

Synchronous and in Real Time: Operation of Multiple Cameras in a GigE Network

A variety of applications require images from multiple cameras to be captured in synchronicity. These can range from 3D triangulation tasks to sports and movement analyses to monitoring applications for conveyor belts. When photographing a shot on goal in soccer, for example, the images have to be captured without delays and at precisely defined times – namely, in real time. Other real time applications include robotics and Automatic Optical Inspection (AOI) tasks for quality assurance systems.

This white paper explains how multi-camera applications can take advantage of the functions inherent to the GigE Vision 2.0 standard to achieve synchronous image capture.

The groundwork is laid out in the Precision Time Protocol (PTP, IEEE1588). PTP establishes a network protocol for achieving precise time synchronicity across multiple devices on a computer network.

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1. What are the Requirements for Image Capture?

To achieve synchronicity or real-time behavior, image acquisition is typically triggered via a digital signal on a dedicated I/O port on the camera. In this setup, each camera must be wired with an extra cable equipped with

a suitable plug. This not only makes it more complex to install, it also costs more, especially if high-quality cables are required (such as those used in drag chain applications).

The current GigE Vision 2.0 standard provides simple alternatives for operating cameras in synchronicity and/or real time without extra cabling. Taking this progress a step further, many applications have now eliminated the need for extra hardware (the trigger box). In this scenario the cameras are triggered from within the software, including for synchronous operation.

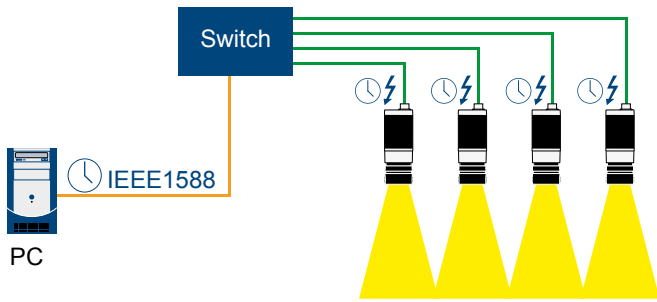
Key components of GigE Vision 2.0 are:

- A shared, high-precision source of time for all network components through PTP (Precision Time Protocol = IEEE 1588)
- Synchronous free run for the cameras
- Trigger-over-Ethernet with Action Command or Scheduled Action Command

The following provides a more precise definition of these functions and sample applications.

2. Network-based Time Synchronization: The Precision Time Protocol (PTP, IEEE 1588)

The Precision Time Protocol defines how network components (such as GigE Vision cameras) work with perfectly synchronized system times while connected to an Ethernet network.



Typical PTP-compatible network setup - All components have the same system time

Depending on whether the PTP-readiness of a given network component is implemented at the hardware or software level, PTP delivers a level of precision ranging from several microseconds to mere nanoseconds. A list of PTP implementations can be found at: http://en.wikipedia.org/wiki/List_of_PTP_implementations

3. Requirements for the Precision Time Protocol and its Functional Method

PTP-ready devices, including the cameras, are required for PTP to function within a network segment. PTP-compatibility in the switch is also desirable for optimized real-time handling. Where necessary, the PC must be equipped with a PTP-ready network card or must be running at least one software solution offering a PTP service. Be aware that software solutions offer less precision here than hardware solutions such as PTP-compliant network cards.

Once these conditions have been fulfilled, the collected PTP-compliant components first determine among themselves which of them has the most precise clock. The other components then all synchronize to meet that time mark, until all are working with precisely the same system time. More details can be found in the infobox.

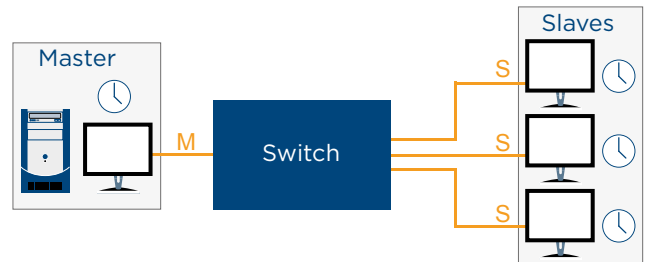
4. Cameras with Precise Time

The current Basler GigEVision cameras - such as those in the ace GigE camera family - implement the PTP service at the hardware level. As a result the cameras achieve synchronization of system times measured in mere nanoseconds.

The major benefit from this level of precision is extremely accurate time stamps appended to camera images as meta information. Camera events can also be annotated with these high-precision time stamps for assessment by real-time critical applications. If for example a motor speeding violation is detected, it is important to record the transgression by multiple cameras from different perspectives. A precise time stamp allows for convenient association of the individual images from the different devices.

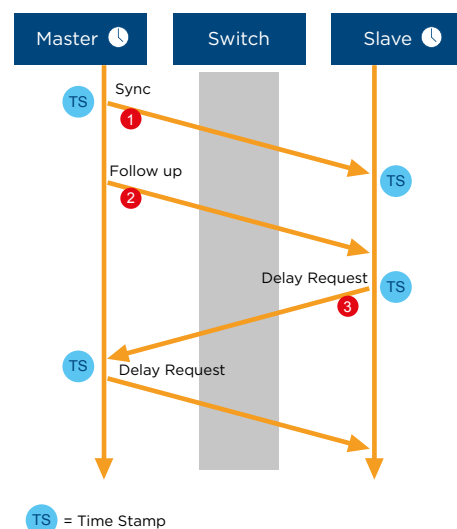
Functional method of PTP

PTP works with two types of clocks: master and slave. One clock in a terminal device is referred to as an ordinary clock, while a clock in a transfer component such as an Ethernet switch is designated as a boundary clock. One master, ideally controlled by wireless signal or GPS receiver, synchronizes all slave clocks connected to it.



Master and slave clocks

The synchronization process works in two steps. The first is a correction of the time difference between master and slave, known as the offset correction. The master sends a cyclical synchronization message - SYNC - with its best estimation of the time (as a time stamp) to the connected slave clocks. At the same time, the system is also measuring the time at which the message was sent to the greatest level of precision available. The master then sends the slave clocks a second follow-up message containing information about the actual, exact send time for the corresponding sync message. The slaves then measure the precise interval between receipt of the first message and the follow-up, using the result to define a corrective 'offset' from the master. The slave clock then adjusts itself to account for the offset.



Time synchronization using PTP

The second phase of the synchronization, known as delay measurement, determines the transit time between slave and master. Using a method similar to the first step, a delay request and a delay response message are sent to the slaves. The results are calculated and then used to adjust the clocks.

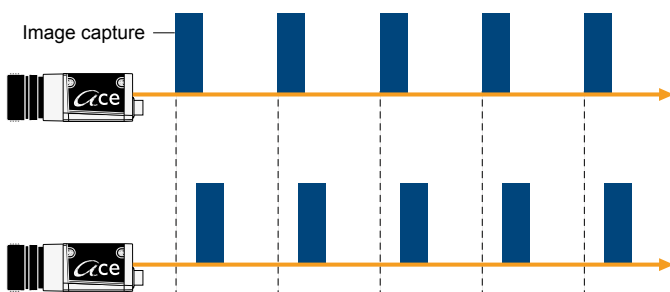
PTP Time Stamps

PTP Time Stamps are 80-bit labels. The time stamps used by GigE Vision cameras (such as in Image Chunks) are only 64 bits long. The GigE Vision 2.0 standard presumes that the 80-bit PTP value will be converted into 64-bit values. While this is theoretically a less powerful solution, there is no practical disadvantage: The 64-bit time stamps offer the same nanosecond levels of precision, but won't exceed their counting limit until Tuesday, November 04, 2262 at 11:47:16 PM GMT.

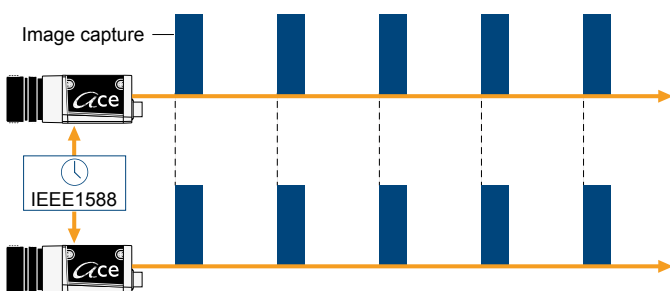
The Precision Time Protocol is a prerequisite for the “Synchronous Free Run” and “Scheduled Action Command” that will be explored next.

5. Synchronous Free Run: The Cameras Run Free – but in Synchronicity

Thanks to PTP, all cameras are working with the same system time, allowing all the cameras to run free – image capture by the individual cameras takes place at the same time for all linked cameras. In practical terms, certain applications may require images to be recorded simultaneously from multiple cameras at multiple perspectives, which is needed to generate a 360° view of a scene, for example. Synchronous image capture is crucial for this, although the individual images must later be associated along a time line. The shared time stamp described above makes this possible.



Without PTP: cameras run with the same frame rate: image capture occurs for each camera at a different moment in time.



With PTP: Cameras acquire their images in complete synchronicity.

6. Trigger-over-Ethernet with Action Commands: Synchronous Image Acquisition via Software Command

The current generation of Basler GigE Vision cameras can receive and react to what are known as Action Commands. An Action Command is an Ethernet packet that can be sent by a network client in broadcast mode to all recipients on a network.

The Three Key Parameters of the Action Command Feature

■ Device Key:

The Device Key acts as a ‘password’ for action commands. Each camera is configured in advance with its own Device Key, a freely selectable 32-bit value. The Device Key is write-only – it cannot be simply read out of the camera. Only Action Commands containing the appropriate key can trigger the event.

■ Group Key:

A freely selectable 32-bit value that serves as the actual identification of the Action Command. Each respective camera only executes an action if the Group Key matches both the protocol message and the Group Key for the camera.

■ Group Mask:

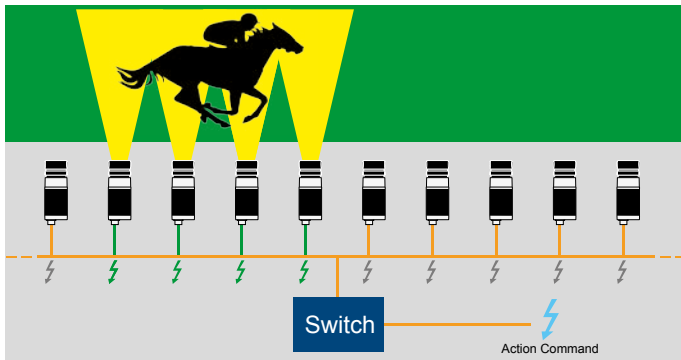
The connected cameras are always addressed by an Action Command together with the appropriate Device Key and Group Key. The Group Mask is a 32-bit mask used to specify a subset of cameras to actually carry out the command

The most important use case for the Action Command is certainly the trigger-over-Ethernet option. In the past, triggering multiple GigE cameras at the same time required a hardwired connection via the camera’s digital port, with a cable connecting each individual camera to a trigger generator. The Action Command makes it possible to trigger multiple cameras in sync via a single broadcast Ethernet packet. The Action Command involved does not initially require PTP functionality. The corresponding command can be triggered simply and easily at the software level, such as by using the Basler pylon Camera Software Suite.

7. Sample Application for the Action Command: Capturing Horses in Motion

One sample application for the action command feature would be an application using in video analysis of horses in motion. Imagine a racetrack with an array of cameras installed along the length of the track. The application calls for four adjacent cameras to film a horse as it runs. Because the acquired images from those four cameras

are to be melded into one single image, synchronous image acquisition is important. All cameras are configured with an identical Group Key, a necessary prerequisite for receipt of an Action Command (with a matching Device Key and identical Group Key). Above and beyond this, the Action Command also encompasses a group mask that ensures that only the four cameras positioned in front of the camera are actually capturing images at any given moment.



All cameras installed along the track receive the Action Command. The Group Mask ensures that only the four cameras positioned in front of the horse at that moment are actually acquire images at any given time.

8. Limits of Real Time Compatibility

It's naturally also possible for the cameras to be triggered from a software program (such as the Basler pylon Camera Software Suite). The difference between a "normal" software trigger and an Action Command comes in the fact that the Unicast-based software trigger is only sent to one single camera. The software trigger is incapable of broadcasting a synchronous trigger to multiple cameras at once.

While image acquisition can be performed in complete sync between the appropriately configured cameras, the reaction between the software-based triggering of the command and the start of image capture is not made in real time. The individual layers of the operating system and the hardware (PC and switches) between the software and network connection for the camera are subjected to a variety of unpredictable factors that impact timing. The result is that the latency between software commands and the start of image acquisition will fluctuate from image to image (known as jitter) - by as much as microseconds.

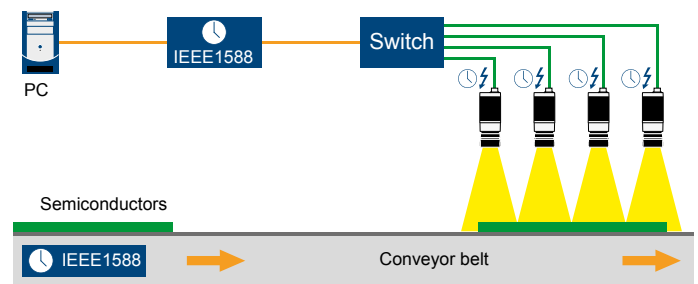
One alternative to software triggering of Action Commands: Special GigE network adapters or PC based machine vision systems (such as those made by National Instruments, IMAGO and others) that send the Action Commands. This is generally handled through a special signal created at the digital input for these devices. This setup avoids the jitter mentioned above and the system reacts in real time.

9. Precision through Pre-Warning: wthe Scheduled Action Command

A software-initiated action command has an ace up its sleeve: A supplemental but special PTP time stamp that specifies a system time at which the Action Command should be performed. An Action Command issued in this way is known as a Scheduled Action Command. It is helpful in re-establishing real-time behavior in a pure software solution. If for example it is known that the maximum delay time between the dispatch of the command from the software and start of image acquisition totals <200 ms, then a PTP time stamp can be selected in the scheduled action command to compensate in all cases for that maximum possible delay.

10. Sample Application for the Scheduled Action Command: Semiconductor Inspections

Semiconductors are transported on a conveyor belt at a uniform speed. They will pass below a series of four cameras installed for inspection purposes. These cameras are positioned directly adjacent to one another and perpendicular to the conveyor belt. Each camera is to acquire an image of the semiconductors at the same precise moment, namely as the semiconductor passes below the cameras' location. Because the individual camera images will then be merged into one single image, it's important that the cameras really do acquire the image at precisely the same moment.



Thanks to PTP, all components are working with the same highly precise system time. The PC can use the Scheduled Action Command to tell the cameras that the next image acquisition cycle must come at a specific time. The camera then capture an image at precisely that moment - latency and jitter are rendered irrelevant.

Let's presume that in this semiconductor example tests have established that the latency between the initiation of the command by the software and the start of the (simultaneous) acquisition of images by the cameras does not exceed 150 ms. Because the speed of the conveyor belt is known and the PTP-compatible conveyor belt is working with the same system time as the PC and cameras, the conveyor belt's control unit can inform the PC software when the next image capture event should occur. The PC then sends a corresponding scheduled action command no less than 150 ms prior to the required image capture time. The image is acquired in perfect sync, down to several microseconds.

11. Summary

GigE Vision 2.0 enables new camera functions based on the Precision Time Protocol (PTP, IEEE 1588): All cameras in a network can synchronize to work with the same precise time, which in turn allows for highly precise time stamps on captured images.

The use of identical system times allows for free running cameras to perform image acquisition in absolute synchronicity.

The Action Command (which, strictly speaking, does not require PTP) allows for cameras to be triggered to take a picture at the same time via a single broadcast software command. Latency, or the delay between the triggering of the command and the actual image capture, can make the process unpredictable.

The additional of a PTP time stamp turns a standard action command into a Scheduled Action Command. The time stamp informs that camera about when it should perform image acquisition. Unlike the simple Action Command, the time for the next image acquisition event can be precisely ordered, compensating for the latency between the triggering of the command in the software and the actual image acquisition.



Author

Frank Karstens
Produktmanager

Product Manager Frank Karstens joined Basler in 2005.

Karstens, who holds a degree in Communications Engineering, initially worked in product support for industrial cameras and camera software.

In 2008 he switched to Basler's IP team, where he assumed responsibility for product support and technical support for software partners.

He assumed responsibility for strategic product management for camera software and camera firmware in 2011.

Contact

Frank Karstens – Produktmanager

Tel. +49 4102 463 492
Fax +49 4102 463 46492
E-Mail: frank.karstens@baslerweb.com

Basler AG
An der Strusbek 60-62
22926 Ahrensburg
Germany

Basler AG

Basler is a leading global manufacturer of digital cameras for industrial and retail applications, medical devices, and traffic systems. Product designs are driven by industry requirements and offer easy integration, compact size, excellent image quality, and a very strong price/performance ratio. Founded in 1988, Basler has more than 25 years of experience in vision technologies. The company employs 500 people at its headquarters in Ahrensburg, Germany, as well as in international subsidiaries and offices in Europe, Asia, and the Americas.

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Basler AG
Germany, Headquarters
Tel. +49 4102 463 500
Fax +49 4102 463 599
sales.europe@baslerweb.com
www.baslerweb.com

Basler, Inc.
USA
Tel. +1 610 280 0171
Fax +1 610 280 7608
sales.usa@baslerweb.com

Basler Asia Pte Ltd.
Singapore
Tel. +65 6367 1355
Fax +65 6367 1255
sales.asia@baslerweb.com

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