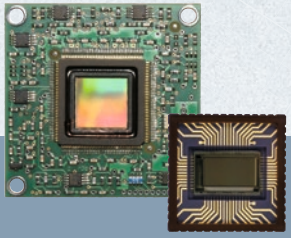
APPLICATIONS

CMOS Sensors
CMOS Cameras/OEM-Modules
Cameras for Machine Vision
Color & Monochrome
LinLog® CMOS Sensor Technology



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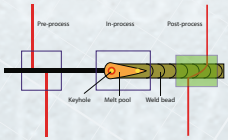

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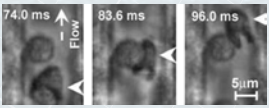

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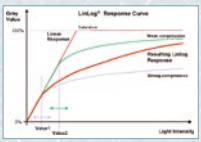
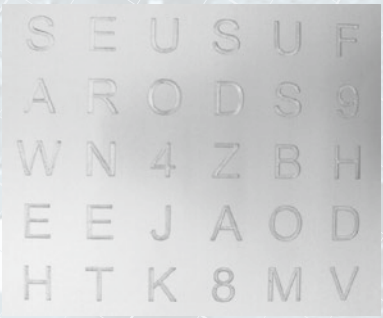
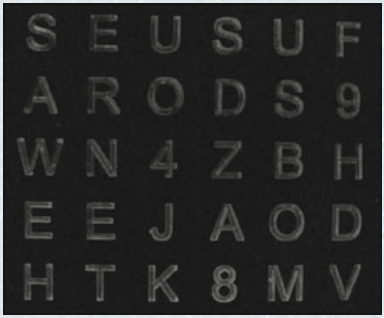


ACCELERATING OPTICAL CHARACTER RECOGNITION

A large number of workpieces in industrial production processes carry codes and IDs that have been engraved or pressed in to the body of the workpiece, in order to allow individual components to be identified, handled and traced throughout the system. The use of optical character recognition (OCR) techniques on highly reflective surfaces is a particularly difficult and time-consuming process. One reason for this is that the text is not sufficiently "visible", significantly limiting the speed of recognition of many OCR techniques.

At the same time, the image processing steps required before recognition can be performed by common OCR processes take up a considerable proportion of the available processor (CPU) capacity. A lack of CPU capacity is a further limiting factor when it comes to dealing with the high frame rates that can be provided by high-speed cameras. By using CMOS cameras equipped with a Pixel Professor module, the capture of IDs and codes can be automated and the recognition of characters can be accelerated.





Figures 1 & 2: Example showing local contrast enhancement by the Pixel Professor. A local contrast operator (5 x 5) has been applied to the original image (left) so that areas of the image with high contrast appear bright and those with low contrast appear dark.

With its integrated Pixel Professor, the Photonfocus camera accomplishes two tasks at the same time. Firstly, it delivers overexposure-free images captured in LinLog® mode, and secondly it submits the images directly to the Pixel Professor for image pre-processing. The pre-processed binary image is then passed on to the computer, where finally the OCR software is executed.

The Pixel Professor allows you to achieve a far higher frame rate in comparison with standard image-processing systems for text recognition that implement OCR exclusively in software. The use of additional camera features to optimise image quality, such as LinLog® or Multiple Regions of Interest (MROI), is not restricted by the use of the Pixel Professor. In fact, the Pixel Professor technology is optimised for use with CMOS camera technology. The new Pixel Professor camera range MV-D1024E-PP01 is suited for use in such applications.

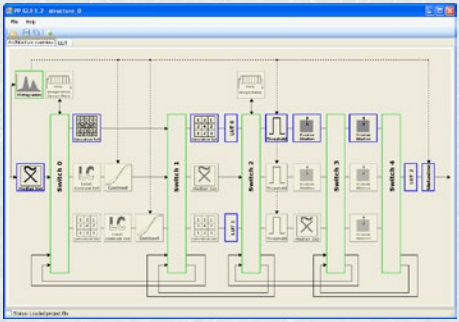


Figure 3: Screenshot of the Pixel Professor configuration utility.

With Pixel Professor technology, image information can be pre-processed in the camera in real time. Depending on the configuration, this allows the image throughput of the OCR software to be increased by a factor of between 10 and 20. By implementing additional filters in the algorithm, segmentation can be improved, which contributes to a further increase in overall character recognition performance.

The properties of the MV-D1024E range of cameras are complemented by the Pixel Professor's pre-processing stages, in which the following operations are implemented: Two-dimensional convolvers with filter matrix (3x3, 5x5, 7x7 or larger), non-linear filters (median, etc.), histogram, morphological operations (such as erosion and dilation), look-up tables (LUT), image buffers, image arithmetic, colour-space conversion, triangulation, histogram calculation for adaptive control of contrast enhancement and threshold levels.

Working with the Pixel Professor functions does not require any special FGPA programming expertise. A user-friendly GUI allows easy operation, and is equipped with a fast preview function to assist in configuring the module.

3D MEASUREMENT WITH STRIPE PROJECTION

Optical 3D measurement processes based on the stripe projection principle allow non-contact, material-independent capture and digitization of component contours in three dimensions. In contrast to common mechanical procedures, optical procedures can be used to sense the topographic parameters of objects quickly and over a wide working area. Moreover, these techniques can be used to determine additional small-scale properties of objects, such as surface roughness.

In the case of 3D measurement using structured light, a source projects a pattern of light and dark stripes onto the area being measured, which the CMOS camera then records using the principles of triangulation. During this procedure, the camera is fixed in a tilted position at a defined angle to the axis of projection (figure 1). Any change to the stripe density and stripe shape can then be interpreted to represent the information on the 3D properties of the object being measured.

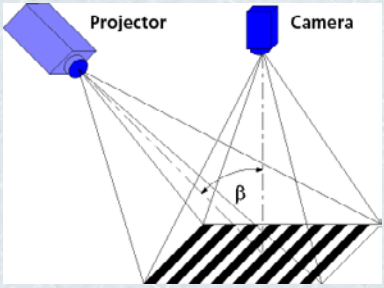


Figure 1: Triangulation principle in 3D measurement with stripe projection

Figure 2: Binary grey code (top) and cosine-shaped modulation (below) used to encode height data

In order to allocate the individual points on the measured solid to coordinates in space, the light-dark structured light stripes must be coded. This is done by overlaying a cosine-shaped intensity profile, along the principle of phase-shifting as used in interferometry. This produces an image record of a "wrapped" phase map, from which the topography can be derived using suitable algorithms in a "phase unwrapping" procedure. Stripe projection procedures are the tool of preference in medical and dental settings, but are also gaining in popularity in industrial applications, such as in the design process for new products (a form of reverse engineering). In particular, they are used in the automotive and aeronautical indus-

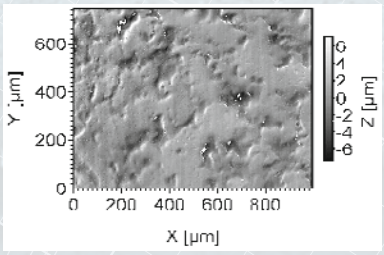


Figure 3: Topography of a chrome-plated steel sheet. Height data is greyscale encoded.

tries as a means of checking the shape of tools and work pieces, since the performance, reliability and speed of optical 3D measurement cannot be matched by existing tactile measurement methods.
This application requires a fast, high dynamic-range camera with a good MTF. Photonfocus CMOS image sensors fulfil all of these requirements excellently. Therefore, the CMOS cameras MV-D1024-80-CL-8 and MV-D1024-160-CL-8 are used to great advantage in such applications.

The following attributes characterise the camera:

- **Dynamic range**: High contrast resolution up to 120 dB with patented LinLog® technology.
- **Resolution**: 1024 x 1024 pixel with a pixel size of 10,6 µm x 10,6 µm.
- **ROI**: Region of Interest (ROI) and Multiple Region of Interest (MROI) allow selection of sub-areas with in a scene.
- **Shutter mode**: The Global shutter allows exposure times in the µs range for high speed applications.
- **Frame rate**: High frame rates from 75 up to 150 frames per second @ full resolution.
- **Dimensions**: Compact body of 55 x 55 x 46 mm^3
- **Interface**: CameraLink® base.

MV-D1024-80-CL-8

LEICA GEOSYSTEMS COORDINATE MEASUREMENT DEVICE

Coordinate measurement devices are used in many industries as standard in production and quality assurance, to determine the geometry of complex-shaped workpieces. Often, non-contact optical measurement techniques are replacing tactile procedures, allowing measurements to be made between 10 and 1000 times faster.

Using traditional techniques, theodolites and arms with multiple articulations were used to measure coordinates. However, these only permitted relatively measurement volumes.

When tracking technology was combined with the photogrammetric procedure, a measurement system was created that not only enabled the position of a measurement point to be determined, but also allowed the orientation of an arbitrary object in space to be determined. The technique is based on the combination of a high-speed camera installed on the laser tracker and a portable measurement device, which contains an array of diodes and a reflector. While the laser tracker establishes the exact position of the reflector, the camera determines the position of the diode array in the photogram, and computes the spatial orientation of the measurement device (T-probe) from this. With six degrees of freedom, the form and orientation of an arbitrary object in space can thus be measured in real time at a rate of more than 100 Hz.
The new optical system is compact and portable, allowing it to be transported easily to

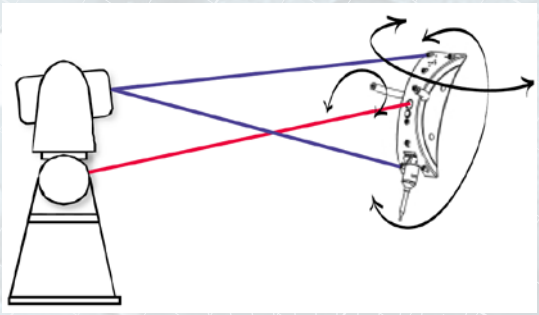


Figure 1: Principle of the LEICA Coordinate Measurement System with laser tracker (left) and T-probe (right).

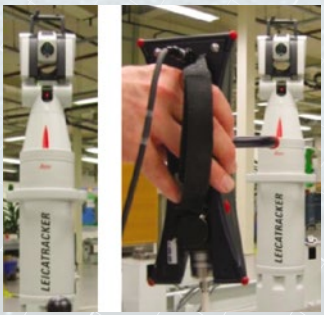


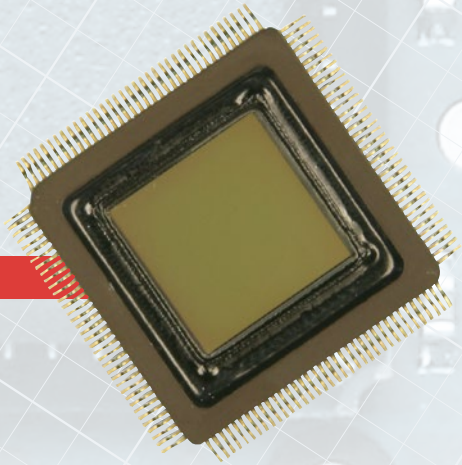
Figure 2: 3D coordinate measurement device ready for use in recording complex-shaped workpieces.

each work area and carry out the next geometric recording task. As a result, large time savings can be achieved in comparison with older measurement techniques, in which the work piece had to be brought to a static measurement system.
A further advantage is the increased measurement volume that can be achieved with this new system.

Due to the high application requirements, the Photonfocus A1024B CMOS sensor has been deployed in a custom camera module.

The following attributes characterise the sensor:

- **Dynamic range**: High contrast resolution up to 120 dB with patented LinLog® technology.
- **Resolution**: 1024 x 1024 pixel with a spartial resolution of 20 µm.
- **Frame rate**: Up to 120 frames per second @ full resolution.



Sensor A1024B

ANALYSING PROCESS INTERRUPTIONS

Figure 1: Faulty spring winding device.

Figure 2: Stemmer Imaging's analysis system with a Photonfocus CMOS camera.

When production lines in a factory are fully automated, any interruptions to the production process must be analysed quickly. The shorter the time needed to investigate the fault, the lower any financial losses that are incurred before production can restart.

A Swiss company, Feller AG, produces a highly diverse range of materials for electrical installations. With rapid changes in the products being requested, and having to meet short delivery lead times, the assembly robots must be retooled frequently. Under such production conditions, production can sometimes be interrupted due to minimal deviations in the production of individual components. Since the human eye is often unable to determine faults in the production process due to the speed of production, Feller AG uses a portable imaging system with a fast Photonfocus VGA camera for failure analysis.

The analysis system, developed by Stemmer Imaging, uses the MV-D640-66-CL-10 camera. The size of the camera, its high dynamic range characteristics and its speed are very well suited for such a role.

The system is used whenever production is interrupted due to a fault (see figure 2). With an acquisition rate of up to 200 images per second, the causes of the fault can be investigated in detail. The images are written to a ring buffer with a 10 second capacity.
As soon as a fault occurs and the alarm is triggered, the system stops recording new

images to allow the images from the previous 10 seconds to be examined. The flexible trigger options of the system also allow images to be recorded for a period of 5 seconds before and after the fault occurs.

When a fault occurred in a spring winding machine at Feller AG (see figure 1), the analysis system enabled the problem to be located within a matter of minutes and then corrected. The rapid installation and ease of use of the system are a decisive advantage.

The system can be quickly understood by non-experts and, thanks to the camera from Photonfocus and modules from Stemmer Imaging, faults can be quickly investigated and fixed. This allows Feller AG to operate a mass production system without high additional costs, even in the high labour cost environment of Switzerland.

The following attributes characterise the camera:

- **Resolution**: 640 x 480 pixel (VGA).
- **Frame rate**: Up to 200 frames per second @ full resolution.
- **Colour format**: Colour or monochrome.
- **Interface**: CameraLink® base and USB 2.0.

MV-D640-66-CL-10

PROCESS MONITORING WITH COAXIAL CMOS CAMERAS

Process monitoring in laser welding is gaining in importance in the production of components for the automotive industry. As a means of further reducing the rate of rejection, the widely-used before-and-after inspection of weld seams is increasingly being complemented by the introduction of on-line process control during the laser welding step itself. The German research institute Forschungsgesellschaft für Strahlwerkzeuge mbH FGSW, as part of the "ACES" project supported by the Baden-Württemberg state foundation (Landesstiftung Baden-Württemberg), carried out one such project. In their work, process monitoring using a coaxially-mounted CMOS camera was investigated in depth. For the ACES project, a camera was required by Forschungsgesellschaft für Strahlwerkzeuge mbH FGSW that had good sensitivity in the near infrared (NIR) range and that had already proven its value in welding applications. In addition, the image processing system would have to be capable of processing frame rates of 1 kHz, so that, at a later date, a control variable could be derived from the results of the automatic analysis for on-line process control. The final choice was made for the Photonfocus MV-D1024E-160 CMOS camera, which had already been used successfully in a number of welding projects. The test bench comprised a 6 kW disk laser, linked to a 2D optical scanner unit with a focal length of 450mm. The focal spot diameter was 600 µm. The laser welding process was observed coaxially through the scanner at a scale of 0.31. The optical setup can be seen in figure 1. The MV-D1024E-160 camera was opera-

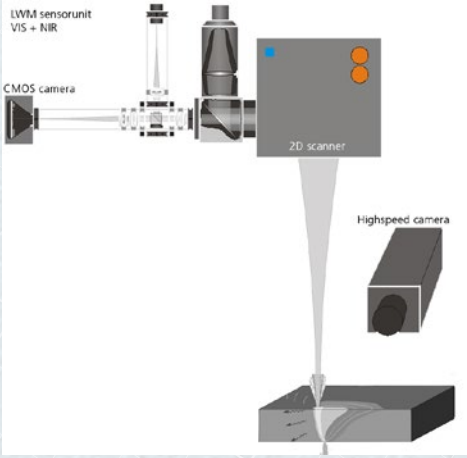
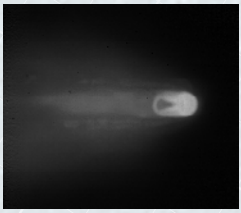
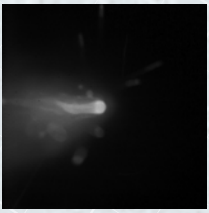


Figure 1 (top): Optical setup with coaxial CMOS camera.
Figure 2 (bottom right): Galvanised steel plate, 5 kW laser power, 9 m/min feed
Figure 3 (bottom left): Galvanised steel plate, 6 kW laser power, 11 m/min feed





ted with a ROI of 324x324 pixels and an exposure time of 0.25 ms.
This resulted in an image rate of 1 kHz. For the purposes of monitoring, the thermal glow was used at a wavelength of 905 nm. The melt-pool did not require additional illumination, since the lower grey levels in the image were enhanced by using the skimming feature of the camera.

The weld tests were conducted using 2 x 0.7 mm galvanised steel plates with a lap joint. Figure 2 shows the situation during coaxial observation of the welding process. The keyhole (on the right) and the melt-pool (left) are clearly visible. The black area behind the keyhole is caused by a fault in welding (root penetration).

Figure 3 clearly shows a melt ejection that comes about due to the increased laser power and feed speed compared with figure 2. With this test bench, the project was able to show that process monitoring using a coaxial CMOS camera is possible. The Photonfocus MV-D1024E-160 CMOS camera was selected for its high dynamic range, very good sensitivity in the NIR range and its high frame rate, which was achieved by a suitable selection of the region of interest (ROI).

The following attributes characterise the camera:

- **Dynamic range**: High contrast resolution up to 120 dB with patented LinLog® technology.
- **Resolution**: 1024 x 1024 pixel with a pixel size of 10,6 µm x 10,6 µm.
- **Frame rate**: Up to 150 frames per second @ full resolution.
- **Shutter mode**: Global shutter for high speed applications with minimum exposure time of 10 µs.
- **Dimensions**: Compact body of 55 x 55 x 46 mm^3.
- **Interface**: CameraLink® base.

MV-D1024E-160

PROCESS MONITORING FOR LASER WELDING

The INESS project (Integration of optical measurement techniques for laser welding process control) focuses on development of an integrated process monitoring system for laser beam welding using solid-state lasers.

Various commercial process monitoring systems for laser beam welding already exist, based on various different methodologies. The motivation to develop a new method for process monitoring was founded in the growing use of laser beam welding in industrial manufacturing settings. Alongside 100% quality monitoring, a reliable control strategy for process optimisation and innovative process monitoring should combine to increase profitability.

The innovative feature of the system that was realised is its combination of pre-process, in-process and post-process observation within a compact construction. The small dimensions were achieved by using a CMOS camera that was able to record and evaluate all three process steps at the same time.

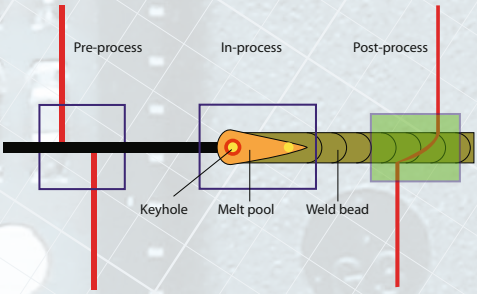


Figure 1: Schematic diagram of the welding process with pre-process, in-process and post-process observation.

Figure 2: Simultaneous image acquisition before, during and after the laser welding process of a component.

Pre-process: Using a light-section (triangulation) procedure, the lap geometry of the work piece can be verified first. This allows the beam position in relation to the work piece to be corrected immediately before the weld process.

In-process: The images taken of the melting bath and capillary geometry are evaluated and used for correlation analysis of welding parameters and defects.

Post-process: During post-process observation, a light-section (triangulation) procedure is used to inspect the weld bead.

This system facilitates a process monitoring procedure that incorporates a high spatial resolution at high processing speeds. During the evaluation phase,

the functionality of the monitoring system was demonstrated in welding of real components.
Due to the demands of the application, the Photonfocus MV-1024-TrackCam CMOS camera was used.

CMOS cameras are used by preference in weld process monitoring applications. The CMOS cameras from Photonfocus have a very high dynamic range, thanks to the LinLog® technology. In addition, and in contrast to CCDs, the regions of interest (ROIs) that can be defined for CMOS cameras prove to be an important feature to allow various areas of an image to be defined, thus allowing image capture to be performed at higher frame rates.

The following attributes characterise the camera:

- **Dynamic range**: High contrast resolution up to 120 dB with patented LinLog® technology.
- **Resolution**: 1024 x 1024 pixel with a spartial resolution of 20 µm.
- **ROI**: Region of Interest (ROI) and Multiple Region of Interest (MROI) allow selection of sub-areas with in a scene.
- **Configuration**: Rapid modification of the most important camera settings.
- **Frame rate**: Up to 75 frame per second @ full resolution.
- **Global Shutter**: No motion artefacts, no ghost images due to Global shutter.
- **Vision System:** Operating under Linux OS.
- **Dimensions**: Compact body of 55 x 55 x 46 mm^3.
- **Interface**: CameraLink® base.

MV-D1024-TrackCam

WELD-SEAM INSPECTION IN THE AUTOMOTIVE INDUSTRY

In modern chassis production facilities in the automotive industry, the traditional techniques of spot welding have been replaced by laser joining techniques, in which prefabricated sheets (called tailored blanks) are joined using laser welding and soldering / brazing processes.

The high demands of the automotive industry in terms of quality call for extraordinarily strict and consistent monitoring and documentation of lasered joints.

This challenge has been met by an automated inspection system that can inspect 100% of the laser joint. Weld defects are detected using a combination of laser triangulation (3D) and greyscale analysis (2D) in three parallel procedures: 3D profile analysis, 2D weld structure analysis (weld texture analysis) and 2D pore analysis.

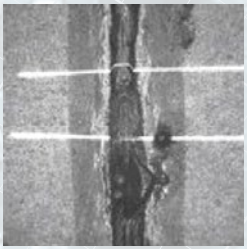


Figure 1: Greyscale image for texture analysis of a lap weld with explusion and spatter. The LinLog technology allows the two laser lines to be recorded at the same time without overexposure.

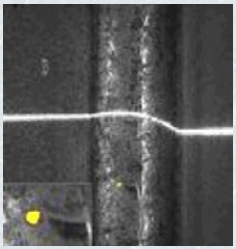


Figure 3: Sensor head consisting of a CMOS camera, laser line generator and flash ring light.

Figure 2: 3D/2D analysis of a lasered joint. The pores detected here have a diameter or 100 µm.

The inspection system has shortened reaction times and has simultaneously contributed to increasing the safety of processes. The objective, automated system meets the high quality standards of the German automotive industry. It also provides an efficient method of documenting the audit trail for tested joints, thus improving the profitability of the chassis production.

Due to the demands of the application, the Photonfocus MV-D1024-80-CL-8 CMOS camera was used.

With the patented LinLog® technology, the camera allows the laser line from the triangulation procedure to be captured while simultaneously recording the greyscale image for pore analysis.

The following attributes characterise the camera:

- **Dynamic range**: High contrast resolution up to 120 dB with patented LinLog® technology.
- **Resolution**: 1024 x 1024 Pixel with a spartial resolution of 20 µm.
- **Frame rate**: High inspection speed of up to 30 m/min due to high frame rates up to 75 frames per second and short exposure times.
- **Dimensions**: Compact body of 55 x 55 x 46 mm^3.
- **Interface**: CameraLink® base.

MV-D1024-80-CL-8

DETECTING PORES IN WELD SEAMS

Quality control is increasing in importance in automated tungsten-inert-gas welding (TIG) processes. Faults, such as pores, in weld seams can cause components to break under high load. Image processing systems are used in welding systems not just for the purposes of quality control, but also to document and improve the process.
In automated TIG welding systems, visual and manual inspection of finished components is much too slow and costly. In addition, the inspection requires an optical resolution of around 10 µm, in order to be able to reliably detect defects in the 50 µm range. If a visual inspection is made, optical aids such as magnifying glasses or microscopes must be used. With these conditions in mind, a high-resolution image processing system is needed for the purposes of quality control. In order to allow inspection to keep pace with component production cycles, the speed requirements for the visual inspection system are also high.
The Swiss company Soutec, based in Neftenbach, has developed its Souvis 5000 inspection system for quality control of weld seams. Depending on the application and measurement head, it can reliably detect defects down to 50 µm at inspection speeds of up to 30 m/min. The inspection system comprises a combined 2D/3D procedure. The measurement heads integrate MV-D1024E-80 CMOS cameras from Photonfocus (see figure 3).

Figure 1: TIG weld seam with weld defect.

Figure 2: Visualisation of the result in the graphical user interface of the Souvis 5000 inspection system.

Figure 3: Souvis 5000 macro measurement head.

In order to cope with the high image-processing speeds demanded by this application, an image processing system was designed, based on the QNX real-time operating system. A particular advantage of the Photonfocus cameras in this respect is the fact the accompanying PFRemote2.0 camera software provides a camera-control software utility that is not tied to any specific operating system.

In order to inspect the components directly after welding, the measurement heads of the Souvis 5000 inspection system are mounted on a robot that can follow the weld seam quickly and precisely. Photonfocus Digipeater modules are used as CameraLink repeaters to ensure data is transferred reliably from the robot to the control system.

The most suitable camera for this application is the MV-D1024E-80. With a frame rate of 75 fps and megapixel resolution, this camera can allow inspection speeds of up to 30 m/min to be achieved. The 2D/3D inspection procedure uses the linear/logarithmic sensor characteristics of the Photonfocus LinLog® technology. The 2D inspection is performed on data in the linear range of the transfer characteristic, while the 3D inspection uses laser triangulation in the logarithmic response range.

The following attributes characterise the camera:

- **Dynamic range**: High contrast resolution up to 120 dB with patented LinLog® technology.
- **Resolution**: 1024 x 1024 pixel with a spartial resolution of 20 µm.
- **Frame rate**: High inspection speed of up to 30 m/min due to high frame rates up to 75 frames per second and short exposure times.
- **Dimensions**: Compact body of 55 x 55 x 46 mm³.
- **Interface**: CameraLink® base.

MV-D1024E-80

TRAFFIC MONITORING IN TUNNELS AND AT TRAFFIC HOTSPOTS

Figures 1 & 2: Tunnel entry zone image recorded with a Photonfocus monochrome camera in linear mode (top) and in LinLog® mode (bottom).

With the latest safety protocols, tunnel operators must be able to intervene as quickly as possible in the case of accidents or other incidents. This speed of response can only be ensured when the entire length of the tunnel, and its entry and exit zones, are subject to video surveillance with no blind spots. The primary aim is to avoid repetition of disasters such as those that occurred in the Mont Blanc and Gotthard tunnels, or at least to keep damage and casualties down to an absolute minimum.

Traditional technologies used for tunnel monitoring are only of limited applicability when it comes to complete automation. Frequently, the surveillance is performed by one or more employees, who must keep their eyes on a number of monitors at the same time.

Particularly problematic areas are the tunnel entry and exit zones, since these are subject to extreme variations in illumination according to the time of day and weather conditions. For such scenarios, high-performance cameras that can process very high levels of contrast are vital. Photonfocus cameras with LinLog technology are used in such applications, in order to monitor and document the critical observation areas around tunnel entrance and exit without interruption.

Figures 3 & 4: Monitoring the tunnel entrance zone from the inside (top) and the outside (below) using a colour CCD camera.

The flexible configuration options on these cameras enable fast adaptation of their working parameters such as exposure time, the linear/logarithmic sensor response, selective signal optimisation in dark areas of the image by skimming, the look-up table and the gamma function, to cope with changing conditions. This allows the same type of camera to be used simultaneously to monitor both the inside and outside of the tunnel.
With this technology, fewer cameras than were previously

required can now be used to continually monitor traffic both inside the tunnel and at entry and exit points. This surveillance technology is also used successfully at critical traffic intersections.

Both the MV-D1024E-40 camera with megapixel CMOS sensor and the MV-D752E-40 camera with CCIR CMOS sensor are well suited to the demands of tunnel surveillance. Both camera models are available with either a USB2.0 or CameraLink interface.

Both cameras offer LinLog® technology and can supply full-resolution frame rates of 37 fps (MV-D1024E-40) and 87 fps (MV-D752E-40).

The following attributes characterise the camera:

- **Dynamic range**: High contrast resolution up to 120 dB with patented LinLog® technology.
- **Resolution**: 1024 x 1024 pixel (MV-D1024E-40) and 752 x 582 pixel (MV-D752E-40).
- **Read-out mode**: Full frame and up to 16 Regions of Interest (ROI).
- **Frame rates**: Up to 37 frames per second (MV-D1024E-40) and 87 frames per second (MV-D752E-40).
- **Shutter mode**: Global shutter for high speed applications with minimum exposure time of 10 µs.
- **Interface**: USB2.0 or CameraLink®.

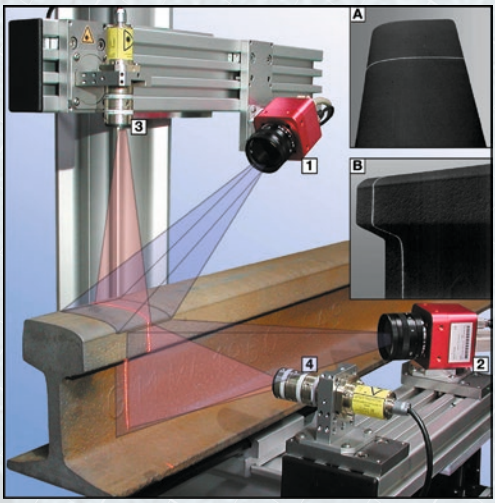
MV-D1024E-40

INSPECTION OF RAILWAY TRACKS

Among the most important considerations for trouble-free rail transport include the rail profile, the rail position, the track gauge, wear to the rails and subsidence of the track bed.

With the help of high-speed CMOS cameras and 3D laser measurement technology, rails can be inspected quickly and reliably, both during production in the rolling mill and using test wagons once the rails have been laid.

Quality control of rails requires the use of two cameras in combination with two laser line generators. The laser lines are projected from both above and to the side of the rails. The upper camera then records the profile of the running surface, while the second camera records the sideways path of the rail profile. The LinLog® technology allows triangulation of the rail profile to be accomplished without the problem of light saturation that occurs with highly varying degrees of reflection. At the same time, the greyscale images provide early warning of wear, such as chatter marks.



Inspection system for quality control of rails using 2 laser lines (3 and 4) and 2 CMOS cameras (1 and 2).
Image section [A]: Light-section image from the top camera [1] used to inspect the running surface (triangulation angle of 60° to the laser line generator [3]).
Image section [B]: Light-section image from the side-mounted camera [2] used to inspect the rail flank (triangulation angle of 45° to the laser line generator [4]).

The inspection system provides an extremely fast, fully automated method of recording defects on rails. This allows possible sources of disruptions in the rail system to be recognised at an early stage, so that repair measures can be initiated before faults actually occur.
During the inspection procedure, various relevant rail properties, such as the wear cha-

racteristics and erosion patterns can be both documented and analysed at the same time.

Due to the requirements of the application, the fast MV-D1024-160-CL-8 CMOS camera from Photonfocus is used, which supports full frame rates of up to 150 fps and triangulation rates of up to 2 kHz. With the help of the LinLog technology used by the image sensor, an extremely reliable triangulation can be achieved. In addition, the system allows simultaneous inspection of the rail surface using the greyscale images recorded in the lower grey level, linear response range.

The following attributes characterise the camera:

- **Dynamic range**: High contrast resolution up to 120 dB with patented LinLog® technology.
- **Resolution**: 1024 x 1024 pixel with a pixel size of 10,6 µm x 10,6 µm.
- **Frame rate**: Up to 150 frames per second @ full resolution.
- **Shutter mode**: Global shutter for high speed applications with minimum exposure time of 10 µs.
- **Dimensions**: Compact body of 55 x 55 x 46 mm^3.
- **Interface**: CameraLink®

MV-D1024-160-CL-8

REAL-TIME ANALYSIS OF THE WING BEATS OF A FRUIT FLY

The fruit fly, of the Drosophilidae family, is widely used by researchers due to its extremely short breeding cycle as a model organism for the study of classical genetics or for recording kinematic data.

From these studies of very small organisms, neuroscientists, nanotechnologists and biomechanics experts hope to gain in-depth knowledge of neurophysiological control processes, which could be useful in the design of microrobots.

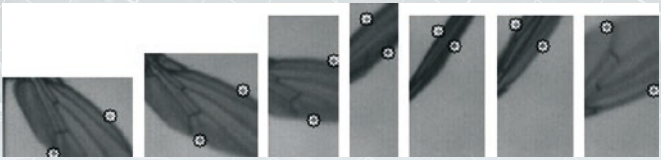
The real time analysis of Drosophila wing beats requires special high-speed cameras so that images can be quickly recorded and simultaneously processed. In order to analyse the kinematics of the wing beat it is sufficient to extract just the portion of the full image (figure 2) that contains information relevant to the wing movement. The recording of the wing movement is carried out by a CMOS camera, with which the observation window (region of interest) can be modified extremely quickly, in terms of its size and position.

« Figure 1: Model organisms for researchers: The Drosophila melanogaster fruit fly.

Figure 2: Analysis of the kinematics of flight from the wing beats of the fruit fly. »

With variable region of interest, the CMOS camera tracks the various positions of the wing (figure 3). The image processing system provides a high degree of flexibility for the complex study of neuromotor controls in small organisms. It can be used to great advantage in the experimental field of biomechanical research at micro and nano levels.

Figure 3: Various window sizes (regions of interest) used in the observation and tracing of the wing position. »



The real time analysis of the Drosophila wing beat was performed using the MV-D1024-TrackCam CMOS camera, which offers a high-speed configuration interface.

The following attributes characterise the camera:

- **Dynamic range**: Up to 120 dB with LinLog®.
- **Resolution**: 1024 x 1024 pixel with a pixel size of 10,6 µm x 10,6 µm.
- **ROI**: Region of Interest (ROI) and Multiple Regions of Interest (MROI).
- **Frame rate**: Up to 75 frames per second @ full resolution.
- **Global Shutter**: No motion artefacts, no ghost images due to Global shutter.
- **Configuration**: Fast modifications of the most important camera settings.
- **Skimming**: To enhance dark regions in the scene.
- **Dimensions**: Compact body of 55 x 55 x 46 mm^3.
- **Interface**: CameraLink® base standard with fast configuration interface (40 MBit/s) in connection with the microEnable III Fast Configuration (SILICONSOFTWARE GmbH) framegrabber.

MV-D1024-TrackCam

USING HIGH-SPEED CAMERAS TO QUANTIFY PLANKTON

The structure and function of biological systems can only be understood when sufficient data is available to describe the systems on, from the analysis of large statistical ensembles. In the field of oceanography, for example, plankton distributions play a major role in modelling the ecosystem. The optical and acoustic systems that are often used to measure plankton distribution have the disadvantage that they are unable to differentiate between particles and plankton. Researchers at the Southampton Oceanography Centre looked for a new solution, which was small enough, light enough and quick enough to be used in a SeaSoar. SeaSoars are underwater systems that are trailed along behind ships. Thanks to their modular construction, they can perform various investigations in the water. Since a SeaSoar is usually towed along at an average speed of 4 m/s, video plankton recorder systems are not usable, since they can only provide sharp images at a speed of up to 3 m/s, and have a very large footprint. Attempts to integrate these systems into SeaSoars have failed due to their construction and large mass.

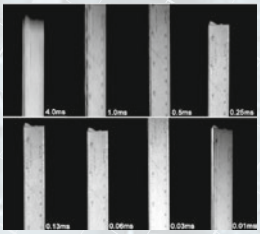


Figure 1: Accelerated scales.

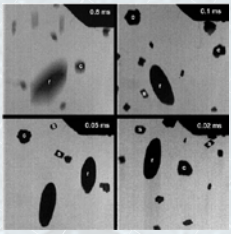


Figure 2: Backlit photograph.

Searching for a suitable alternative to traditional video plankton recorder systems, researchers came across the Photonfocus MV-D1024-80 CMOS camera. The studies were then carried out using this camera, thanks to the camera's optimum speed and size for the application.

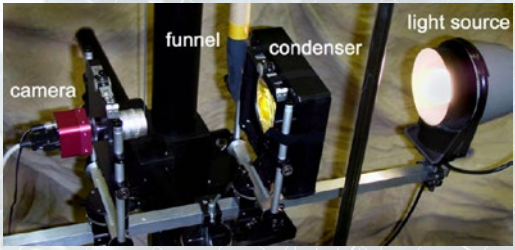


Figure 3: Test bench.

Lab tests were carried out to investigate the conditions in which the MV-D1024-80 CMOS camera can be used and the settings required. An important aspect of plankton quantification is that the images have minimum amounts of blurring, so that individual objects can be clearly identified.

The requirements were for a 6.6% degree of blur at an object size of 300 µm. The resolution demanded by the application was just 512 x 512 pixels, which allowed a frame rate of 300 fps to be taken. With moving graduated scales, the correct aperture and illumination times could be determined by experiment (see figure 1). During the tests, it was found that the fact that the scales were illuminated by studio spot lights represented a problem. Such a bright light source cannot be used under water. The challenge was solved by a backlight arrangement (see figure 3), in which the light source is directed directly at the camera. While this then only allows the outlines of the objects being investigated to be detected, it is sufficient to identify the different types of plankton with the required accuracy (see figure 2). Thanks to the Photonfocus MV-D1024-80 camera, the Southampton Oceanography Centre team was able to demonstrate the options for a fast, small plankton quantification system.

The Photonfocus camera was selected because it meets the speed requirements and its robust yet small construction allow it to be housed in a SeaSoar.

The following attributes characterise the camera:

- **Dynamic range**: High contrast resolution up to 120 dB with patented LinLog® technology.
- **Resolution**: 1024 x 1024 pixel with a pixel size of 10,6 µm x 10,6 µm.
- **Frame rate**: High inspection speed of up to 4 m/min due to high frame rates up to 75 frames per second and short exposure times.
- **Dimensions**: Compact body of 55 x 55 x 46 mm^3.
- **Interface**: CameraLink® base.

MV-D1024-80-CL-8

HIT THE BULL'S-EYE!

A research team from the Technical University of Munich, Germany (TU München) set itself the goal of developing an automated dartboard with a very unusual characteristic: while the dart was flying towards the board, the board should be moved precisely and accurately so that the dart would hit the centre of the board – at the bull's eye.

The average flight-time of a dart is around 250 ms. Therefore, the system would have to determine the coordinates of the dart's trajectory within 100 to 150 ms, in order for the movement mechanism to have enough time to react. This problem can only be solved using a very fast system of cameras.

In order to best capture the trajectory, two high-speed megapixel cameras from Photonfocus were used. One of the cameras records the trajectory of the dart from above, and the other from the side, in order to record movement in both the horizontal and vertical planes. This system allows the trajectory to be determined from just a few images in a sequential recording, with sufficient accuracy that the point of impact of the dart can be computed. During the remaining flight-time of the dart, the computer controls linear motors to move the dartboard so that the dart always hits the bull's eye.

Figure 1: Dartboard with its axis control.

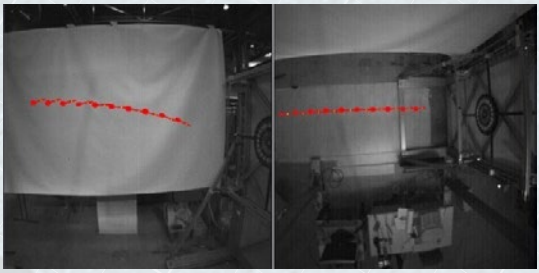


Figure 2: Evaluated flight images of the dart for both camera positions.

During the planning phase, the dartboard project was discussed in very sceptical terms. It seemed unrealistic that the trajectory of the dart could be captured sufficiently accurately within the short period of time, to allow computation and then movement of the dartboard to the correct position.

A significant contribution to the solution of this task was made by the high-speed MV-D1024-160-CL-8 cameras from Photonfocus. With the completion of the project, the capability of the entire system, comprising the high-speed cameras, a powerful evaluation computer and actuators was proven.

Due to the demands of the application, the fast Photonfocus MV-D1024-160-CL-8 CMOS camera was used.

The following attributes characterise the camera:

- **Dynamic range**: High contrast resolution up to 120 dB with patented LinLog® technology.
- **Resolution**: 1024 x 1024 pixel.
- **Frame rate**: Up to 150 frames per second @ full resolution.
- **Global Shutter**: Enables exposure times in the µs range.
- **Skimming**: To enhance dark regions in the scene.
- **Dimensions**: Compact body of 55 x 55 x 46 mm^3.
- **Interface**: CameraLink® base.

MV-D1024-160-CL-8

SIGNAL RECOGNITION IN ROAD TRAFFIC

Photonfocus cameras can be used for ensuring the safety of road traffic. While traffic monitoring in tunnels (see application report "Traffic monitoring in tunnels and at traffic hotspots") is able to increase safety with external controls, as this report demonstrates, drivers in road traffic can also be supported by driver-assistance systems. In order to control traffic nowadays, traffic signs are used. However, these are ineffectual if the driver does not recognise or take notice of them. In a study conducted by the Technical Highschool (Hochschule für Technik) in Rapperswil (HSR), students demonstrated how traffic signs could be detected and evaluated automatically, as well as showing the options offered by a signal-recognition system.

Figure 1: Typical road situation.

Figure 2: Road situation from figure 1 after evaluation with a Sobel filter.

A supportive signal-recognition system works in three stages. The first stage performs image capture, the second performs recognition and evaluation of traffic signs, and the third stage informs the driver of the maximum permitted speed, in the case of speed signals. The first stage requires the use of a camera that is able to take in the driver's field of vision, and supply images that are capable of being evaluated despite changing levels of brightness and at different speeds. Since these requirements are a perfect match for CMOS cameras, Photonfocus supported the project with a MV-D750E-20-U2 camera, which is based on the D750 sensor that has been certified for use in the automotive industry. The sensor has a wide VGA (WVGA) resolution of 750 x 400 pixels, which is optimized for recording road images. Thanks to the USB2.0 interface, the MV-D750E-20-U2 camera is easy to manage and can be used in prototypes in the development of driver-assistance systems.

The students developed a software analysis tool with the aid of a set of test images. This tool allowed the signs to be recognised and their information to be evaluated. In addition to the development of a signal recognition system, an analysis was undertaken of systems available on the market, to determine if similar systems were already in use in vehicles.
It was found that the automotive industry is currently pressing on with development of driver-assistance systems. Manufacturers are not simply concentrating on signal recogni-

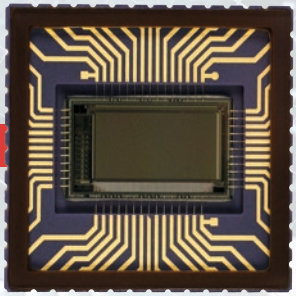
tion, but also on lane recognition, night-vision systems and parking aids. Photonfocus worked with AMIS to develop the D750 CMOS image sensor for these applications, which has been certified for use in the automotive industry and is used in sensor modules by various vehicle manufacturers.

Thanks to the CMOS technology, image sensors can be implemented in the form of powerful system-on-chip solutions (SoC). This allows highly integrated circuits containing the entire camera functionality to be developed for extremely price-sensitive in-car applications. With the Photonfocus LinLog® technology, extremely demanding illumination conditions such as direct light, fading, tunnel entrances and exits can be overcome. Moreover, the D750 image sensor works throughout the entire automotive temperature range from -40 to 105° C.

In the development of prototypes for driver-assistance systems, the MV-D750E-20-U2 camera is used successfully for evaluation. In the subsequent system solutions, the D750 image sensor will be fully integrated.

The following attributes characterise the sensor:

- **Resolution**: 750 x 400 pixel (Wide-VGA).
- **Dynamic range**: High contrast resolution up to 120 dB with patented LinLog® technology.
- **Temperature range:** From -40 °C up to 105 °C.
- **Technologie**: System-on-Chip solution (SoC).



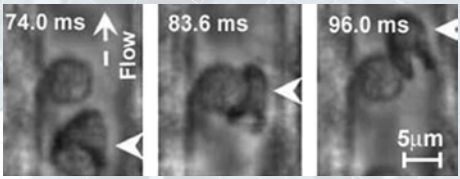
Bildsensor D750

BLOOD CELL DIAGNOSIS

In a newly developed in-vivo analysis method, blood diagnoses can be carried out, that allow conclusions to be drawn regarding blood transport functions and the interactions of blood cells with medicines, drugs or radiation. The findings of such studies can lead to the early recognition of illnesses, and help in the development of suitable therapies for treatment of these illnesses.

With current methods, such as flow cytometry, specific cell markers must be attached to blood cells to allow measurement of the extent to which the cells absorb and reflect the radiated light, and the level of fluorescence they emit. A team of researchers at Arkansas University selected a different technical approach for their investigations, in which the MV-D1024-160-CL-8 CMOS high-speed camera from Photonfocus was connected to a light microscope. This allowed selective investigation movement behaviour of the "faster" red blood cells (v = 5 – 10 mm/s) and the relatively "slower" white blood cells (v = 50 µm/s),

The read-out speed of the MV-D1024-160-CL CMOS camera is dependent on the selection of the region of interest (ROI). This allows the size of the ROI to be optimised in respect of the size and speed of movement of the blood cells to be investigated.



« *In-vivo investigations of the changes in shape of red blood cells at bottlenecks in a flow cell.*

Depending on the type of blood cells being analysed (erythrocytes, leukocytes and platelets), image sequences with up to 10,000 frames per second were recorded and analysed. The high-speed recordings revealed many enlightening details about the speed at which the red blood cells rush past the slower "rolling" leukocytes, and the extent to which they deform in the process.
For the first time, these in-vivo blood investigations allowed researchers to see at high temporal and spatial resolutions, that the red blood cells exhibit a very dynamic deforma-

tion when they move through narrow or geometrically irregular regions, or when they interact with other cells.

The in-vivo blood cell analysis used a MV-D1024-160-CL-8, since the size of the region of interest (ROI) is freely definable and the capture speed increases linearly with the reduction in the ROI in terms of its x and y dimensions. Both of these camera properties are ensured by the read-out architecture developed by Photonfocus for its CMOS image sensors, which is significantly different to the architecture used by competitors.

The following attributes characterise the camera:

- **Dynamic range**: Up to 120 dB with LinLog® technology.
- **Resolution**: 1024 x 1024 pixel.
- **ROI**: Region of Interest (ROI) and Multiple Region of Interest (MROI).
- **Shutter mode**: Global shutter with minimum exposure time of 10 µs.
- **Frame rate**: Global shutter with minimum exposure time of 10 µs.
- **Anschluss**: C-Mount.
- **Interface**: CameraLink® base.

MV-D1024-160-CL-8

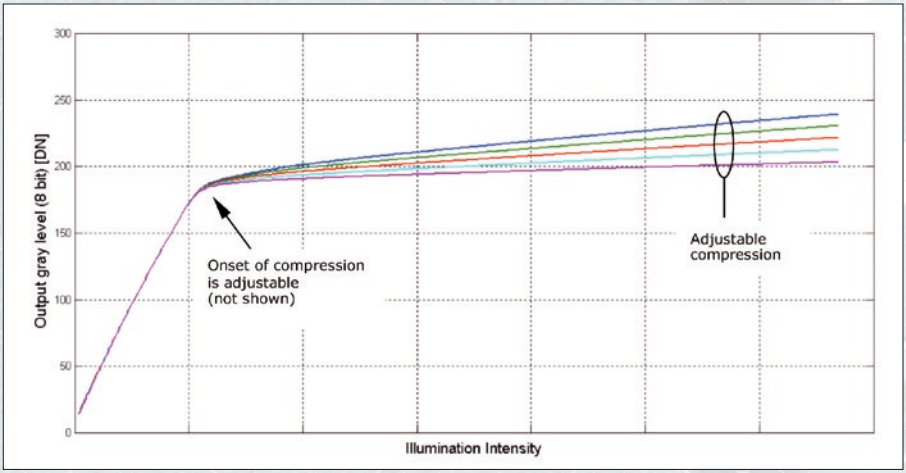
TECHNOLOGY

LinLog® Technology

Standard matrix sensors used in vision systems have a linear response curve. This means that the incident light intensity is translated into a proportional voltage output of the photo detector. Due to this fact, conventional CCD and CMOS sensors can only translate a limited intensity range into an output signal which is also influenced by the full well capacity, the signal to noise ratio and other parameters of the photo detector.

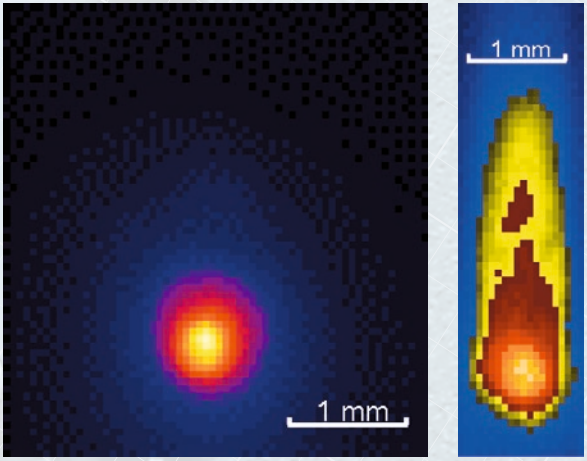
On the other hand, there exist vision systems which can handle much greater intensity ranges like that of the human vision system – the eye – or the photographic film. The response curve of the eye is logarithmic and we detect light over an intensity range of 180 dB or about 1,000,000,000:1. In the case of the photographic film, the S-curve and the Schwarzschild effect are well known. These effects prevent saturation in bright scenes, but there is also a threshold illumination necessary to trigger the development of a silver grain. Vision engineers look to such nonlinear detectors to solve the problems of applications like welding inspection, intrusion detection with strong back lights, etc.

Consequently the vision community was really excited as the first CMOS image sensors offering logarithmic response curves became available. But even these detectors suffer from several drawbacks. The three most important drawbacks are the absence of an electronic shutter, image lag and the temperature dependence of the output signal. The continuous conversion from incident light to an output signal in the logarithmic CMOS imager makes the capture of fast sequences impossible. Image lag, caused by a slow low-pass filter inside the continuous-time pixel circuit, limits the usage of such detectors in conditions where bright scenes are followed by low light conditions. Furthermore, the temperature dependence of the output signal makes calibrations and thermal stabilisation of these detectors essential.



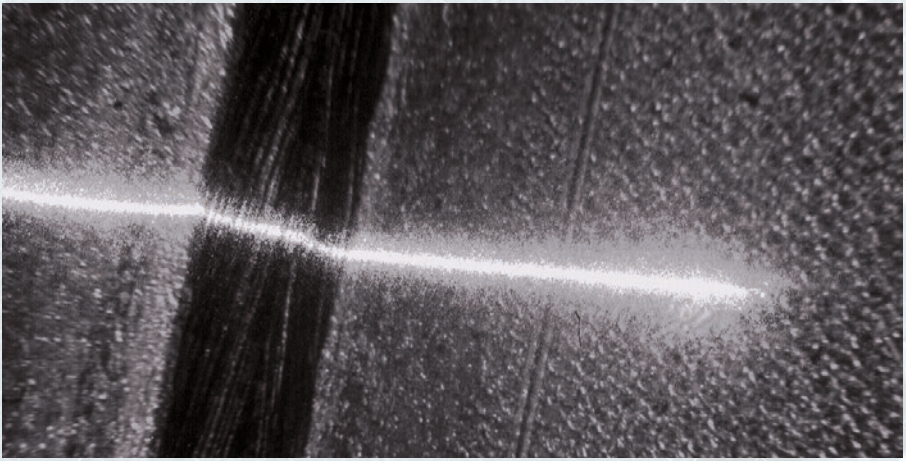
LinLog® response curve of the CMOS camera MV-D1024E at various LinLog® settings

Photonfocus offers the LinLog® technology which circumvents all of these drawbacks with a combined linear-logarithmic response curve. The pixel structure has a global shutter and allows high speed image capture due to a second independent reset of the storage node, which also eliminates image lag effects. In the low light region the response of the detector is linear. This gives a very good grey scale resolution in this range. High intensities are compressed due to the logarithmic properties of the pixel in bright conditions. The onset of the logarithmic compression and the strength of the compression can be adjusted with the help of several LinLog® parameters. These parameters can be adjusted by the customer in software, allowing an optimal adaption to the application. The figure above gives an insight into the possibilities to adjust the response curve offered by Photonfocus LinLog® cameras.



Pictures from laser welding: picture of the keyhole from a CCD camera (left) and a CMOS camera with LinLog® technology (right)

CMOS sensors and cameras with the LinLog® response curve are in use not only in standard applications but also in welding applications and laser triangulation. Here, the customer can adjust the response curve to extract additional information about the production process or for quality control / inspection.
The images from laser welding show a direct comparison between a CCD camera and a CMOS camera from Photonfocus. The melting pool behind the keyhole could not be resolved with the CCD camera. With a LinLog® CMOS camera the structure of the melting pool becomes visible. Alongside the high dynamic range of the CMOS camera, the frame rate for the inspection is also increased by read out of only a small region of interest (ROI). This made an effective process control with a frame rate of over 1 kHz possible.



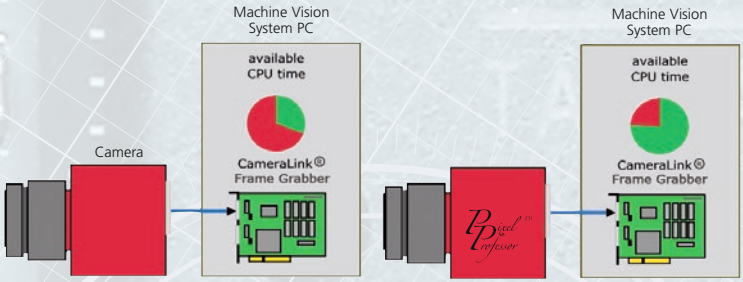
Combined 2-D/3-D inspection of a welding seam

Another example is laser triangulation combined with defect detection in the grey scale of the image. The image is taken from such a combined 2-D/3-D inspection. The structure of the welding seam and surrounding material is inspected in the linear region of the detector response curve. The laser line for the triangulation is captured in the logarithmic range. This enables a reliable detection of the line in bright regions where reflections from metal are strong and in more weakly reflecting zones of the welding seam without losing the laser line used for the profilometry.

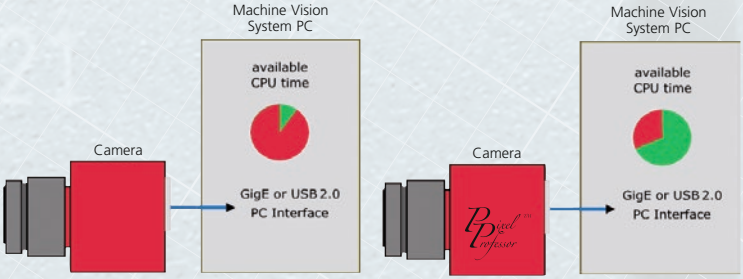
Further applications can be found on the Photonfocus home page:
http://www.photonfocus.com/

Pixel Professor™ Technology

With the Pixel Professor™ technology Photonfocus provides a high performance image pre-processing solution on camera. This enables the build up of machine vision systems with distributed intelligence. With the image pre-processing in the camera, the CPU load in the vision system can be reduced dramatically. As a consequence, the frame rate in an existing inspection system could be increased or, in the same processing time, more advanced algorithms could be used to process the image data leading to better inspection results. The technology is scalable and can be fitted to the customer's application. Alongside standard operators for pre-processing, user operators can be implemented on the hardware resources. Alternating frame capture setups can be realized with an embedded sequencer to achieve maximum frame rates. With the pre-processing hardware in the camera, reliance on specialized frame grabbers or other hardware accelerators is removed.

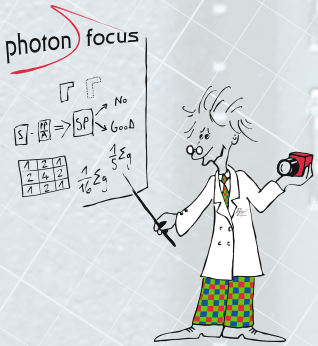


Even when using USB 2.0 and GigE interfaces, pre-processing on the camera increases the image data throughput. With these interfaces, there is no frame grabber needed and hence no frame grabber available to provide pre-processing hardware. With the Pixel Professor™ in the camera, pre-processed data are sent directly over the USB 2.0 or GigE interface, taking the load off the CPU.



The Pixel Professor™ technology supports common image pre-processing operations in pipelined processors such as:

- Two dimensional convolvers
  3 x 3 , 5 x 5 , 7 x 7 or more
- Nonlinear filters (Median etc.)
- Histogrammer
- Erosion and dilation
- Adaptive threshold
- Image buffer
- Image arithmetic
- Colour space conversion
- Look-Up Tables (LUT)
- Triangulation module



Benefits:

- Reduction of pre-processing time increases frame rate in the application
- Enhanced algorithms with same CPU-load compared to software image processing
- The Pixel Professor™ complements the superior features of CMOS cameras
- Real-time processing of up to 640 Megapixel per second (Mps)
- "Zero" latency

Quality control | Motion Analysis
Process control | Automotive
Welding | Medicine & Science
ITS & Security | Technology

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Address
Photonfocus AG
Bahnhofplatz 10
8853 Lachen
Schweiz

Telephone **main office** +41 (0)55 451 00 00

Fax **main office** +41 (0)55 451 00 01

Email **general** info@photonfocus.com
sales sales@photonfocus.com

Internet **website** www.photonfocus.com

For more information about our worldwide distributors please visit our website.