Multi-sensor system for the precise and efficient inspection of roads, railways and similar assets

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3D laser scanner contained in a housing and mounted on the roof of a vehicle.
Credit: Fraunhofer IPM

Critical infrastructure such as transport networks are the lifelines of

modern society. Extreme weather events may cause damage to railway tracks, roads, tunnels and bridges. The Fraunhofer Institute for Physical Measurement Techniques (IPM) has developed a novel 3-D laser scanner that can be used to closely monitor transport infrastructure and plan maintenance work in a timely manner. The multispectral sensor system measures surface structures as well as the surface moisture on objects, all in a single inspection process.

Winter storms, heavy rainfall and floods can cause significant damage to railway networks and roads. Detecting cracks and other defects in road surfaces, tunnel walls and other essential infrastructure is crucial—and one way to do this is by using surveying vehicles with non-contact, high-precision mobile laser scanners that can map their surroundings in three dimensions. Researchers from Fraunhofer IPM in Freiburg have developed a tunnel inspection system (TIS) that works with two different laser wavelengths. As well as capturing the geometry of the tunnel, bridge or other structure, this system also stands out for its unique ability to measure surface moisture. The TIS can determine whether the interior wall of a tunnel is dry or damp, for example, thereby providing vital clues as to the tunnel's structural health. Unlike camera-based methods, the TIS also works in adverse lighting conditions. As well as tunnels, the scanner can also assess the structural health of roads and railways. The georeferenced 3-D data it produces can be automatically evaluated.

Fastest laser scanner in the world

The TIS can detect defects as small as a few millimeters. "Mounted on the surveying vehicle, the scanner scans the structure at a speed of up to 80 kilometers an hour, measuring its overall geometry and—during subsequent inspections—any changes in this geometry," says Professor Alexander Reiterer, a scientist at Fraunhofer IPM. The system captures two million measurement points a second—in other words, the measuring beam covers the distance between the TIS and the object it is

measuring, such as a wall, two million times a second. A rotating mirror is used to deflect the measurement beam in a 360-degree radius 200 times a second, ensuring blanket coverage of the object under inspection. This makes it the fastest scanner of its kind in the world. It can measure distances of up to 80 meters, which is more than enough for its purpose. The result of this scanning process is a 3-D model of the environment in the form of a point cloud. Designed to work even in harsh conditions, the TIS exhibits excellent tolerance to heat and cold and can operate at temperatures from -50 degrees Celsius to +50 degrees Celsius.

Laser scanners generally work on the principle of time-of-flight measurement. In other words, they measure the time it takes for light to travel from the emitter to the object and back to the detector and calculate the distance based on the speed of light. The TIS takes a different approach by using the more complex phase shift method: "This involves high-frequency modulation of the intensity of the emitted signal. The time it takes light to travel to the target and back is calculated from the phase shift between the emitted and received signal," says the researcher.

Surface moisture is measured using two laser beams of different wavelengths (1,320 nm and 1,450 nm) which are emitted collinearly. These are absorbed by water to differing, but very specific, degrees. The intensity of the measured signals gives an indication of the amount of moisture on the surface of the tunnel wall. "Infrared light is strongly absorbed by water, and that physical effect is something we can take advantage of. We use two very closely adjacent wavelengths, one of which is absorbed strongly and the other much less strongly. The difference allows us to calculate the amount of moisture."

Machine learning makes analysis more efficient

The high-resolution, georeferenced data produced by the scanner is made available in a digital format. Digital measurement data is a key prerequisite for long-term infrastructure monitoring. The subsequent analysis is based on machine learning methods. Using specially developed algorithms, the system automatically detects which objects are present in the area under examination. This might be anything from a light pole to a crack in the wall. The system then assigns additional information to each data point specifying the object to which it belongs. This provides the basis for automatically deriving comprehensive map materials. But before the algorithms can interpret the measured data, they first need to be trained. "The big challenge is building up a database that is suitable for training," says Reiterer. Fraunhofer IPM has already collected data for a wide range of applications that it can use for custom and application-specific training.

Compact and maintenance-free

The TIS is currently at the prototype stage and has already been evaluated in a Swiss test tunnel where it successfully performed an initial series of measurements. The researchers are aiming to make the final product extremely compact, measuring just $30 \times 30 \times 30$ cm^3. Another thing that makes the scanner unique is the fact that the entire system comes as a fully enclosed, self-contained product. The rotating components that deflect the laser beam are housed in a glass cylinder. "Encapsulating the system in this way makes it robust, long-life and maintenance-free," says Reiterer.

The next step is to test it on roads and railways under real-life conditions. "Much of Europe's transport infrastructure is in a poor state of repair. It is vital that we start monitoring it more frequently and in much greater detail. The only way to do that is by developing systems that make these kind of inspections more efficient. For the first time, the TIS offers us a multimodal system that can simultaneously measure

multiple parameters, namely geometry (3-D data), structure (cracks) and moisture. This is a big step forward in terms of costs, speed and efficiency," says the scientist.

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