameters are, for example:

<code>'grab_timeout'</code>	timeout after which the operators <code>grab_image</code> and <code>grab_image_async</code> stop waiting for an image and return an error (see also <a href="#">section 5.2.1</a> on page 30 and <a href="#">section 6.2</a> on page 33)
<code>'volatile'</code>	enable volatile grabbing (see also <a href="#">section 5.1.3</a> on page 20)
<code>'continuous_grabbing'</code>	switch on a special acquisition mode which is necessary for some image acquisition devices to achieve real-time performance (see also <a href="#">section 5.1.5</a> on page 24)
<code>'trigger_signal'</code>	signal type used for external triggering, e.g., rising or falling edge
<code>'image_width', 'image_height', 'start_row', 'start_column', 'generic', 'external_trigger', 'port'</code>	“duplicates” of some of the general parameters described in <a href="#">section 4.1</a> on page 14, allowing to modify them dynamically, i.e., after opening the connection (see also <a href="#">section 4.3</a> on page 17)

Depending on the acquisition interface, various other parameters may be available, which allow, e.g., to add an offset to the digitized video signal or modify the brightness or contrast, to specify the exposure time or to trigger a flash. Some acquisition interfaces offer special parameters for the use of line scan cameras (see also [section 6.3](#) on page 38), or parameters controlling digital output and input lines.

Which special parameters are provided by an acquisition interface is described in the already mentioned online documentation. You can also query this information by calling the operator `info_framegrabber` as shown below; [figure 6](#) depicts the result of double-clicking `ParametersValue` in the Variable Window after executing the line:

```
info_framegrabber (AcqName, 'parameters', ParametersInfo, ParametersValue)
```

To set a parameter, you call the operator `set_framegrabber_param`, specifying the name of the parameter to set in the parameter `Param` and the desired value in the parameter `Value`. For example, in [section 3.2.4](#) on page 11 the following line was used to switch to port 0:

```
set_framegrabber_param (AcqHandle, 'port', Port0)
```

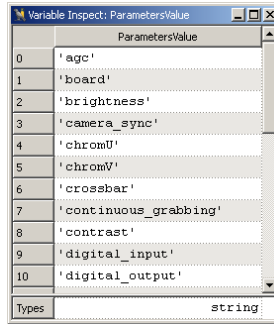


Figure 6: Querying available special parameters via `info_framegrabber`.

You can also set multiple parameters at once by specifying tuples for `Param` and `Value` as in the following line:

```
set_framegrabber_param (AcqHandle, ['image_width','image_height'], [256, \
                               256])
```

For all parameters which can be set with `set_framegrabber_param`, you can query the current value using the operator `get_framegrabber_param`. Some interfaces also allow to query additional information like minimum and maximum values for the parameters. For example, the HALCON 1394I IDC 1394 interface allows to query the minimum and maximum values for the brightness:

```
get_framegrabber_param (AcqHandle, 'brightness_range', BrightnessRange)
MinBrightness := BrightnessRange[0]
MaxBrightness := BrightnessRange[1]
```

Thus, you can check a new brightness value against those boundaries before setting it:

```
get_framegrabber_param (AcqHandle, 'brightness', CurrentBrightness)
NewBrightness := CurrentBrightness + 10
if (NewBrightness > MaxBrightness)
    NewBrightness := MaxBrightness
endif
set_framegrabber_param (AcqHandle, 'brightness', NewBrightness)
```



## 4.3 Fixed vs. Dynamic Parameters

The distinction between fixed and dynamic parameters is made relating to the lifetime of a connection to an image acquisition device. *Fixed parameters*, e.g., the `CameraType`, are set once when opening the connection with `open_framegrabber`. In contrast, those parameters which can be modified via `set_framegrabber_param` during the use of the connection are called *dynamic parameters*.

As already noted in [section 4.2](#) on page 15, some image acquisition interfaces allow to modify general parameters like `ImageWidth` or `ExternalTrigger` dynamically via `set_framegrabber_param`, by providing a corresponding special parameter with the same name but written with small letters and underscores, e.g., `'image_width'` or `'external_trigger'`.

Independent of whether a general parameter can be modified dynamically, you can query its current value by calling the operator `get_framegrabber_param` with its “translated” name, i.e., capitals replaced by small letters and underscores as described above.

## 5 The Various Modes of Grabbing Images

Section 2 on page 6 showed that grabbing images is very easy in HALCON – you just call `grab_image`! But of course there's more to image grabbing than just to get an image, e.g., how to assure an exact timing. This section therefore describes more complex grabbing modes.

### 5.1 Real-Time Image Acquisition



As a technical term, the attribute *real-time* means that a process guarantees that it meets given deadlines. Please keep in mind that **none of the standard operating systems, i.e., neither Windows nor Linux, are real-time operating systems**. This means that the operating system itself does not guarantee that your application will get the necessary processing time before its deadline expires. From the point of view of a machine vision application running under a non-real-time operating system, the most you can do is assure that real-time behavior is not already prevented by the application itself.

In a machine vision application, real-time behavior may be required at multiple points:

**Image delay:** The camera must “grab” the image, i.e., expose the chip, at the correct moment, i.e., while the part to be inspected is completely visible.

**Frame rate:** The most common real-time requirement for a machine vision application is to “reach frame rate”, i.e., acquire and process all images the camera produces.

**Processing delay:** The image processing itself must complete in time to allow a reaction to its results, e.g., to remove a faulty part from the conveyor belt. As this point relates only indirectly to the image acquisition it is ignored in the following.

#### 5.1.1 Non-Real-Time Grabbing Using `grab_image`

Figure 7 shows the timing diagram for the standard grabbing mode, i.e., if you use the operator `grab_image` from within your application. This operator call is “translated” by the HALCON acquisition interface and the SDK into the corresponding signal to the frame grabber board (marked with ‘Grab’). Obviously, in case of digital cameras connected by USB 2.0, IEEE 1394 or GigE there is no actual frame grabber board; nevertheless, the principles of the various grabbing modes remain the same.

The frame grabber now waits for the next image. In the example, a free-running analog progressive-scan camera is used, which produces images continuously at a fixed frame rate; the start of a new image is indicated by a so-called *vertical sync signal*. The frame grabber then digitizes the incoming analog image signal and transforms it into an image matrix. If a digital camera is used, the camera itself performs the digitizing and transfers a digital signal which is then transformed into an image matrix by the frame grabber. Please refer to [appendix B.2](#) on page 45 for more information about interlaced grabbing.

The image is then transferred from the frame grabber into computer memory via the PCI bus using *DMA* (direct memory access). This transfer can either be *incremental* as depicted in [figure 7](#), if the frame grabber has only a FIFO buffer, or in a single burst as depicted in [figure 8](#) on page 21, if the frame grabber has a frame buffer on board. The advantage of the incremental transfer is that the transfer is concluded earlier. In contrast, the burst mode is more efficient; furthermore, if the incremental transfer via the PCI bus cannot proceed for some reason, a FIFO overflow results, i.e., image data is lost. Note

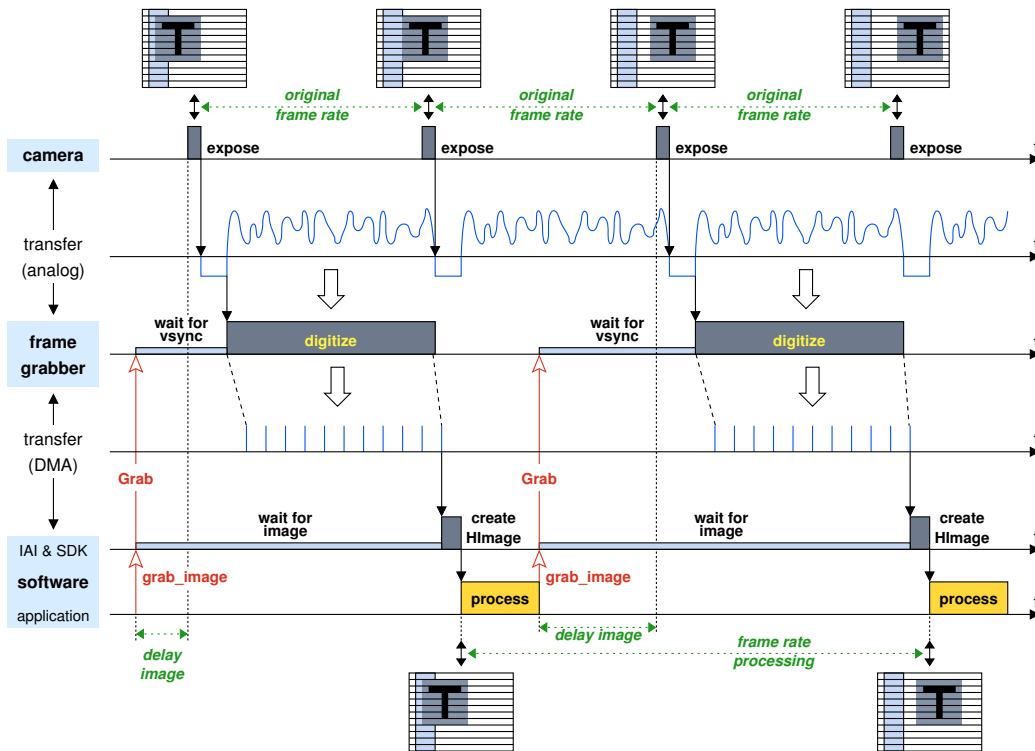


Figure 7: Standard timing using `grab_image` (configuration: free-running progressive-scan camera, frame grabber with incremental image transfer).

that in both modes the transfer performance depends on whether the PCI bus is used by other devices as well!

When the image is completely stored in the computer memory, the HALCON acquisition interface transforms it into a HALCON image and returns the control to the application which processes the image and then calls `grab_image` again. However, even if the processing time is short in relation to the frame rate, the camera has already begun to transfer the next image which is therefore “lost”; the application can therefore only process every second image.

You can check this behavior using the HDevelop example program `examples\solution_guide\image_acquisition\real_time_grabbing_falcon.dev` (preconfigured for the HALCON FALCON interface, please adapt the parts which open the connection for your own image acquisition device grabber), which determines achievable frame rates for grabbing and processing (here: calculating a difference image) first separately and then together as follows:

```
grab_image (BackgroundImage, AcqHandle)
count_seconds (Seconds1)
for i := 1 to 20 by 1
    grab_image (Image, AcqHandle)
    sub_image (BackgroundImage, Image, DifferenceImage, 1, 128)
endfor
count_seconds (Seconds2)
TimeGrabImage := (Seconds2-Seconds1)/20
FrameRateGrabImage := 1 / TimeGrabImage
```

To see the non-deterministic image delay, execute the operator `grab_image` in the step mode by pressing Step; the execution time displayed in HDevelop's status bar will range between once and twice the original frame period. Please note that on Linux systems, the time measurements are performed with a lower resolution than on Windows systems.

### 5.1.2 Grabbing Without Delay Using Asynchronously Resettable Cameras

If you use a free-running camera, the camera itself determines the exact moment an image is acquired (exposed). This leads to a delay between the moment you call `grab_image` and the actual image acquisition (see [figure 7](#) on page 19). The delay is not deterministic, but at least it is limited by the frame rate; for example, if you use an NTSC camera with a frame rate of 30 Hz, the maximum delay can be 33 milliseconds.

Of course, such a delay is not acceptable in an application that is to inspect parts at a high rate. The solution is to use cameras that allow a so-called *asynchronous reset*. This means that upon a signal from the frame grabber, the camera resets the image chip and (almost) immediately starts to expose it. Typically, such a camera does not grab images continuously but only on demand.

An example timing diagram is shown in [figure 8](#). In contrast to [figure 7](#), the image delay is (almost) zero. Furthermore, because the application now specifies when images are to be grabbed, all images can be processed successfully; however, the achieved frame rate still includes the processing time and therefore may be too low for some machine vision applications.

### 5.1.3 Volatile Grabbing

As shown in [figure 7](#) on page 19, after the image has been transferred into the computer memory, the HALCON acquisition interface needs some time to create a corresponding HALCON image which is then returned in the output parameter `Image` of `grab_image`. Most of this time (about 3 milliseconds on a 500 MHz Athlon K6 processor for a gray value NTSC image) is needed to copy the image data from the buffer which is the destination of the DMA into a newly allocated area.

You can switch off the copying by using the so-called *volatile grabbing*, which can be enabled via the operator `set_framegrabber_param` (parameter 'volatile'):

```
set_framegrabber_param (AcqHandle, 'volatile', 'enable')
```

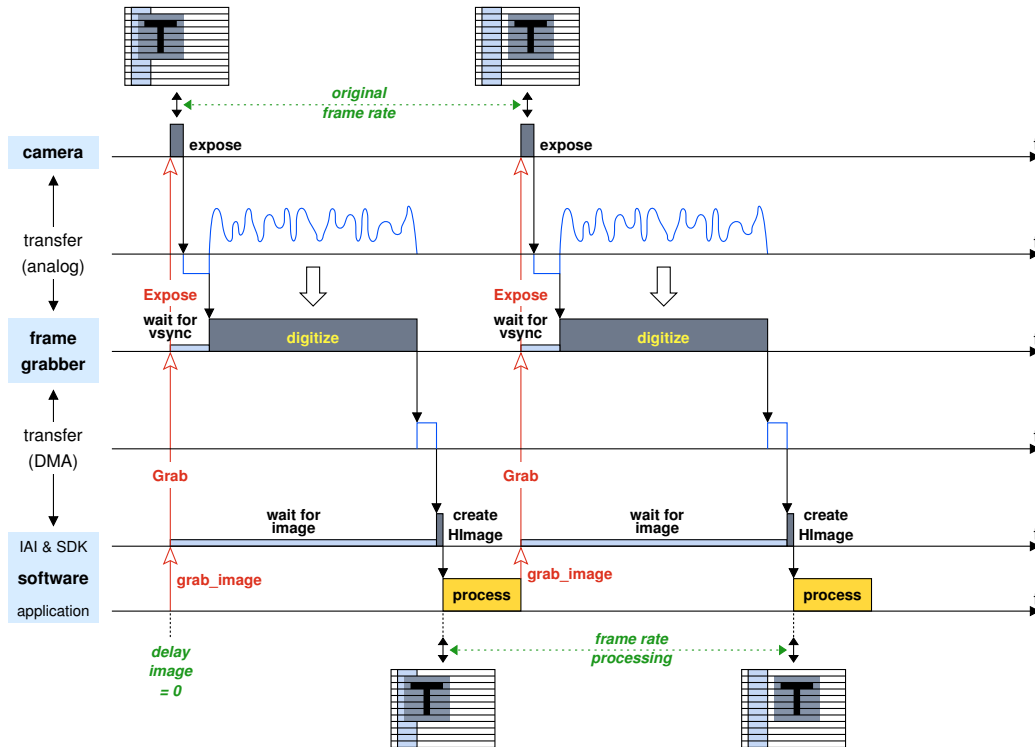



Figure 8: Using an asynchronously resettable camera together with `grab_image` (configuration: progressive-scan camera, frame grabber with burst transfer, volatile grabbing).

Then, the time needed by the image acquisition interface to create the HALCON image is significantly reduced as visualized in figure 8. Note that usually volatile grabbing is only supported for gray value images!

The drawback of volatile grabbing is that grabbed images are overwritten by subsequent grabs. To be more exact, the overwriting depends on the number of image buffers allocated by the acquisition interface or SDK. Typically, at least two buffers exist; therefore, you can safely process an image even if the next image is already being grabbed as in figure 10 on page 25. Some acquisition interfaces allow to use more than two buffers, and even to select their number dynamically via `set_framegrabber_param` (parameter 'num\_buffers').

Please note that **volatile grabbing is not really volatile within HDevelop**, i.e., images are copied nevertheless, otherwise there would be scenarios when HDevelop would crash. 

Thus, to experiment with volatile grabbing using the HDevelop example program `examples\solution_guide\image_acquisition\volatile_grabbing_falcon.dev` (preconfigured for the HALCON FALCON interface, please adapt the parts which open the connection for your own frame grabber), you must export it to a programming language or use HDevEngine.

After grabbing a first image and displaying it via

```
grab_image (FirstImage, AcqHandle)
dev_open_window (0, 0, Width/2, Height/2, 'black', FirstWindow)
dev_display (FirstImage)
```

change the scene and grab a second image which is displayed in an individual window:

```
grab_image (SecondImage, AcqHandle)
dev_open_window (0, Width/2 + 8, Width/2, Height/2, 'black', SecondWindow)
dev_display (SecondImage)
```

Now, images are grabbed in a loop and displayed in a third window. The two other images are also displayed each time. If you change the scene before each grab you can see how the first two images are overwritten in turn, depending on the number of buffers.

```
dev_open_window (Height/2 + 66, Width/4 + 4, Width/2, Height/2, 'black', \
                ThirdWindow)
for i := 1 to 10 by 1
    grab_image (CurrentImage, AcqHandle)
    dev_set_window (ThirdWindow)
    dev_display (CurrentImage)
    dev_set_window (FirstWindow)
    dev_display (FirstImage)
    dev_set_window (SecondWindow)
    dev_display (SecondImage)
endfor
```

#### 5.1.4 Real-Time Grabbing Using *grab\_image\_async*

The main problem with the timing using *grab\_image* is that the two processes of image grabbing and image processing run sequentially, i.e., one after the other. This means that the time needed for processing the image is included in the resulting frame rate, with the effect that the frame rate provided by the camera cannot be reached by definition.



This problem can be solved by using the operator *grab\_image\_async*. Here, the two processes are decoupled and can run asynchronously, i.e., **an image can be processed while the next image is already being grabbed**. Figure 9 shows a corresponding timing diagram: The first call to *grab\_image\_async* is processed similar to *grab\_image* (compare figure 7 on page 19). The difference becomes apparent after the transfer of the image into computer memory: Almost immediately after receiving the image, the acquisition interface automatically commands the frame grabber to acquire a new image. Thus, the next image is grabbed while the application processes the previous image. After the processing, the application calls *grab\_image\_async* again, which waits until the already running image acquisition is finished. Thus, the full frame rate is now reached. Note that some frame grabbers fail to reach the full frame rate even with *grab\_image\_async*; section 5.1.5 on page 24 shows how to solve this problem.

In the HDevelop example program `examples\solution_guide\image_acquisition\real_time_grabbing_falcon.dev`, which was already described in section 5.1.1 on page 18, the reached frame rate for asynchronous processing is determined as follows:

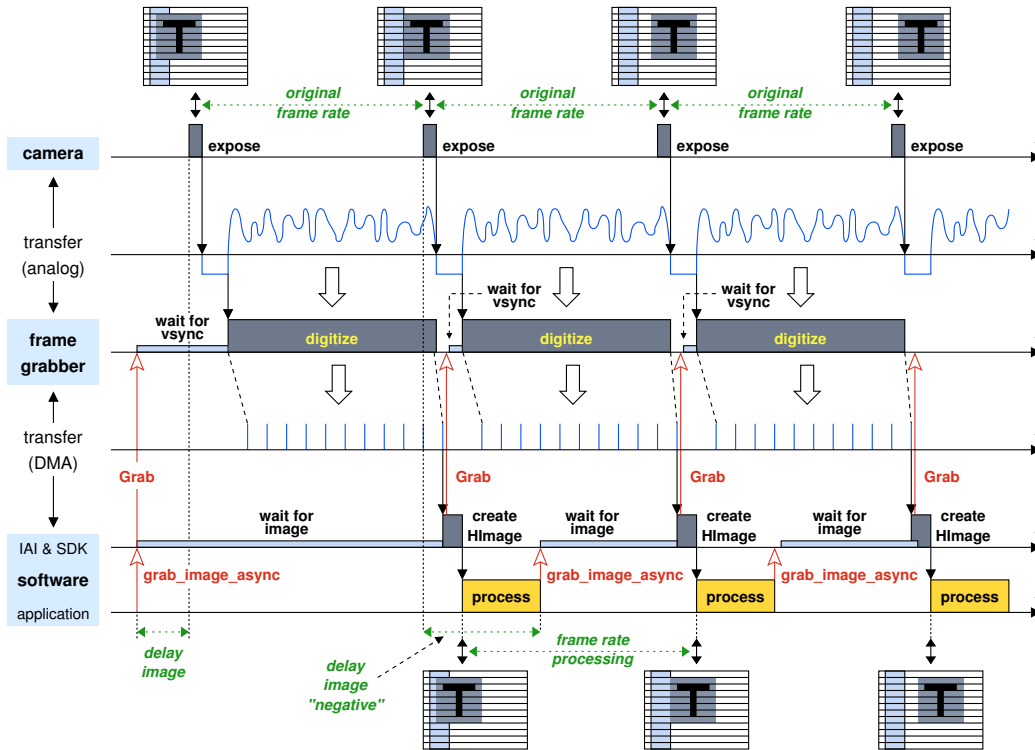


Figure 9: Grabbing and processing in parallel using `grab_image_async`.

```

grab_image (BackgroundImage, AcqHandle)
count_seconds (Seconds1)
for i := 1 to 20 by 1
    grab_image_async (Image, AcqHandle, -1)
    sub_image (BackgroundImage, Image, DifferenceImage, 1, 128)
endfor
count_seconds (Seconds2)
TimeGrabImageAsync := (Seconds2-Seconds1)/20
FrameRateGrabImageAsync := 1 / TimeGrabImageAsync

```

As can be seen in [figure 9](#), the first call to `grab_image_async` has a slightly different effect than the following ones, as it also triggers the first grab command to the frame grabber. As an alternative, you can use the operator `grab_image_start` which just triggers the grab command; then, the first call to `grab_image_async` behaves as the other ones. This is visualized, e.g., in [figure 10](#); as you can see, the advantage of this method is that the application can perform some processing before calling `grab_image_async`.

Note that you can use `grab_image_start` in combination with the special parameter 'start\_async\_after\_grab\_async' to specify exactly when a grab command is triggered during asynchronous grabbing. In [section 5.3.1](#) on page 30, this is used for asynchronous grabbing with

multiple cameras.

In the example, the processing was assumed to be faster than the acquisition. If this is not the case, the image will already be ready when the next call to `grab_image_async` arrives. In this case, you can specify how “old” the image is allowed to be using the parameter `MaxDelay`. Please refer to [section 5.1.7](#) on page 26 for details.

Please note that when using `grab_image_async` it is not obvious anymore which image is returned by the operator call, because the call is decoupled from the command to the frame grabber! In contrast to `grab_image`, which always triggers the acquisition of a new image, `grab_image_async` typically returns an image which has been exposed before the operator was called, i.e., the image delay is negative (see [figure 9](#))! Keep this effect in mind when changing parameters dynamically; contrary to intuition, the change will not affect the image returned by the next call of `grab_image_async` but by the following ones! Another problem appears when switching dynamically between cameras (see [section 5.3.1](#) on page 30).

### 5.1.5 Continuous Grabbing

For some frame grabbers, `grab_image_async` fails to reach the frame rate because the grab command to the frame grabber comes too late, i.e., after the camera has already started to transfer the next image (see [figure 10a](#)).

As a solution to this problem, some acquisition interfaces provide the so-called *continuous grabbing mode*, which can be enabled only via the operator `set_framegrabber_param` (parameter ‘continuous\_grabbing’):

```
set_framegrabber_param (AcqHandle, 'continuous_grabbing', 'enable')
```

In this mode, the frame grabber reads images from a free-running camera continuously and transfers them into computer memory as depicted in [figure 10b](#). Thus, the frame rate is reached. If your frame grabber supports continuous grabbing, you can test this effect in the example program `examples\solution_guide\image_acquisition\real_time_grabbing_falcon.dev`, which was already described in the previous sections; the program measures the achievable frame rate for `grab_image_async` without and with continuous grabbing.

We recommend to use continuous grabbing only if you want to process every image; otherwise, images are transmitted over the PCI bus unnecessarily, thereby perhaps blocking other PCI transfers.

Note that some acquisition interfaces provide additional functionality in the continuous grabbing mode, e.g., the HALCON BitFlow interface. Please refer to the corresponding documentation for more information.



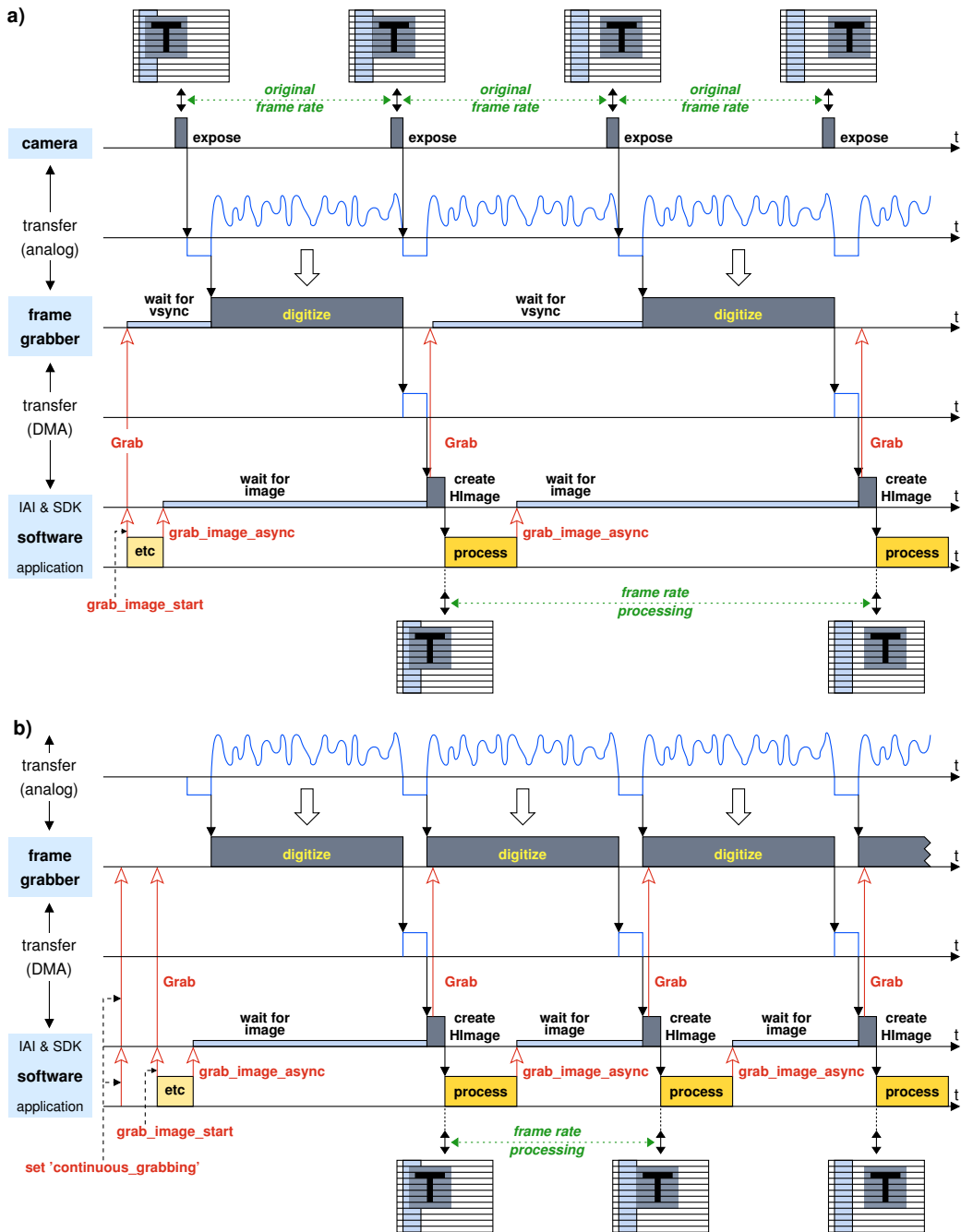


Figure 10: a) `grab_image_async` fails to reach frame rate; b) problem solved using continuous grabbing.

### 5.1.6 Using `grab_image_async` Together With Asynchronously Resettable Cameras

As described in [section 5.1.2](#) on page 20, you can acquire images without delay by using an asynchronously resettable camera. [Figure 11](#) shows the resulting timing when using such a camera together with `grab_image_async`. When comparing the diagram to the one in [figure 8](#) on page 21, you can see that a higher frame rate can now be reached, because the processing time is not included anymore.

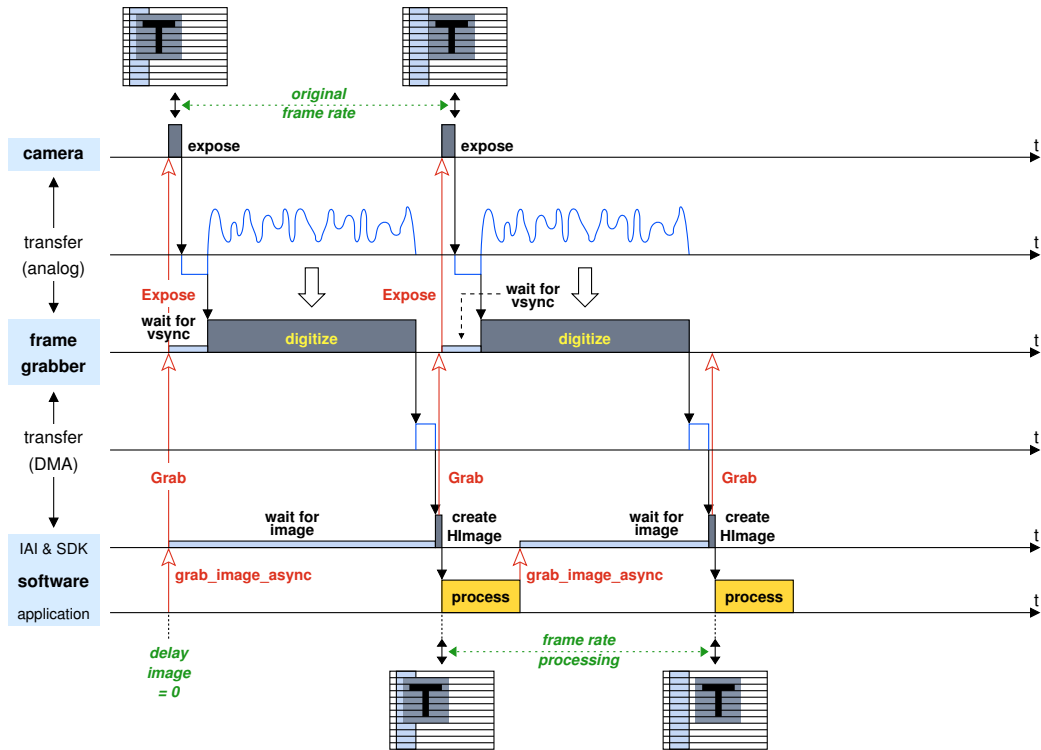


Figure 11: Using an asynchronously resettable camera together with `grab_image_async` (configuration as in [figure 8](#) on page 21).

### 5.1.7 Specifying a Maximum Delay

In contrast to `grab_image`, the operator `grab_image_async` has an additional parameter `MaxDelay`, which lets you specify how “old” an already grabbed image may be in order to be accepted. [Figure 12](#) visualizes the effect of this parameter. There are two cases to distinguish: If the call to `grab_image_async` arrives before the next image has been grabbed (first call in the example), the parameter has no effect. However, if an image has been grabbed already (second and third call in the example), the elapsed time since the last grab command to the frame grabber is compared to `MaxDelay`. If it is smaller (second call in the example), the image is accepted; otherwise (third call), a new image is grabbed.

Please note that the delay is not measured starting from the moment the image is exposed, as you might perhaps expect! Currently, only a few device SDKs provide this information; therefore, the last grab

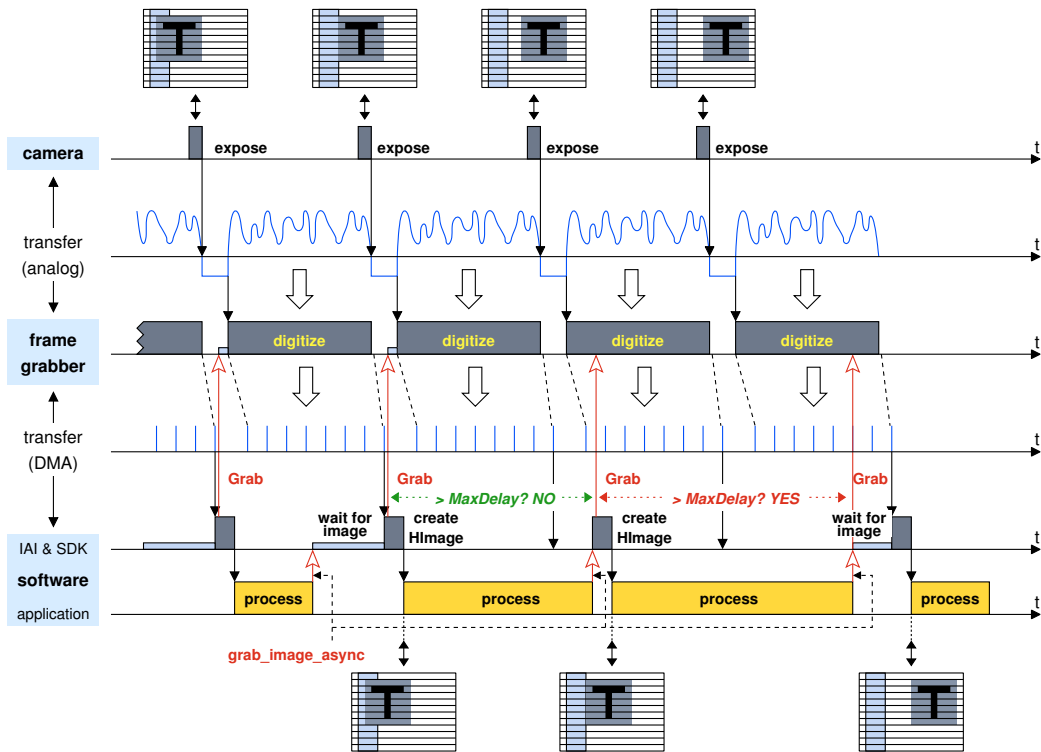


Figure 12: Specifying a maximum delay for `grab_image_async` (using continuous grabbing).

command from the interface to the frame grabber is used as the starting point instead.

Note that the parameter `MaxDelay` in the operator `grab_image_async` has a completely different meaning than the additional parameter `'grab_timeout'`: Using `'grab_timeout'` you can set a timeout for the acquisition process, i.e., the grab operators return after a certain time period with an appropriate error.

## 5.2 Using an External Trigger

In the previous section, the software performing the machine vision task decided when to acquire an image (*software trigger*). In industrial applications, however, the moment for image acquisition is typically specified externally by the process itself, e.g., in form of a hardware trigger signal indicating the presence of an object to be inspected. Most image acquisition devices are therefore equipped with at least one input line for such signals, which are called *external triggers*.

From HALCON's point of view, external triggers are dealt with by the image acquisition device, the only thing to do is to inform the device to use the trigger. You can do this simply by setting the parameter `ExternalTrigger` of `open_framegrabber` to 'true'. Some acquisition interfaces also allow to enable or disable the trigger dynamically using the operator `set_framegrabber_param` (parameter 'external\_trigger').

Figure 13a shows the timing diagram when using an external trigger together with `grab_image` and a free-running camera. After the call to `grab_image`, the image acquisition device waits for the trigger signal. When it appears, the procedure described in the previous section follows: The device waits for the next image, digitizes it, and transfers it into computer memory; then, the HALCON acquisition interface transforms it into a HALCON image and returns the control to the application which processes the image and then calls `grab_image` again, which causes the image acquisition device to wait for the next trigger signal.

The (bad) example in figure 13a was chosen on purpose to show an unsuitable configuration for using an external trigger: First of all, because of the free-running camera there is a non-deterministic delay between the arrival of the trigger signal and the exposure of the image, which may mean that the object to be inspected is not completely visible anymore. Secondly, because `grab_image` is used, trigger signals which arrive while the application is processing an image are lost.

Both problems can easily be solved by using an asynchronously resettable camera together with the operator `grab_image_async` as depicted in figure 13b.

The C++ example program `examples\solution_guide\image_acquisition\cpp\error_handling_timeout_leutron.cpp` (preconfigured for the HALCON Leutron interface) shows how simple it is to use an external trigger: The connection is opened with `ExternalTrigger` set to 'true':

```
HFramegrabber    framegrabber;

framegrabber.OpenFramegrabber(acqname, 1, 1, 0, 0, 0, 0, "default", -1,
                              "gray", -1, "true", camtype, device,
                              -1, -1);
```

Then, images are grabbed:

```
HImage           image;

do
{
    image = framegrabber.GrabImageAsync(-1);
} while (button == 0);
```

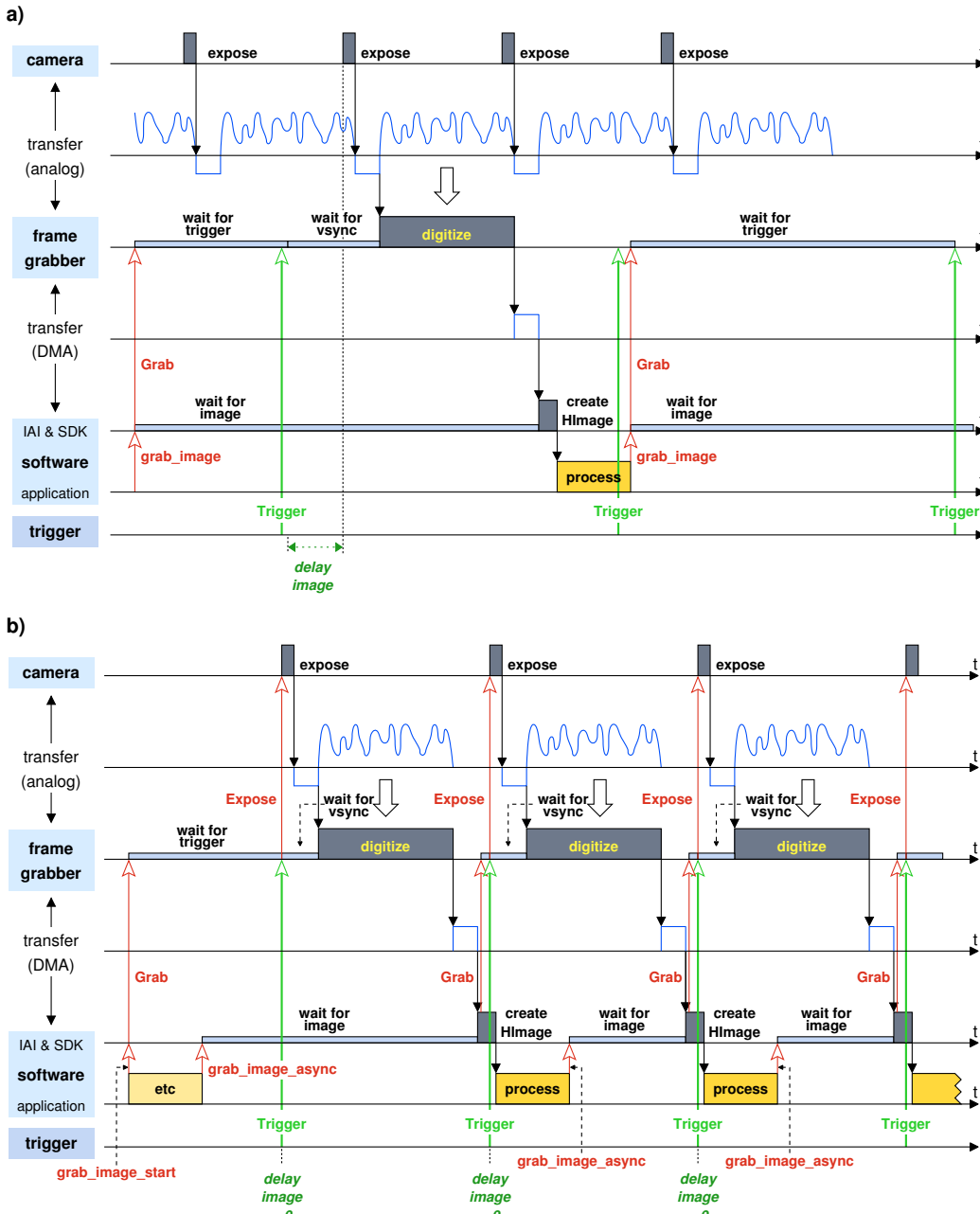


Figure 13: Using an external trigger together with: a) free-running camera and `grab_image`; b) asynchronously resettable camera and `grab_image_async`.

The example contains a customized error handler which checks whether there is an external trigger; this part is described in detail in [section 6.2.3](#) on page 35.

### 5.2.1 Special Parameters for External Triggers

Most image acquisition interfaces allow to further configure the use of external triggering via the operator `set_framegrabber_param`. As mentioned in [section 4.2](#) on page 15, some interfaces allow to enable and disable the external trigger dynamically via the parameter `'external_trigger'`. Another useful parameter is `'grab_timeout'`, which sets a timeout for the acquisition process (some interfaces provide an additional parameter `'trigger_timeout'` just for triggered grabbing). Without such a timeout, the application would hang if for some reason no trigger signal arrives. In contrast, if a timeout is specified, the operators `grab_image` and `grab_image_async` only wait the specified time and then return an error code or raise an exception, depending on the programming language used. [Section 6.2](#) on page 33 shows how to handle such errors.

Other parameters allow to further specify the form of the trigger signal (`'trigger_signal'`), e.g., whether the falling or the rising edge is used as the trigger, select between multiple trigger input lines, or even filter trigger signals. Some acquisition interfaces also allow to influence the exposure via the trigger signal.

## 5.3 Acquiring Images From Multiple Cameras

The timing diagrams shown in the previous sections depicted the case of a single camera. Below we discuss some issues which arise when acquiring images from multiple cameras (see [section 3.2](#) on page 9 for possible configurations).

### 5.3.1 Dynamic Port Switching and Asynchronous Grabbing

If you switch dynamically between multiple cameras connected to a single board as described in [section 3.2.4](#) on page 11, you must be careful when using `grab_image_async`: By default, the acquisition interface commands the frame grabber board to grab the next image automatically after it received the current image — but before the next call of `grab_image_async`! If you switched to another camera before this call, the frame grabber might already be busy grabbing an image from the first camera.

Some acquisition interfaces solve this problem by providing the parameter `'start_async_after_grab_async'` for the operator `set_framegrabber_param` which allows to disable the automatic grab command to the frame grabber board.

```
set_framegrabber_param (AcqHandle, 'start_async_after_grab_async', \
                        'disable')
```

Now, all grab commands must be issued explicitly with the operator `grab_image_start`. The following code shows how to switch between cameras in a loop:

```
* switch to camera 0 and grab a first image
set_framegrabber_param (AcqHandle, 'port', Port0)
grab_image_start (AcqHandle, -1)
grab_image_async (Image0, AcqHandle, -1)
disp_image (Image0, WindowHandle0)
while (1)
    * switch to camera 1 and start a new grab
    set_framegrabber_param (AcqHandle, 'port', Port1)
    grab_image_start (AcqHandle, -1)
    * meanwhile, process image 0
    * then get image from camera 1
    grab_image_async (Image1, AcqHandle, -1)
    disp_image (Image1, WindowHandle1)
    * switch to camera 0 and start a new grab
    set_framegrabber_param (AcqHandle, 'port', Port0)
    grab_image_start (AcqHandle, -1)
    * meanwhile, process image 1
    * then get image from camera 0
    grab_image_async (Image0, AcqHandle, -1)
    disp_image (Image0, WindowHandle0)
endwhile
```

### 5.3.2 Simultaneous Grabbing

Some image acquisition interfaces provide special functionality to grab images *simultaneously* from multiple (synchronized) cameras. Typically, the cameras are connected to a single frame grabber board; the Leutron interface also allows to grab simultaneously from cameras connected to multiple boards. As described in [section 3.2.5](#) on page 11, the images are grabbed by a single call to [grab\\_image](#) or [grab\\_image\\_async](#), which return them in form of a multi-channel image. Depending on the acquisition interface, it may be necessary to switch on the simultaneous grabbing via the operator [set\\_framegrabber\\_param](#).

Please keep in mind that even if a HALCON acquisition interface supports simultaneous grabbing, this might not be true for every frame grabber board the interface supports! In order to grab multiple images simultaneously, a frame grabber board must be equipped with multiple “grabbing units”; for example, an analog frame grabber board must be equipped with multiple A/D converters. Please check this in the documentation of your frame grabber board.

Even if a HALCON acquisition interface does not provide the special simultaneous grabbing mode, you can realize a similar behavior “manually”, e.g., by connecting each (asynchronously resettable) camera to a single frame grabber board and then using a common external trigger signal to synchronize the grabbing.

## 6 Miscellaneous

### 6.1 Acquiring Images From Unsupported Image Acquisition Devices

If you want to use an image acquisition device that is currently not supported by HALCON, i.e., for which no HALCON interface exists, there exist two principal ways: First, you can create your own HALCON acquisition interface; how to do this is described in detail in the [Image Acquisition Interface Programmer's Manual](#).

As an alternative, you can pass externally created images, i.e., the raw image matrix, to HALCON using the operators [gen\\_image1](#), [gen\\_image3](#), [gen\\_image1\\_extern](#), or [gen\\_image3\\_extern](#), which create a corresponding HALCON image. The main difference between the operators [gen\\_image1](#) and [gen\\_image1\\_extern](#) and their variants for three-channel images is that the former copies the image matrix when creating the HALCON image, whereas the latter doesn't, which is useful if you want to realize *volatile grabbing* as described in [section 5.1.3](#) on page 20.

The C example program `examples\solution_guide\image_acquisition\c\use_extern_image.c` shows how to use the operator [gen\\_image1\\_extern](#) to pass standard gray value images to HALCON. In this case, the image matrix consists of 8 bit pixels (bytes), which can be represented by the data type `unsigned char`. At the beginning, the program calls a procedure which allocates memory for the images to be “grabbed”; in a real application this corresponds to the image buffer(s) used by the image acquisition device SDK.

```
unsigned char *image_matrix_ptr;
long          width, height;

InitializeBuffer(&image_matrix_ptr, &width, &height);
```

The example program “simulates” the grabbing of images with a procedure which reads images from an image sequence and copies them into the image buffer. Then, the content of the image buffer is transformed into a HALCON image (type byte) via [gen\\_image1\\_extern](#). The parameter [ClearProc](#) is set to 0 to signal that the program itself takes care of freeing the memory. The created HALCON image is then displayed. The loop can be exited by clicking into the HALCON window with any mouse button.

```
Hobject      image;
long         window_id;

open_window (0, 0, width, height, 0, "visible", "", &window_id);
while (!ButtonPressed(window_id))
{
    MyGrabImage((const unsigned char **) &image_matrix_ptr);
    gen_image1_extern(&image, "byte", width, height,
                     (long) image_matrix_ptr, (long) 0);

    disp_obj(image, window_id);
}
```

If your image acquisition device supplies images with more than 8 bit pixels, you must adapt both the data type for the image matrix and the type of the created HALCON image (parameter [Type](#) of



`gen_image1_extern`). In case of color images HALCON expects the image data in form of three separate image matrices. Correspondingly, you can create a HALCON image by calling the operators `gen_image3` or `gen_image3_extern` with the three pointers to the matrices. Please refer to [appendix A](#) on page 41 for more information about HALCON images in general.

## 6.2 Error Handling

Just as the HALCON acquisition interfaces encapsulate the communication with an image acquisition device, they also encapsulate occurring errors within the HALCON error handling mechanism. How to catch and react to these errors is described below for HDevelop programs and also for programs using HALCON's programming language interfaces.

Some HALCON acquisition interfaces provide special parameters for `set_framegrabber_param` which are related to error handling. The most commonly used one is the parameter 'grab\_timeout' which specifies when the image acquisition device should quit waiting for an image. The examples described in the following sections show how to handle the corresponding HALCON error.

Note that all example programs enable the signaling of low level errors via the operator `set_system`, e.g., in HDevelop syntax via

```
set_system ('do_low_error', 'true')
```

In this mode, low level errors occurring in the image acquisition device SDK (or in the HALCON acquisition interface) are signaled by a message box.

### 6.2.1 Error Handling in HDevelop

The HDevelop example `examples\solution_guide\image_acquisition\error_handling_timeout_leutron.dev` shows how to handle HALCON errors in a HDevelop program. To "provoke" an error, `open_framegrabber` is called with `ExternalTrigger = 'true'`. If there is no trigger, a call to `grab_image` results in a timeout; HDevelop reacts to this error with the popup dialog shown in [figure 14](#) and stops the program.

```
open_framegrabber (AcqName, 1, 1, 0, 0, 0, 0, 'default', -1, 'default', -1, \
                  'true', CameraType, Device, -1, -1, AcqHandle)
set_framegrabber_param (AcqHandle, 'grab_timeout', 2000)
grab_image (Image, AcqHandle)
```

HALCON lets you modify the reaction to an error with the operator `set_check` (in HDevelop: `dev_set_check`). If you set it to '`~give_error`', the program does not stop in case of an error but only stores its cause in form of an error code. To access this error code in HDevelop, you must define a corresponding variable using the operator `dev_error_var`. Note that this variable is updated after each operator call; to check the result of a single operator we therefore recommend to switch back to the standard error handling mode directly after the operator call as in the following lines:

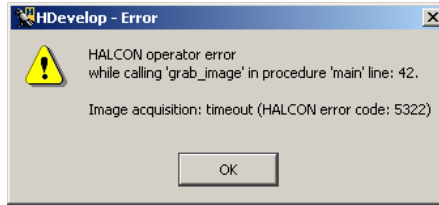


Figure 14: Popup dialog in HDevelop signaling a timeout.

```
dev_error_var (ErrorNum, 1)
dev_set_check ('~give_error')
grab_image (Image, AcqHandle)
dev_error_var (ErrorNum, 0)
dev_set_check ('give_error')
```

To check whether a timeout occurred, you compare the error variable with the code signaling a timeout (5322); a list of error codes relating to image acquisition can be found in the Image Acquisition Interface Programmer's Manual, [appendix D](#) on page 79. In the example, the timeout is handled by disabling the external trigger mode via the operator [set\\_framegrabber\\_param](#) (parameter 'external\_trigger'). Then, the call to [grab\\_image](#) is tested again.

```
if (ErrorNum = 5322)
    set_framegrabber_param (AcqHandle, 'external_trigger', 'false')
    dev_error_var (ErrorNum, 1)
    dev_set_check ('~give_error')
    grab_image (Image, AcqHandle)
    dev_error_var (ErrorNum, 0)
    dev_set_check ('give_error')
endif
```

Now, the error variable should contain the value 2 signaling that the operator call succeeded; for this value, HDevelop provides the constant `H_MSG_TRUE`. If you get another error code, the program accesses the corresponding error text using the operator [get\\_error\\_text](#).

```
if (ErrorNum # H_MSG_TRUE)
    get_error_text (ErrorNum, ErrorText)
endif
```

If your image acquisition interface does not provide the parameter 'external\_trigger', you can realize a similar behavior by closing the connection and then opening it again with [ExternalTrigger](#) set to 'false'.

## 6.2.2 Error Handling Using HALCON/C

The mechanism for error handling in a program based on HALCON/C is similar to the one in HDevelop; in fact, it is even simpler, because each operator automatically returns its error code. However, if a

HALCON error occurs in a C program, the default error handling mode causes the program to abort.

The C example program `examples\solution_guide\image_acquisition\c\error_handling_timeout_leutron.c` performs the same task as the HDevelop program in the previous section; if the call to `grab_image` succeeds, the program grabs and displays images in a loop, which can be exited by clicking into the window. The following lines show how to test whether a timeout occurred:

```
set_check ("~give_error");
error_num = grab_image (&image, acqhandle);
set_check ("give_error");
switch (error_num)
{
case H_ERR_FGTIMEOUT:
```

As you see, in a C program you can use predefined constants for the error codes (see the Image Acquisition Interface Programmer's Manual, [appendix D](#) on page 79, for a list of image acquisition error codes and their corresponding constants).

## 6.2.3 Error Handling Using HALCON/C++

If your application is based on HALCON/C++, there are two methods for error handling: If you use operators in their C-like form, e.g., `grab_image`, you can apply the same procedure as described for HALCON/C in the previous section.

In addition, HALCON/C++ provides an exception handling mechanism based on the class `HException`, which is described in the Programmer's Guide, [section 5.3](#) on page 42. Whenever a HALCON error occurs, an instance of this class is created. The main idea is that you can specify a procedure which is then called automatically with the created instance of `HException` as a parameter. How to use this mechanism is explained in the C++ example program `examples\solution_guide\image_acquisition\cpp\error_handling_timeout_leutron.cpp`, which performs the same task as the examples in the previous sections.

In the example program `examples\solution_guide\image_acquisition\cpp\error_handling_timeout_leutron.cpp` (preconfigured for the HALCON Leutron interface), the procedure which is to be called upon error is very simple: It just raises a standard C++ exception with the instance of `HException` as a parameter.

```
void MyHalconExceptionHandler(const Halcon::HException& except)
{
    throw except;
}
```

In the program, you “install” this procedure via a class method of `HException`:

```
int main(int argc, char *argv[])
{
    using namespace Halcon;
    HException::InstallHandler(&MyHalconExceptionHandler);
```

Now, you react to a timeout with the following lines:

```
try
{
    image = framegrabber.GrabImage();
}
catch (HException except)
{
    if (except.err == H_ERR_FGTIMEOUT)
    {
        framegrabber.SetFramegrabberParam("external_trigger", "false");
    }
}
```

As already noted, if your image acquisition interface does not provide the parameter 'external\_trigger', you can realize a similar behavior by closing the connection and then opening it again with [ExternalTrigger](#) set to 'false':

```
if (except.err == H_ERR_FGTIMEOUT)
{
    framegrabber.OpenFramegrabber(acqname, 1, 1, 0, 0, 0, 0, "default",
                                  -1, "gray", -1, "false", camtype,
                                  "default", -1, -1);
}
```

Note that when calling [OpenFramegrabber](#) via the class `HFramegrabber` as above, the operator checks whether it is called with an already opened connection and automatically closes it before opening it with the new parameters.

### 6.2.4 Error Handling Using HALCON/COM

The HALCON/COM interface uses the standard COM error handling technique where every method call passes both a numerical and a textual representation of the error to the calling framework. How to use this mechanism is explained in the Visual Basic example program `examples\solution_guide\image_acquisition\vb\error_handling_timeout_leutron.vbp`, which performs the same task as the examples in the previous sections.

For each method, you can specify an error handler by inserting the following line at the beginning of the method:

```
On Error GoTo ErrorHandler
```

At the end of the method, you insert the code for the error handler. If a runtime error occurs, Visual Basic automatically jumps to this code, with the error being described in the variable `Err`. However, the returned error number does not correspond directly to the HALCON error as in the other programming languages, because low error numbers are reserved for COM. To solve this problem HALCON/COM uses an offset which must be subtracted to get the HALCON error code. This offset is accessible as a property of the class [HSystemX](#):

```
ErrorHandler:
  Dim sys As New HSystemX
  ErrorNum = Err.Number - sys.ErrorBaseHalcon
```

The following code fragment checks whether the error is due to a timeout. If yes, the program disables the external trigger mode and tries again to grab an image. If the grab is successful the program continues at the point the error occurred; otherwise, the Visual Basic default error handler is invoked. Note that in contrast to the other programming languages HALCON/COM does not provide constants for the error codes.

```
If (ErrorNum = 5322) Then
  Call FG.SetFramegrabberParam("external_trigger", "false")
  Set Image = FG.GrabImage
  Resume Next
```

If the error is not caused by a timeout, the error handler raises it anew, whereupon the Visual Basic default error handler is invoked.

```
Else
  Err.Raise (Err.Number)
End If
```

If your image acquisition interface does not provide the parameter 'external\_trigger', you can realize a similar behavior by closing the connection and then opening it again with [ExternalTrigger](#) set to 'false'. Note that the class [HFramegrabberX](#) does not provide a method to close the connection; instead you must destroy the variable with the following line:

```
Set FG = Nothing
```

## 6.2.5 Error Handling Using HALCON/.NET

For error handling with HALCON/.NET (e.g., in C# or Visual Basic .NET applications) please refer to the Programmer's Guide, [section 10.7](#) on page [103](#).

## 6.3 Line Scan Cameras

From the point of view of HALCON there is no difference between area and line scan cameras: Both acquire images of a certain width and height; whether the height is 1, i.e., a single line, or larger does not matter. In fact, in many line scan applications the image acquisition device combines multiple acquired lines to form a so-called *page* which further lessens the difference between the two camera types.

The main problem is therefore whether your frame grabber supports line scan cameras. If yes, you can acquire images from it via HALCON exactly as from an area scan camera. With the parameter `ImageHeight` of the operator `open_framegrabber` you can sometimes specify the height of the page; typically, this information is set in the camera configuration file. Some HALCON acquisition interfaces allow to further configure the acquisition mode via the operator `set_framegrabber_param`.

The images acquired from a line scan camera can then be processed just like images from area scan cameras. However, line scan images often pose an additional problem: The objects to inspect may be spread over multiple images (pages). To solve this problem, HALCON provides special operators: `tile_images` allows to merge images into a larger image, `merge_regions_line_scan` and `merge_cont_line_scan_xld` allow to merge the (intermediate) processing results of subsequent images.

How to use these operators is explained in the HDevelop example program `examples\solution_guide\image_acquisition\line_scan.dev`. The program is based on an image file sequence which is read using the HALCON virtual acquisition interface `File`; the task is to extract paper clips and calculate their orientation. Furthermore, the gray values in a rectangle surrounding each clip are determined.

An important parameter for the merging is over how many images an object can be spread. In the example, a clip can be spread over 4 images:

```
MaxImagesRegions := 4
```

The continuous processing is realized by a simple loop: At each iteration, a new image is grabbed, and the regions forming candidates for the clips are extracted using thresholding.

```
while (1)
    grab_image (Image, AcqHandle)
    threshold (Image, CurrRegions, 0, 80)
```

The current regions are then merged with ones extracted in the previous image using the operator `merge_regions_line_scan`. As a result, two sets of regions are returned: The parameter `CurrMergedRegions` contains the current regions, possibly extended by fitting parts of the previously extracted regions, whereas the parameter `PrevMergedRegions` contains the rest of the previous regions.

```
merge_regions_line_scan (CurrRegions, PrevRegions, CurrMergedRegions, \
                        PrevMergedRegions, ImageHeight, 'top', \
                        MaxImagesRegions)
connection (PrevMergedRegions, ClipCandidates)
select_shape (ClipCandidates, FinishedClips, 'area', 'and', 4500, 7000)
```

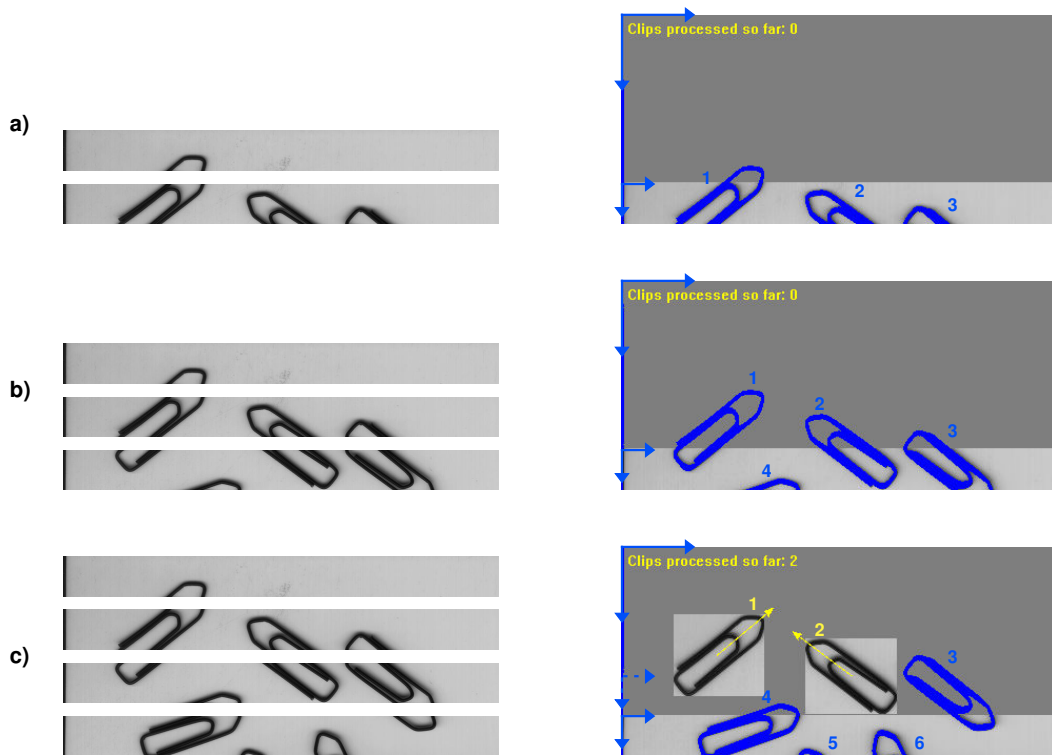


Figure 15: Merging regions extracted from subsequent line scan images: state after a) 2, b) 3, c) 4 images (large coordinate system: tiled image; small coordinate systems: current image or most recent image).

The regions in `PrevMergedRegions` are “finished”; from them, the program selects the clips via their area and further processes them later, e.g., determines their position and orientation. The regions in `CurrMergedRegions` are renamed and now form the previous regions for the next iteration.

```
copy_obj (CurrMergedRegions, PrevRegions, 1, -1)
endwhile
```

Note that the operator `copy_obj` does not copy the regions themselves but only the corresponding HAL-CON objects, which can be thought of as references to the actual region data.

Before we show how to merge the images let’s take a look at [figure 15](#), which visualizes the whole process: After the first two images `CurrMergedRegions` contains three clip parts; for the first one a previously extracted region was merged. Note that the regions are described in the coordinate frame of the current image; this means that the merged part of clip no. 1 has negative coordinates.

In the next iteration ([figure 15b](#)), further clip parts are merged, but no clip is finished yet. Note that the coordinate frame is again fixed to the current image; as a consequence the currently merged regions seem to move into negative coordinates.

After the fourth image ([figure 15c](#)), clips no. 1 and 2 are completed; they are returned in the parameter

**PrevMergedRegions**. Note that they are still described in the coordinate frame of the previous image (depicted with dashed arrow); to visualize them together with **CurrMergedRegions** they must be moved to the coordinate system of the current image using the operator **move\_region**:

```
move_region (FinishedClips, ClipsInCurrentImageCoordinates, -ImageHeight, \
            0)
```

Let's get back to the task of merging images: To access the gray values around a clip, one must merge those images over which the **PrevMergedRegions** can be spread. At the beginning, an empty image is created which can hold 4 images:

```
gen_image_const (TiledImage, 'byte', ImageWidth, \
                ImageHeight * MaxImagesRegions)
```

At the end of each iteration, the “oldest” image, i.e., the image at the top, is cut off the tiled image using **crop\_part**, and the current image is merged at the bottom using **tile\_images\_offset**:

```
crop_part (TiledImage, TiledImageMinusOldest, ImageHeight, 0, ImageWidth, \
          (MaxImagesRegions - 1) * ImageHeight)
concat_obj (TiledImageMinusOldest, Image, ImagesToTile)
tile_images_offset (ImagesToTile, TiledImage, [0, \
          (MaxImagesRegions-1)*ImageHeight], [0, 0], [-1, -1], \
          [-1, -1], [-1, -1], [-1, -1], ImageWidth, \
          MaxImagesRegions * ImageHeight)
```

As noted above, the regions returned in **PrevMergedRegions** are described in the coordinate frame of the most recent image (depicted with dashed arrows in [figure 15c](#)); to extract the corresponding gray values from the tiled image, they must first be moved to its coordinate system (depicted with longer arrows) using the operator **move\_region**. Then, the surrounding rectangles are created using **shape\_trans**, and finally the corresponding gray values are extracted using **add\_channels**:

```
move_region (FinishedClips, ClipsInTiledImageCoordinates, \
            (MaxImagesRegions-1) * ImageHeight, 0)
shape_trans (ClipsInTiledImageCoordinates, AroundClips, 'rectangle1')
add_channels (AroundClips, TiledImage, GrayValuesAroundClips)
```



# Appendix

## A HALCON Images

In the following, we take a closer look at the way HALCON represents and handles images. Of course, we won't bother you with details about the low-level representation and the memory management; HALCON takes care of it in a way to guarantee optimal performance.

### A.1 The Philosophy of HALCON Images

There are three important concepts behind HALCON's image objects:

#### 1. Multiple channels

Typically, one thinks of an image as a matrix of pixels. In HALCON, this matrix is called a *channel*, and images may consist of one or more such channels. For example, gray value images consist of a single channel, color images of three channels.

The advantage of this representation is that many HALCON operators automatically process all channels at once; for example, if you want to subtract gray level or color images from another, you can apply `sub_image` without worrying about the image type. Whether an operator processes all channels at once can be seen in the parameter description in the reference manual: If an image parameter is described as (multichannel-)image or (multichannel-)image(-array) (e.g., the parameter `ImageMinuend` of `sub_image`), all channels are processed; if it is described as image or image(-array) (e.g., the parameter `Image` of `threshold`), only the first channel is processed.

For more information about channels please refer to [appendix A.3.2](#).

#### 2. Various pixel types

Besides the standard 8 bit (type byte) used to represent gray value image, HALCON allows images to contain various other data, e.g. 16 bit integers (type `int2` or `uint2`) or 32 bit floating point numbers (type `real`) to represent derivatives.

Most of the time you need not worry about pixel types, because HALCON operators that output images automatically use a suitable pixel type. For example, the operator `derivate_gauss` creates a `real` image to store the result of the derivation. As another example, if you connect to an image acquisition device selecting a value  $> 8$  for the parameter `BitsPerChannel`, a subsequent `grab_image` returns an `uint2` image.

#### 3. Arbitrarily-shaped region of interest

Besides the pixel information, each HALCON image also stores its so-called *domain* in form of a HALCON region. The domain can be interpreted as a region of interest, i.e., HALCON operators (with some exceptions) restrict their processing to this region.

The image domain inherits the full flexibility of a HALCON region, i.e., it can be of arbitrary shape and size, can have holes, or even consist of unconnected points. For more information about domains please refer to [appendix A.3.3](#) on page 43.

The power of HALCON's approach lies in the fact that it offers full flexibility but does not require you to worry about options you don't need at the moment. For example, if all you do is grab and process standard 8 bit gray value images, you can ignore channels and pixel types. At the moment you decide to use color images instead, all you need to do is to add some lines to decompose the image into its channels. And if your camera / frame grabber provides images with more than 8 bit pixel information, HALCON is ready for this as well.

## A.2 Image Tuples (Arrays)

Another powerful mechanism of HALCON is the so-called *tuple processing*: If you want to process multiple images in the same way, e.g., to smooth them, you can call the operator (e.g., [mean\\_image](#)) once passing all images as a tuple (array), instead of calling it multiple times. Furthermore, some operators always return image tuples, e.g., [gen\\_gauss\\_pyramid](#) or [inspect\\_shape\\_model](#).

Whether an operator supports tuple processing can be seen in the parameter description in the reference manual: If an input image parameter is described as `image(-array)` or `(multichannel-)image(-array)` (e.g., the parameter `Image` of [mean\\_image](#)), it supports tuple processing; if it is described as `image` or `(multichannel-)image` (e.g., the parameter `Image` of [find\\_bar\\_code](#)), only one image is processed.

For information about creating or accessing image tuples please refer to [appendix A.3.6](#).

## A.3 HALCON Operators for Handling Images

Below you find a brief overview of operators that allow to create HALCON images or to modify “technical aspects” like the image size or the number of channels.

### A.3.1 Creation

HALCON images are created automatically when you use operators like [grab\\_image](#) or [read\\_image](#). You can also create images from scratch using the operators listed in the HDevelop menu Operators ▸ Image ▸ Creation, e.g., [gen\\_image\\_const](#) or [gen\\_image1\\_extern](#) (see also [section 6.1](#) on page 32).

### A.3.2 Channels

Operators for manipulating channels can be found in the HDevelop menu Operators ▸ Image ▸ Channel. You can query the number of channels of an image with the operator [count\\_channels](#). Channels can be accessed using [access\\_channel](#) (which extracts a specified channel without copying), [image\\_to\\_channels](#) (which converts a multi-channel image into an image tuple), or [decompose2](#) etc. (which converts a multi-channel image into 2 or more single-channel images). Vice versa, you can create a multi-channel image using [channels\\_to\\_image](#) or [compose2](#) etc., and add channels to an image using [append\\_channel](#).

### A.3.3 Domain

Operators for manipulating the domain of an image can be found in the HDevelop menu Operators ▸ Image ▸ Domain. Upon creation of an image, its domain is set to the full image size. You can set it to a specified region using `change_domain`. In contrast, the operator `reduce_domain` takes the original domain into account; the new domain is equal to the intersection of the original domain with the specified region. Please also take a look at the operator `add_channels`, which can be seen as complementary to `reduce_domain`.

### A.3.4 Access

Operators for accessing information about a HALCON image can be found in the HDevelop menu Operators ▸ Image ▸ Access. For example, `get_image_pointer1` returns the size of an image and a pointer to the image matrix of its first channel.

### A.3.5 Manipulation

You can change the size of an image using the operators `change_format` or `crop_part`, or other operators from the HDevelop menu Operators ▸ Image ▸ Format. The menu Operators ▸ Image ▸ Type-Conversion lists operators which change the pixel type, e.g., `convert_image_type`. Operators to modify the pixel values, can be found in the menu Operators ▸ Image ▸ Manipulation, e.g., `paint_gray`, which copies pixels from one image into another.

### A.3.6 Image Tuples

Operators for creating and accessing image tuples can be found in the HDevelop menu Operators ▸ Object ▸ Manipulation. Image tuples can be created using the operators `gen_empty_obj` and `concat_obj`, while the operator `select_obj` allows to access an individual image that is part of a tuple.

## B Parameters Describing the Image

When opening a connection with `open_framegrabber`, you can specify the desired image format, e.g., its size or the number of bits per pixel, using its nine parameters, which are described in the following.

### B.1 Image Size

The following 6 parameters influence the size of the grabbed images: `HorizontalResolution` and `VerticalResolution` specify the *spatial resolution* of the image in relation to the original size. For example, if you choose `VerticalResolution` = 2, you get an image with half the height of the original as depicted in [figure 16b](#). Another name for this process is (vertical and horizontal) *subsampling*.

With the parameters `ImageWidth`, `ImageHeight`, `StartRow`, and `StartColumn` you can grab only a part of the (possibly subsampled) image; this is called *image cropping*. In [figure 16](#), the image part to be grabbed is marked with a rectangle in the original (or subsampled) image; to the right, the resulting image is depicted. Note that the resulting HALCON image always starts with the coordinates (0,0), i.e., the information contained in the parameters `StartRow` and `StartColumn` cannot be recovered from the resulting image.

Depending on the involved components, both subsampling and image cropping may be executed at different points during the transfer of an image from the camera into HALCON: in the camera, in the frame grabber, or in the software. Please note that in most cases you get no direct effect on the performance in form of a higher frame rate; exceptions are CMOS cameras which adapt their frame rate to the requested image size. Subsampling or cropping on the software side has no effect on the frame rate; besides, you can achieve a similar result using `reduce_domain`. If the frame grabber executes the subsampling or cropping you may get a positive effect if the PCI bus is the bottleneck of your application and prevents

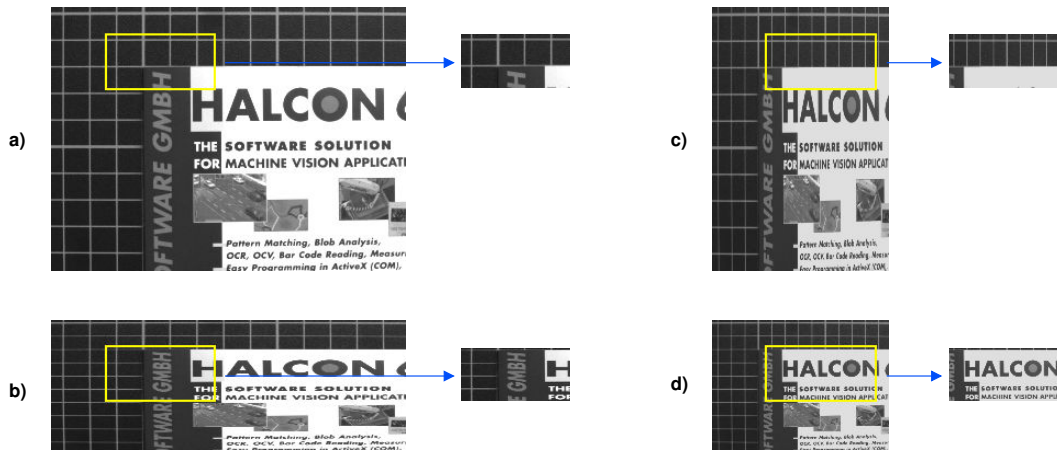


Figure 16: The effect of image resolution (subsampling) and image cropping (`ImageWidth` = 200, `ImageHeight` = 100, `StartRow` = 50, `StartColumn` = 100): a) `HorizontalResolution` (HR) = `VerticalResolution` (VR) = 1; b) HR = 1, VR = 2; c) HR = 2, VR = 1; d) HR = VR = 2.

you from getting the full frame rate. Some acquisition interfaces allow *dynamic image cropping* via the operator `set_framegrabber_param`.

Note that HALCON itself does not differentiate between area and line scan cameras as both produce images – the former in form of frames, the latter in form of so-called *pages* created from successive lines (number specified in the parameter `ImageHeight`). [Section 6.3](#) on page 38 contains additional information regarding the use of line scan cameras.

## B.2 Frames vs. Fields

The parameter `Field` is relevant only for analog cameras that produce signals following the video standards originally developed for TV, e.g., NTSC or PAL. In these standards, the camera transmits images (also called *frames*) in form of two so-called *fields*, one containing all odd lines of a frame, the other all even lines of the next frame. On the frame grabber board, these two fields are then *interlaced*; the resulting frame is transferred via the PCI bus into the computer memory using DMA (*direct memory access*).

[Figure 17](#) visualizes this process and demonstrates its major drawback: If a moving object is observed (in the example a dark square with the letter 'T'), the position of the object changes from field to field, the resulting frame shows a distortion at the vertical object boundaries (also called *picket-fence effect*). Such a distortion seriously impairs the accuracy of measurements; industrial vision systems therefore often use so-called *progressive scan* cameras which transfer full frames (see [figure 18](#)). Some cameras also “mix” interlacing with progressive scan as depicted in [figure 19](#).

You can also acquire the individual fields by specifying `VerticalResolution = 2`. Via the parameter `Field` you can then select which fields are to be acquired (see also [figure 20](#)): If you select 'first' or

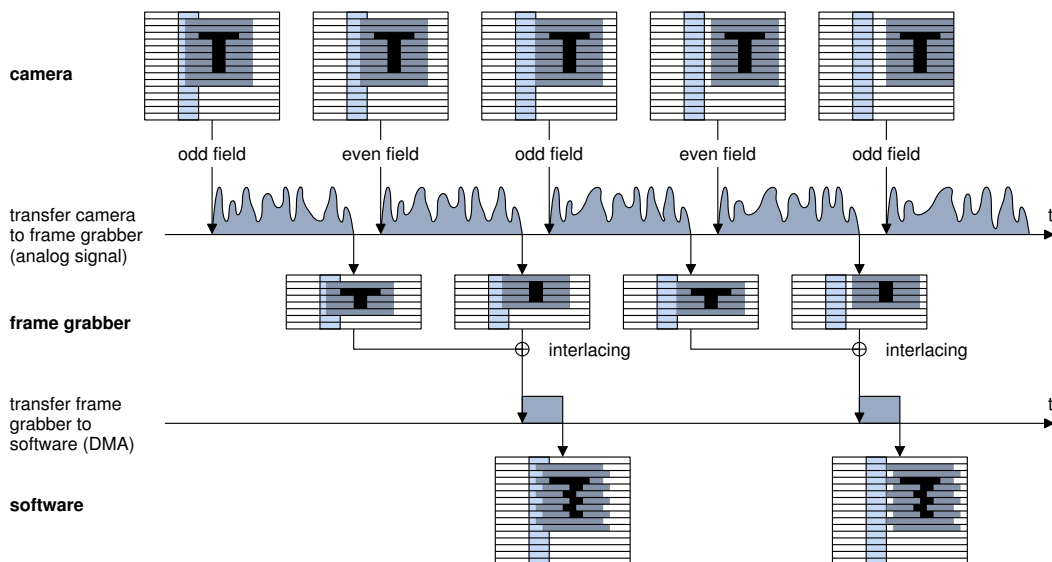


Figure 17: Interlaced grabbing (`Field = 'interlaced'`).

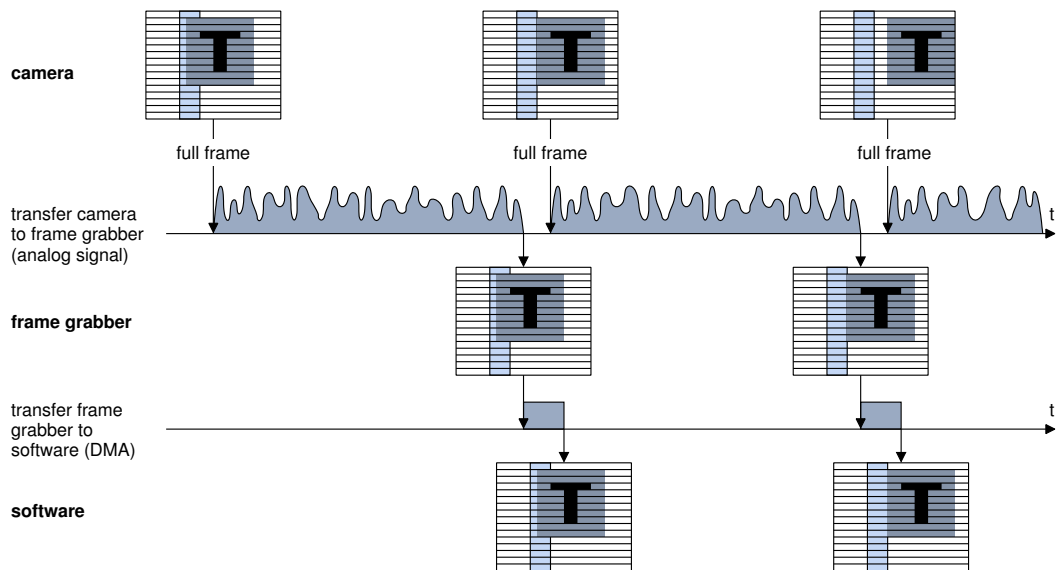


Figure 18: Progressive scan grabbing (**Field** = 'progressive').

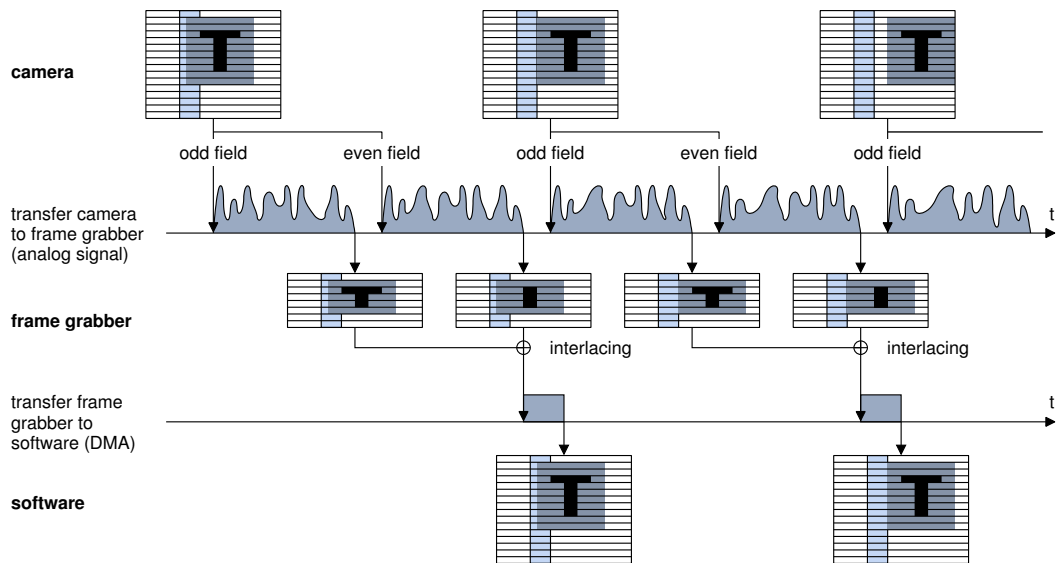


Figure 19: Special form of interlaced grabbing supported by some cameras.

'second', you get all odd or all even fields, respectively; if you select 'next', you get every field. The latter mode has the advantage of a higher field rate, at the cost, however, of the so-called *vertical jitter*: Objects may seem to move up and down (like the square in [figure 20](#)), while structures that are one pixel wide appear and disappear (like the upper part of the 'T').

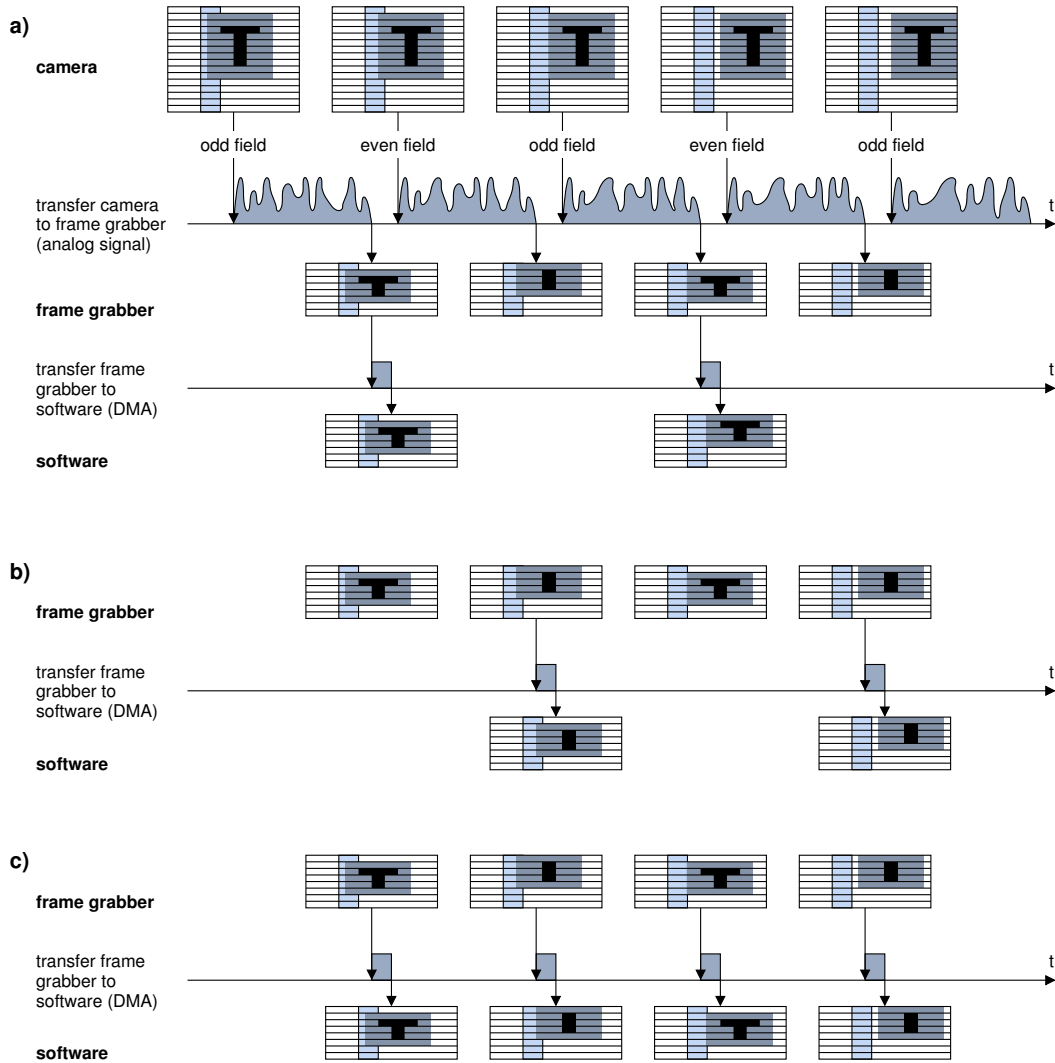


Figure 20: Three ways of field grabbing: a) 'first'; b) 'second'; c) 'next' .

By specifying `Field = 'first', 'second', or 'next'` for a full resolution image (`VerticalResolution = 1`), you can select with which field the interlacing starts.

Figure 21 shows a timing diagram for using `grab_image` together with an interlaced-scan camera. Here, you can in some cases increase the processing frame rate by specifying 'next' for the parameter `Field`. The frame grabber then starts to digitize an image when the next field arrives; in the example therefore only one field is lost.

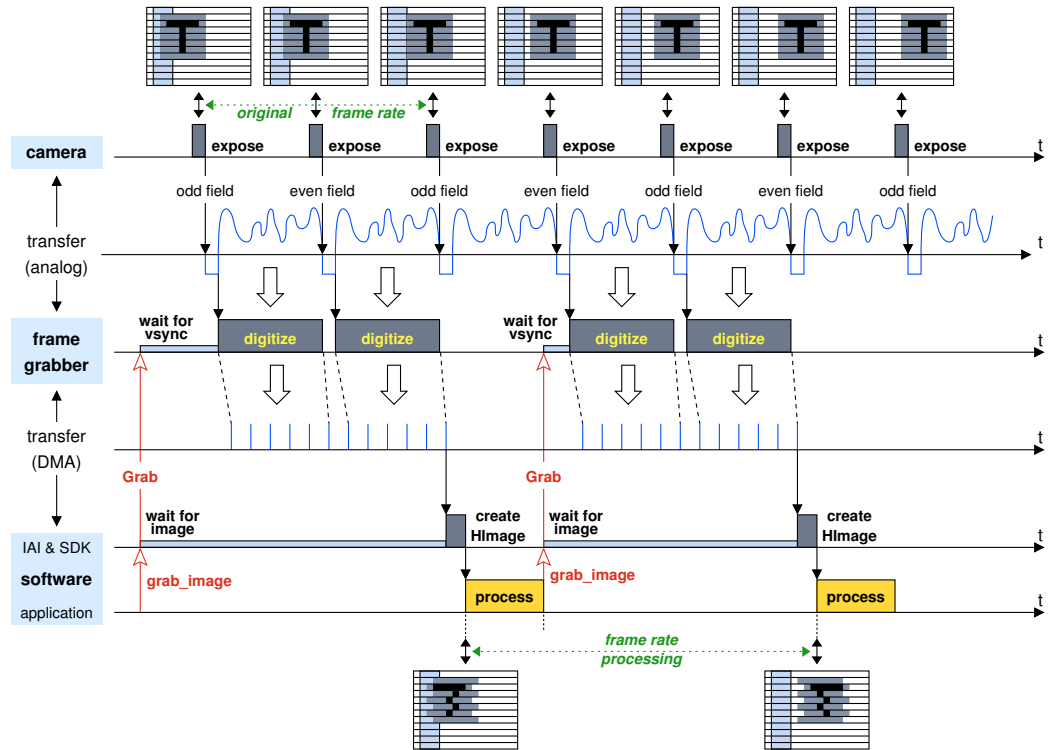


Figure 21: Grabbing interlaced images starting with the 'next' field.

### B.3 Image Data

The parameters described in the previous sections concentrated on the size of the images. The *image data*, i.e., the data contained in a pixel, is described with the parameters **BitsPerChannel** and **ColorSpace**. To understand these parameters, a quick look at HALCON's way to represent images is necessary: A HALCON image consists of one or more matrices of pixels, which are called *channels*. Gray value images are represented as single-channel images, while color images consist of three channels, e.g., for the red, green, and blue part of an RGB image. Each image matrix (channel) consists of *pixels*, which may be of different *data types*, e.g., standard 8 bit (type `byte`) or 16 bit integers (type `int2` or `uint2`) or 32 bit floating point numbers (type `real`). For detailed information about HALCON images please refer to [appendix A](#) on page 41.

The two parameters correspond to the two main aspects of HALCON images: With the parameter **ColorSpace**, you can select whether the resulting HALCON image is to be a (single-channel) gray value image (value `'gray'`) or a (multi-channel) color image (e.g., value `'rgb'`). The parameter **BitsPerChannel** specifies how many bits are *transmitted* per pixel per channel from the frame grabber to the computer; the pixel type of the HALCON image is then chosen to accommodate the transmitted number of pixels.

For example, if a frame grabber is able to transmit 10 bit gray value images, select **ColorSpace** = `'gray'` and **BitsPerChannel** = 10 and you will get a single-channel HALCON image of the type



'uint2', i.e., 16 bit per channel. Another example concerns RGB images: Some frame grabbers allow the values 8 and 5 for [BitsPerChannel](#). In the first case,  $3 \times 8 = 24$  bit are transmitted per pixel, while in the second case only  $3 \times 5 = 15$  (padded to 16) bit are transmitted; in both cases, a three-channel 'byte' image results.

## C Object Appearance

The previous chapters showed you how to acquire images. This appendix looks at the step that precedes the image acquisition, i.e., it provides you with hints how to setup your vision system so that the acquired images contain useful and correct information. For a correct measurement result the different components involved in the process of taking images have to be considered. These are first of all the object of interest, the light that makes the object visible, the camera, which stores the spatially assigned intensities of incoming light, and the geometrical relation between the camera and the object of interest. Further, the individual components consist of different single components, e.g., the camera comprises a lens and a CCD chip. All the involved components yield sources for errors, e.g., caused by lens distortions or the digitalization process.

For all machine vision tasks and especially for highly accurate measuring you should be aware of the error sources that are attached to your specific equipment and of their influence on the appearance of the objects of interest in the image. A correct image analysis is only possible if the features of interest are clearly visible and for many tasks also geometrically correct. Thus, we here discuss the

- lighting conditions ([appendix C.1](#)), which control the visibility of the object, and
- the geometrical relations between camera and object ([appendix C.2](#)), which influence the geometrical appearance of the objects in the image and control the further processing of the image.

### C.1 Lighting

The success of an image analysis task, especially for highly accurate measuring purposes depends on the visibility of the objects of interest in the image. To obtain images with clearly visible objects, the lighting conditions during image acquisition have to be considered carefully. Dependent on the surface of the object and the direction of the light, some parts of the object may reflect more light than others so that the image does not necessarily map the actual object outlines but also reflections and shadows. With bad lighting conditions, too sparse or too much light is received by the camera, which leads to low contrasts at the object borders at least in parts of the image. The task to acquire images that represent the objects of interest as clear edges or homogeneous regions is rather demanding and involves a certain part of intuition. This section summarizes some basic knowledge about lighting and tries to convey to you a feeling for choosing the right lighting conditions for your specific task. In detail, it goes deeper into

- the reflection properties of the object and
- the characteristics of the light source.

#### C.1.1 Reflection Properties of the Object

Before selecting a specific light source, the specific characteristics of the objects that are to be inspected have to be considered. Dependent on an object's surface light is differently reflected. We differentiate two extreme reflection behaviors:

- specular reflection and

- diffuse reflection.

With specular reflection a ray of light is reflected with almost full intensity into a single direction (see [figure 22](#), left). Specular reflection is dominant for objects with a low surface roughness like a mirror or plain steel.

With diffuse reflection a ray of light is reflected as several rays of light with less intensity but various directions (see [figure 22](#), right). Diffuse reflection is dominant for objects with a high surface roughness like a sheet of paper or sand blasted surfaces.

Generally, objects can not clearly be assigned to one of the two reflection behaviors but lie somewhere in between. Some objects have a rather luminous surface and react mainly with specular reflection, whereas objects with a rather dull surface react mainly with a diffuse reflection.

For an object that reacts mainly with specular reflection, the intensity of the reflected light is rather strong but due to its limited direction the object's visibility in the image heavily depends on the angle of incidence the ray of light comes from. To increase the chance that the reflected light hits the camera lense in a way the object is clearly mapped in the image, a diffuse light source is recommended. Then, light waves come from and therefore are reflected to different directions.

For an object that reacts mainly with a diffuse reflection less light is reflected, but, as the light waves are reflected into several directions, the visibility of the object does not depend that much on the exact position of the light source. The following section gives a brief overview of basic types of light sources and the influence of their position in relation to the camera and object.

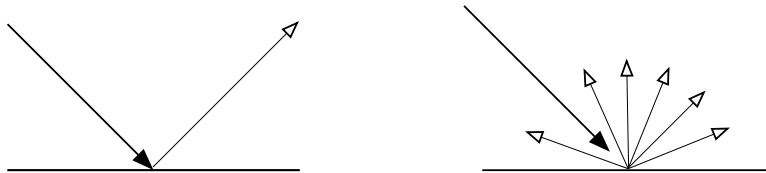


Figure 22: The two (extreme) types of reflection: (left) specular reflection, (right) diffuse reflection.

## C.1.2 Characteristics of the Light Source

Knowing the characteristics of the object, the light sources and their positions in relation to the object and camera positions have to be selected. To obtain clear-cut edges without disturbing reflections you should not rely on day light but use controlled light. In particular, when taking several images the lighting conditions additionally should not change over time. The characteristics of the lighting can be split into

- the specific type of light source, based on the direction the light waves are propagated to, and
- the spatial relation between light source, object, and camera.

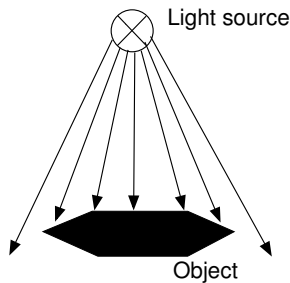
Similar to the reflection properties of object surfaces, light sources can produce light that is limited to specific directions or light that emanates into different directions. We differentiate between

- directed light and
- diffuse light.

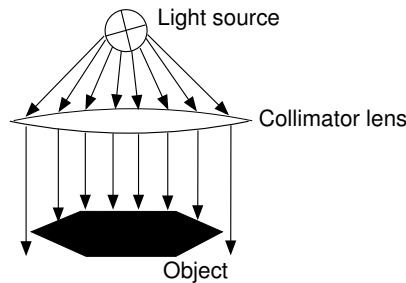
Directed light is described by rays of light following a defined direction. This may be a single point light that emanates concentric light when placed near the object and almost parallel light when placed far away from the object (see [figure 23](#), left), but also a telecentric light for which the rays of light are adjusted into exactly parallel directions using a collimator lens (see [figure 23](#), middle). As all rays of light come from and are reflected to similar directions, strong shadows and reflections may occur. For non-flat objects a telecentric light may be more suitable because a point light may lead to small perspective distortions. With a telecentric light the 2D outline of the object in the image corresponds to the cross-section of the 3D object and the size of the object in the image is independent of the distance between the camera and the object. But note that telecentric light is mainly suited for small objects as the light only hits the whole object to be measured if the object is smaller or the same size as the diameter of the lens.

Diffuse light scatters the rays of light, so that an object is lighted from several directions. That way, strong shadows and reflections on the object can be minimized. In [figure 23](#) the diffuse light is illustrated as a single point light source that is scattered into several rays of light with different directions using a diffuser. In practice, several diffuse light sources are placed at different positions, e.g., in form of a ring light, to disperse the light as much as possible.

Directed point light



Directed telecentric light



Diffuse light

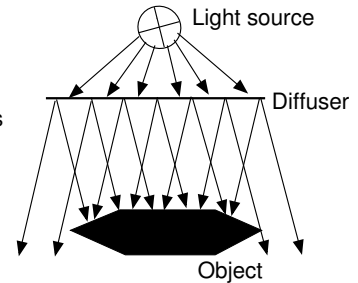


Figure 23: Directed and diffuse light: (left) point light, (middle) telecentric light, and (right) diffuse light.

Besides the propagation of the light waves seen from the light source, the direction of light seen from the object-camera unit has to be considered for a successful image analysis. [Figure 24](#) illustrates the different lighting methods. They are coarsely differentiated into

- front light and
- back light.

Front light is used for all objects for which the structure of the surface or any components on the surface are of interest, e.g., if scratches in the surface of an object are searched for or if several object parts are to be investigated, e.g., the different components of a board. Front light can be differentiated into

- lightfield lighting (including coaxial lighting) and

Front light

Back light

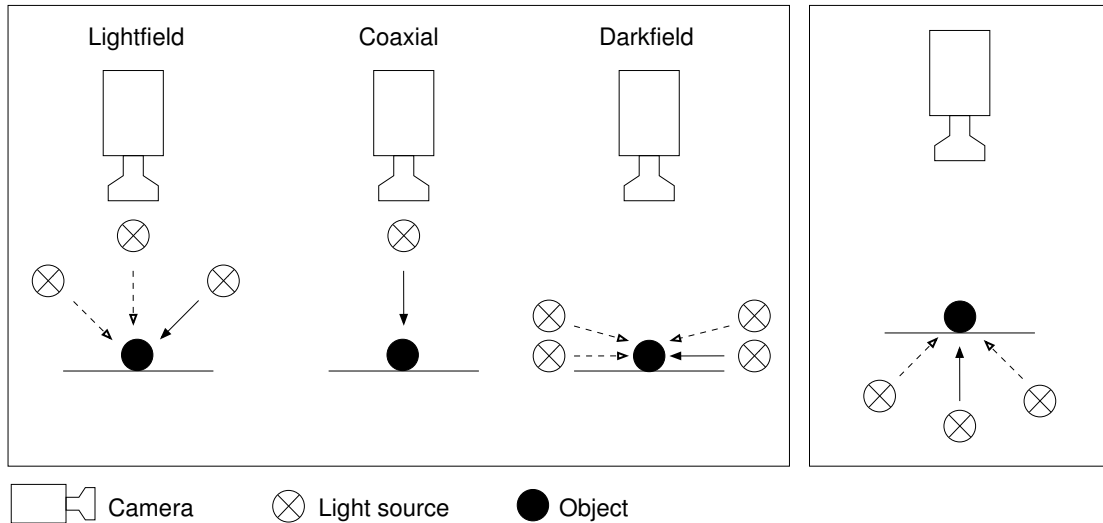


Figure 24: Light sources differentiated due to their spatial relation to object and camera.

- darkfield lighting.

With a lightfield lighting the light approximately hits the object surface in a right angle. A special case of a lightfield lighting is the coaxial lighting, which emanates directly from the direction of the camera lens. The light of a darkfield lighting comes from the side, i.e., it hits the object approximately parallel to its surface. Lightfield lighting is the standard lighting that is used for most applications in machine vision, whereas darkfield lighting is needed to highlight object parts that are not visible when lighted from above, e.g., relief structures in the object's surface.

Back light is used if the outer contour of the object gives the relevant information. The light source is placed behind the object and the object is mapped to the image as a homogeneous dark region against a light background. Opposite to images with widespread gray values, such a 'binary' image is rather easy to process.

Dependent on the object's surface and your specific task, you combine front or back light with a directed or diffuse light source. The list of light sources introduced here does not claim to be complete, but tries to convey to you a first impression on the complexity of the lighting task. To get more information about these and further light sources, e.g., also about polarized light or x-rays, we recommend to read more comprehensive literature with the specific focus on lighting.

## C.2 Geometry

The lighting conditions are important to obtain clearly visible objects in the image. To obtain geometrically correct images of the objects of interest, we additionally have to consider the geometrical conditions between the camera and the object of interest during the image acquisition. The geometrical correctness

of the object's representation in the image depends on various influences like the used equipment and the geometrical relation between the camera and the object plane. The geometrical distortions with the most influence are lense distortions and perspective distortions. These are described in detail in the Solution Guide III-C, [section 3.3](#) on page 54. There, you also get detailed information about the techniques to compensate both distortions, in particular using camera calibration and a following transformation of either the image, a contour, or a set of image points into world coordinates. The intention of this section is to give you the basic information about the relation between camera and object and thus help you to plan the right camera position for your specific task.

Two main concepts for the relation between the pose (position and orientation) of a camera and the pose of the object are relevant for measuring in an image:

- the orthogonal view and
- the oblique view.

In the orthogonal view the camera looks at the object plane at a right angle (see [figure 25](#), left). Thus, for a flat object and a normal lense the length of a line's representation in the image corresponds to the length of the corresponding real line multiplied by a unique scale factor. For non-flat objects, due to perspective distortions a normal lense may cause small distortions at the border of the object, dependent also on the position of the object in the image. These distortions can be avoided using a camera with a telecentric lense. In contrast to the telecentric lense used for directing the light rays of a telecentric light source, the telecentric lense of a camera does not send but receive parallel rays of light. But similar to the telecentric light, a telecentric lense in a camera is mainly suited for small objects as the whole object is only mapped completely in the image if the object is smaller or the same size as the diameter of the lense.

The oblique view is used if limited space does not allow for a setup with an orthogonal view. Here, the angle between the camera and the object plane can be arbitrary (see [figure 25](#), right). The oblique view leads to a perspectively distorted geometry of the image content. Thus, the length of a line in the image can not be translated directly to the length of the real object. A transformation is necessary that reconstructs the geometry of the orthogonal case. The parameters needed for the transformation can be obtained by calibrating the camera (see [Solution Guide III-C](#)).

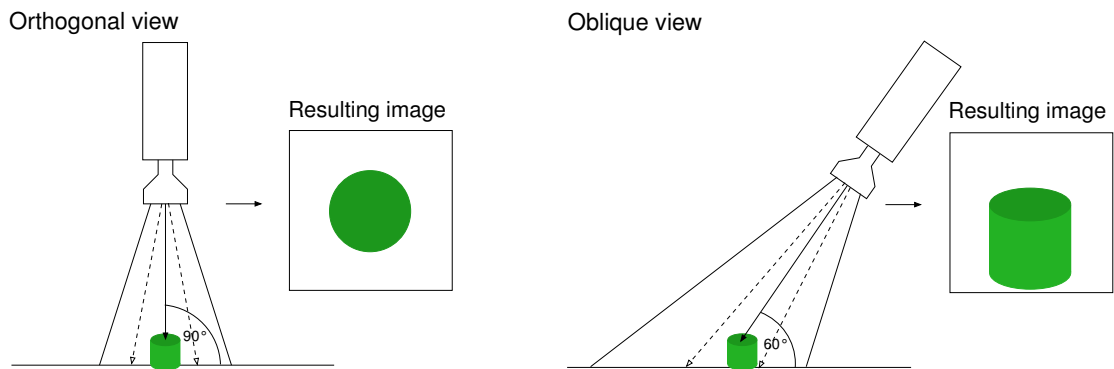


Figure 25: The two views on a plane: (left) orthogonal view and (right) oblique view.





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