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**See what’s next.   
Camera system gives tunneling machines new sights**

*High resolution cameras mounted in the cutter head of a tunnel boring machine enable structural analysis and geological documentation of the drilling surface.*

Tunnel boring machines (TBMs) are increasingly being utilized in major projects such as the Brenner Base Tunnel in the Austrian Alps. Full face TBMs are mobile, electronically operated machines that pierce rock with a rotating drilling head, remove the muck, and, depending on the type of construction, secure the excavated tunnel with shotcrete, rock bolts and wire mesh or prefabricated segments of reinforced concrete. They allow for higher rates of advancement to be achieved compared to other excavation methods (e.g. blasting) and provide the workers with enhanced protection. Approximately 70% of the work on the Brenner Base Tunnel is completed by up to six TBMs simultaneously (see Brenner Basistunnel BBT SE, www.bbt-se.com/).

Despite the frequent use of TBMs, the geological documentation of the drilling face lies behind that of conventional tunnel drives mainly due to visibility restrictions. In conventional tunneling, geological mapping is usually performed by a geologist and is not impeded by an obstructed view to the face. However, in mechanized tunneling, the view to the face is obstructed by the cutter head. There are only a few openings through the cutter head, such as scrapers, cutting discs and manholes, which restrict the validity of the geological mapping of the face.

In collaboration with Geodata GmbH, the Institute for Subsurface Engineering of Montanuniversität in Leoben, Austria has developed a camera system for boring machines used in tunnel construction projects, which helps solve this issue. Allied Vision’s distribution partner and imaging technology provider Stemmer Imaging, located in Puchheim, Germany, also cooperated in the system’s development.

The camera system was developed during a current R&D project called TBMonitor. It was field-tested in a hard rock TBM drive of the Brenner Base Tunnel constructed by ARGE Tulfes Pfons, a bidding consortium of Strabag AG and Salini Impregilo S.p.A. Mounted in the disc housings, the camera system provides high resolution images and color-coded relief presentations of the entire face. Thus, mineral composition, spatial position of stratifications, and depth of cavities can be determined. This valuable information enables an assessment of the structural analysis and verification of the tendered geological model’s correctness, ensuring continuous tunnel boring free from disruption.

**Camera system**To expand coverage of the face area, the camera-based system was designed to be light and flexibly mounted in different disc housings. This enables TBMs without extra camera openings to be equipped with the camera system. After the completion of a TBM stroke, the cutter head must be retracted a few centimeters and the material between cutter head and face must be mucked out, preventing material from falling through the scrapers. This step is done for the working safety of the operator and to avoid damage to the camera system. The number of camera tracks can be adjusted to the distance between the retracted cutter head and the face. The camera system can be installed with a single camera or multiple cameras.

The camera unit encompasses a rugged camera designed to operate in extreme environments and fluctuating lighting conditions, paired with a 5 mm fixed focal length lens. Allied Vision’s Prosilica GT2000 Gigabit Ethernet (GigE) Vision camera, equipped with the 2.2 Megapixel CMOSIS CMV2000 CMOS sensor, offers Precise iris (P-iris) lens control allowing users to fix the aperture size to optimize depth of field, exposure and gain without the need for additional control elements. Equipped with Power over Ethernet functionality (PoE), the camera can be operated with a single cable for power supply and data transfer, making the integration of the camera system into the cutter head very easy.

In conjunction with the aperture settings, the lens and a specially designed LED ring provide a broad depth of field ranging from approximately 20 to 200 cm. The LED ring produces more than 10,000 lumens that illuminate break-outs in the face of more than 1 m depth. The LED ring flashes with a duration of 4 milliseconds, sufficiently preempting any motion blur that could interfere with the photogrammetric processing of the images. The Prosilica GT2000 is set to continuous auto exposure within a region of interest that updates the exposure time for each image. This ensures equal illumination of the images covering both cavities and stable face. It also avoids overexposure/underexposure of the face so the images can be well processed by photogrammetric software.

For image recording, the cutter head is manually rotated just over 360°. The cameras are, then, taken out and reinstalled in adjacent disc housings after each rotation. The spacing between two camera tracks can be manually set, depending on the distance between the cutter head and face.

**Control unit**

The control unit contains a PC, power supply, and a uniaxial inclination sensor.

Additionally, the control unit provides interfaces to several cameras that can be operated in parallel to accelerate the measuring campaign if desired. The camera and the control unit are connected via a Category 7 cable allowing frames rates up to 10 gigabits per second (10 GigE). The power supply is secured by a multi-pole cable.

The control unit is mounted in the disc housing of the double discs near the rotation center of the cutter head. The camera control software running on the PC is based on Allied Vision’s Software Development Kit, Vimba. The software triggers the camera in a fixed rate of 2 images per second, providing sufficient overlap and a surplus of images. The control unit is set to automatically initiate the image recording after the PC has booted. A new directory, where the images are stored, is created with every start of the image recording. No direct input to the system is necessary, avoiding interacting with the camera control as much as possible. The PC can be remotely controlled with an Android device (e.g. a smartphone) to assess the quality of the images taken.

The control unit is equipped with an inclination sensor establishing a common coordinate system for all images taken in one measuring campaign. Each image is assigned an angular value retrieved from the inclination sensor when the camera signals it is taking an image. The inclination angle and the known relative position of the disc housing can determine the absolute position of the camera in the 3D reference coordinate system of the cutter head. This provides essential information during photogrammetric processing.

**Photogrammetric processing**

Determining the exact position and shape of objects in a 3D space is completed by applying photogrammetric processing. Photogrammetry uses different measuring and evaluation methods to analyze digital images with the aim of creating a 3D model. For photogrammetric processing of the face images, the Institute for Subsurface Engineering chose PhotoScan, from Agisoft LLC, as it provides a rich Python Application Programming Interface (API). A full-face camera campaign can consist of more than a thousand overlapping images. PhotoScan ensures simple operation by allowing an operator to simply select a camera calibration file and text file containing orientation data. The result is a dense 3D reconstruction of the entire face. A high resolution orthophoto (distortion-free, true-to-scale representation of the surface) showing equal illumination covering break-outs and stable face areas is created, providing details that cannot be seen behind the cutter head. Based on this image, a color-coded relief presentation of the face is also generated.

“Digital imaging of the face leads to objective geological mapping which offers an incontrovertible basis of geological assessment.” says Robert Wenighofer, Project Assistant at the Institute of Subsurface Engineering of Montanuniversität Leoben.

“After more than a year of utilizing the camera system, photogrammetric processing has proven to be an appropriate means of documenting the face, even in the harsh environment of a hard rock TBM drive. The camera system provides high resolution orthophotos and relief presentations of the face representing an objective basis for geological mapping,” is his conclusive assessment.

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[www.subsurface.at](http://www.subsurface.at)  
www.bbt-se.com

**Allied Vision company profile**For over 25 years, Allied Vision has been helping people to see the bigger picture. Allied Vision supplies camera technology and image capture solutions for industrial machine vision applications and embedded systems. With a deep understanding of customers’ needs, Allied Vision finds individual solutions for every application, a practice which has made Allied Vision one of the leading camera manufacturers worldwide in the machine vision market.   
The company has eight locations in Germany, Canada, the United States, Singapore, China, France, and the UK, and is represented by a network of distribution partners in over 30 countries. [www.alliedvision.com](http://www.alliedvision.com)

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