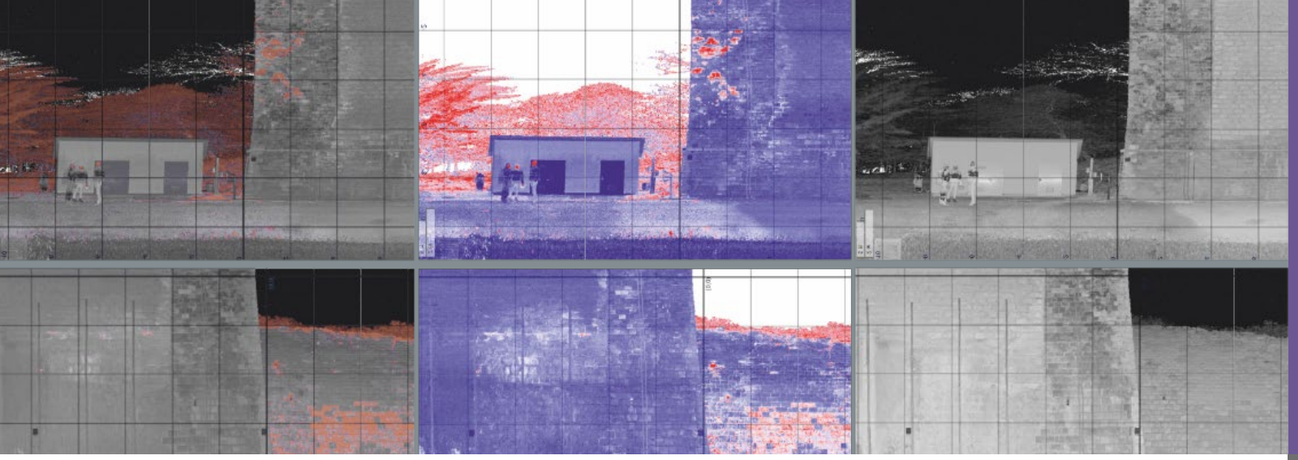

< In order to enable the automated measurement of moisture in tunnels, Fraunhofer IPM is using multispectral laser scanning for the first time. Wet areas at the tunnel entrance (upper row) and on a tunnel wall (lower row) are revealed by the absorption information (color-coded red).

Multispectral laser scanner detects moisture in tunnels

In addition to geometry and surface condition, moisture is another important parameter measured in tunnel condition monitoring. Fraunhofer IPM has now updated its Clearance Profile Scanner CPS, originally designed for railway inspection down to the millimeter, with an additional multispectral phase scanner. The CPS² is capable of measuring objects' moisture levels in addition to their geometry.

In Germany alone, over four hundred road, rail, and subway tunnels require regular inspections – and many of these are several decades old. Every year, the costs of maintaining and repairing these tunnels amount to nearly one billion euros. What's particularly astonishing is that the condition of these structures is still surveyed manually for the most part, requiring them to be fully closed off. Due to the different measurement techniques used, the data obtained are not uniform and not always available in a digital format. Mobile scanners – some of which are already in use today – promise to resolve this issue, offering many advantages over conventional measurement techniques. They are quick and accurate, they can be operated under any lighting conditions, and they deliver digital, location-referenced measurement data.

First multispectral phase scanner

While LiDAR (light detection and ranging) solutions based on the ToF (time-of-flight) method are typically used for generating rough representations of objects, Fraunhofer IPM uses phase shift measurement for its CPS. With a relative measuring precision of 1 to 5 mm at a measuring rate of 2 MHz, it offers much higher performance than ToF-based systems and is thus suited to producing accurate digital representations of structures or their surroundings.

Until now, laser scanners that measure using multiple different wavelengths have only been marketed by a few companies, exclusively as ToF systems and primarily for use in airborne applications such as vegetation mapping as well as bathymetry. At about one cubic meter in size and over 70 kg, these systems are cumbersome and heavy. As well as offering lower resolution and measuring rates than phase shift measurement solutions, they have proven to be insufficiently eye-safe (laser safety Class 4) in practice. With the CPS², the team has managed to develop the first multispectral phase scanner that can scan quickly and accurately from mobile platforms. The system is compact and easy to handle, measuring about 30 cm × 30 cm × 30 cm, and features an eye-safe Class 1 laser scanner.

The first-generation CPS carries out geometric measurements using a near-infrared laser with a wavelength of 1500 nm. With the next generation CPS², designed for measuring moisture, the laser wavelength was reduced to 1450 nm corresponding to the spectral signature of water. An additional laser with a wavelength of 1320 nm has been integrated into the CPS². Water does not exhibit any absorption at this wavelength, allowing this laser to serve as a reference. A comparative measurement of the two wavelengths – within and directly next to the absorption band of water – shows whether water is present on the surface of the measurement object. Geometric measurements can be taken by both lasers simultaneously.

> The CPS² relies on near-infrared (NIR) differential optical absorption spectroscopy (DOAS). DOAS is a common method for determining the moisture levels of food products, for example. Two collinear laser beams of different wavelengths scan the surface of the measurement object. These beams are specifically absorbed by water. The measuring beam with a wavelength of 1450 nm is selected to correspond with the absorption band of water. The second laser with a wavelength of 1320 nm lies outside of this absorption band and serves as a reference. An intensity analysis of the two signals gives the moisture value. The recorded intensities of both wavelengths are compared with the standardized target intensities of an ideal, dry Lambertian scatterer with a reflectance of about 90 percent. This makes it possible to differentiate even between different moisture levels (e. g. high, intermediate, low) extremely accurately, taking into account the reduction of the overall intensity due to material changes, color, debris, etc.

On the right track – tests prove the system's usability

In 2019, test measurements were taken in multiple locations across Europe as part of a cooperative effort with tunnel inspection companies and railway operators. The CPS² was equipped with positioning sensor technology and driven through tunnels atop a hand-pushed, rail-mounted platform. This configuration allowed for a measurement rate for both wavelengths of 2 MHz. Moving at 5 km/h, the scanner mapped the tunnel wall with a lateral resolution of approximately 3 mm × 7 mm. High-resolution test measurements at a tunnel entrance and on a tunnel wall show that the moisture on the surface of the structure is reliably detected (image above center). In addition to moisture, the geometry and surface of the tunnel walls are mapped down to the millimeter, enabling deformations, cracks and chipped-off surface material to be identified. The CPS² is the first system to enable simultaneous digital and location-referenced mapping of water ingress, surface defects, and geometry in a single pass through a tunnel. Moreover, the system clearly recognizes vegetation (image above, upper row), since this also contains a lot of water and therefore exhibits a spectral signature in the infrared range. The CPS² is thus also suited to detecting vegetation along railroad tracks, for example.

Novel deflection unit for higher speeds

As part of the Eurostars OpOrTunIty project, Fraunhofer IPM is currently working with a number of European companies on an expanded version of the CPS², the tunnel inspection system TIS. A novel deflection unit is intended to enable the combination of multiple lasers, the ultimate goal being to increase the speed at which measurements are taken in order to record water ingress, surface defects, and geometry simultaneously at a lateral resolution in the millimeter range and at a speed of 80 km/h through the tunnel. This would eliminate the need for tunnel closures during measurement.

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