WHITEPAPER

Building and construction surveying with laser scanning technology

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Pure mathematics: Automatic object recognition

For humans, a lively street is like a very busy picture: cars, signs, trees, people and buildings, often one in front of the other. The brain is able to classify and pinpoint these objects effortlessly. But when an attempt is made to automate this process, it becomes clear how truly complex it is. As part of a research project, Fraunhofer IPM developed algorithms for the automatic identification and classification of objects on the road, with artificial neural networks forming the basis for pattern recognition.

Today, infrastructure is surveyed using high-performance cameras or laser scanners, which deliver high-resolution images and very accurate, georeferenced measurement data. Modern laser scanners record several million measurement points per second, providing a detailed map of the surrounding environment in the form of a 3D point cloud. The results are generally evaluated manually, which requires viewing extensive volumes of data (point clouds and image data). The automation of at least part of this time consuming process is the goal of a research project commissioned by Lehmann + Partner GmbH that Fraunhofer IPM is conducting for the Federal Highway Research Institute (BASt). The project involves developing algorithms to automatically identify, classify and locate elements of road infrastructure in 3D measurement data.

In order to evaluate road scenes, scientists are turning to complex learning algorithms based on the concept of deep learning using artificial neural networks (ANNs). This approach has been shown to be superior to traditional methods of object recognition. While the latter use feature sets provided by the developer, ANNs learn to recognize the relevant features on the basis of training data. In ANNs, the information provided passes through a large number of interconnected artificial neurons, where it is processed and transmitted to other neurons. ANNs learn the output patterns which correspond to specific input patterns with the help of manually annotated training data. On the basis of this »experience«, new types of input data can then be analyzed in real time. ANNs have proven to be very robust when confronted with variations on characteristic colors, edges and shapes.

Recognizing, classifying and locating objects on the roads is time consuming. Pattern recognition using artificial neural networks automates this process.

Data fusion: Scanner data and camera images are merged to create the data pool

The more detailed the information in the data set, the more successfully objects can be recognized and classified. Camera and scanner data collected by a survey vehicle outfitted with laser scanners developed by Fraunhofer IPM and operated by project partner Lehmann + Partner form the basis of the project. Merged scanner and camera data serve as a suitable starting point for automatic object recognition. In one approach, georeferenced scanner data points are initially transferred to a grid format containing depth information and are then linked with RGB camera data. This pixel-based RGB-D(epth) data set contains a corresponding depth image for each RGB camera image, which makes it the ideal input format for ANNs. Scientists think that the depth values will help the network separate overlapping objects and generally make classifying and locating objects a more robust process.

Camera image and evaluated measurement image: Colored segmentation masks mark the forms of the identified objects.

Using semantic segmentation to identify 3D georeferenced objects

The architecture of the network, in other words the number of network layers and the type of hierarchical links, is adapted to each specific task. The network is trained using a training data set. To this end, images are first semantically segmented manually and each pixel is attributed to a specific object class. Once a network has been trained with this data, it can be expanded to include additional object classes at any time with a new training data set. Using the pixel coordinates of the objects identified in the image data, the segmentation can be back-projected into the point cloud. To make this possible, the camera and laser scanner must be accurately aligned and the appropriate calibration parameters must be determined in a corresponding one-time process. Segmenting the point cloud enables georeferenced objects to be identified in 3D.

The topic of automatic object recognition is of interest to anyone faced with the task of evaluating large volumes of data. In the future, the challenges of surveying infrastructure will pale in comparison with the requirements of the automotive industry, which relies on this technology for self-driving vehicles. In autonomous driving, moving objects must be recognized in real time. This is where the neural networks of the human brain remain superior – for now.

DEEP LEARNING As a method of machine learning, deep learning is a subfield of artificial intelligence which relies on smart algorithms. For example, training data sets are used to identify objects in a picture. Deep learning is based on artificial neural networks and has been shown to be more robust when confronted with the varying forms and obscured, damaged or faded objects that are typical of street scenes than traditional methods of object recognition.

Construction progress: Aerial capture and automated analysis

Major construction sites have a lot going on, with large quantities of materials and objects moved around daily. A laser scanner developed by Fraunhofer IPM for STRABAG AG captures road construction sites from the air to document these changes. The 3D data obtained are automatically analyzed with specially designed software.

Monitoring and documenting project progress at major construction sites is important for providers of construction services such as STRABAG AG. Project managers in the construction industry are increasingly using digital data and special software for this purpose. These form the basis for what is known as Building Information Modeling (BIM), which helps with the optimal planning and implementation of construction projects.

Drones equipped with cameras have been in use for quite some time at major construction sites, such as traffic route construction, to document the status of the project. They fly over the area every few days and deliver a wealth of information including the position and size of asphalt and gravel surfaces, guardrails, curbs, manhole covers or trees as well as the stock and storage location of construction materials and equipment. At present, the 3D data computed from camera images is »manually« analyzed, that is, through visual inspection. A joint project of STRABAG and Fraunhofer IPM is aimed at making this process more efficient.

The challenge: Accurate recognition of objects in 3D point clouds

A measurement system developed by Fraunhofer IPM, which uses a laser scanner in addition to cameras, is installed on a UAV (unmanned aerial vehicle) platform and directly delivers a georeferenced 3D point cloud as well as camera data. The eye-safe measurement system weighs only two kilograms and can capture an area of several hundred square meters in less than ten minutes. The laser scanner generates up to 60 profiles per second with 1000 measuring points each perpendicular to the flight path. The precision of a single point measurement is approximately 1 cm.

Monitoring large construction sites from the air with cameras and laser scanners supports optimal planning and documentation of construction projects.

The 3D data generated by the scanner offers two major advantages. Unlike camera images, the measuring beams penetrate vegetation, so that even ground points under trees or shrubs can be captured. In addition, this approach eliminates unwanted shadow effects, which are unavoidable with camera-only systems. Moreover, the 3D point clouds generated by the scanner with RGB information from the images provide the best basis for an automated analysis of the measured data. Until now, this process has been akin to that of »paint by numbers«: the 3D point cloud is analyzed by manually extracting objects. In the future, the process of data interpretation is expected to be taken over by specially designed learning algorithms that work on the principle of »deep learning« based on artificial neural networks (ANN). In its basic state, such an ANN resembles a crude network of artificial neural connections. The ANN is prepared for the eventual task of classification with a specially generated training dataset, as only known objects can be reliably identified.

Ready for take-off: A STRABAG employee gets the drone ready to go. The data recorded are later automatically analyzed.

Classified 3D model of the construction site

Apart from training the ANN, the other prerequisite for automated data analysis is the appropriate preparation of input data. The intelligent fusion of camera and scanner data forms the ideal data pool. The camera data plug any gaps in the 3D point cloud and provide additional color information, while depth information from the 3D point cloud enables, for example, better differentiation of overlapping objects than would have been possible with the help of camera data alone. A framework developed by Fraunhofer IPM projects the scanner data accurately and precisely onto the images of the color camera. This way each RGB image of the scene is assigned a corresponding depth channel. The RGB-D(epth) data prepared in this manner along with a trained network make the data analysis very robust to object variations and changes in view angles and light conditions. And that is critical, as no two construction sites are alike and no measurements are made in a controlled environment. Project partner STRABAG will get an executable software package that creates classified datasets in the industry-standard LAS format, which, if required, can be linked to other data such as BIM or CAD data. This creates the digital data that form the basis for the efficient management of large construction projects.

TRAINING DATASET FOR ARTIFICIAL NEURAL NETWORKS (ANN) To create a training dataset, thousands of datasets containing the prototypical elements of a construction site scenario are manually annotated. All the border areas of a relevant object, a streetlight or a tree for instance, are marked down to the pixel. This creates prototypical polygon faces that are assigned to predefined object classes. These annotated faces serve as input patterns for the ANN and later recognize geometry, color and other descriptive parameters to create the associated output pattern, i.e. a specific object class. Fraunhofer IPM has developed a software tool for data annotation, which makes this process efficient.

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Tunnel vision: Sensor determines condition of tunnel structures

In the future, a laser-based multispectral sensor will be able to simultaneously identify the geometry, surface structure, moisture level and vegetation growth of tunnel constructions. This system will determine all relevant parameters in a single measurement run at speeds of up to 80 km/h. As a result, it will be possible to perform inspection and maintenance of tunnels far more efficiently and economically.

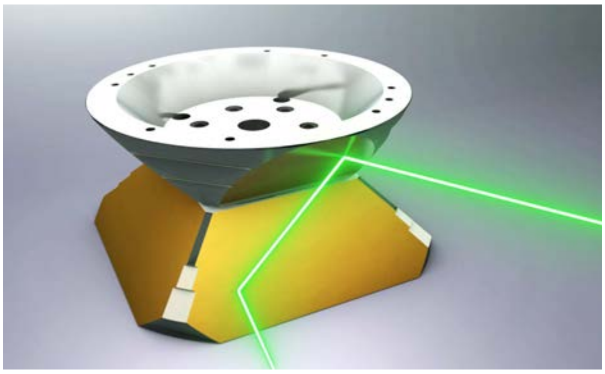
Tunnels are critical transit connections for both passenger traffic and goods transportation, particularly in Central Europe. However, they also play an important role in drainage systems and as mine access shafts. In Germany alone, over four hundred road, rail and subway tunnels require regular inspections – and many of these are several decades old. In addition, there are some 250,000 kilometers of tunnel-like structures in the sewer network. Every year, the costs of maintaining and repairing tunnels amount to nearly one billion euros solely in Germany. As part of the IncaS (IntracavityScan) in-house Fraunhofer project, Fraunhofer IPM has developed a multispectral sensor that will significantly reduce the costs of tunnel inspection while improving the quality of measurement data at the same time.

Multiwavelength measurement

The scientists use a novel laser scanner design for performing measurements with multiple wavelengths. The measured data of the different wavelength are then combined. This allows for a seamless and dense detection of 3D geometries, surface structures, moisture levels and vegetation growth on tunnels in a single measurement run. The measurement system operates at high travel speeds meaning that it will no longer be necessary to close routes during surveying. Propagation delays in laser light backscattering are used to survey the geometry of a given structure. Up to two million measuring points per second ensure high resolution. In order to measure surface moisture, two lasers with different wavelengths are used. The laser light is specifically absorbed by water, depending on the respective wavelength of 1.3 and 1.45 µm. An intensity analysis of the two signals gives the moisture value. These data on geometry and moisture allow the researchers to ascertain information on vegetation, such as moss and algae growth. Features of the surface structure are detected based on the intensity of the backscattered light: High spatial resolution is required here in order to generate realistic, photo-like images of cracks in the

In the future, a novel measurement system will determine the geometry, surface structure and vegetation growth on tunnel constructions simultaneously and at high speed.

surface structure measuring just a few millimeters. The laser illuminates the object along a line parallel to the direction of travel. A specially adapted receiver lens forms a planar image of the signals and thus generates a continuous gray-scale picture of the surface. Resolutions of 1.5 mm x 1.5 mm are achieved at travel speeds of up to 80 km/h using this patented technology from Fraunhofer IPM.



A specially configured deflection unit was designed to meet the requirements of 360° scanning and multiwavelength measurements. This also ensures that all eight laser beams are projected onto the tunnel wall without distortion. This image shows an example of one beam.

Innovative scanner design for true 360° scanning and multiwavelength measurements

For the first time, a specially developed, square bifrustum-shaped scanning device has made it possible to use laser beams of several different wavelengths synchronously to produce undistorted images (see drawing). This was not possible with the laser scanners available to date, as the light paths could not be clearly isolated. The device also enables true 360° scanning for the first time. Previously, mechanical fixings created shading and made it necessary to perform multiple measurements. Data from several measurements had to be fused to create an unbroken 3D model – an error-prone process that has now been eliminated by the new system. The bifrustum has four facets that cover an angle range of just under 180° each so as to avoid artifacts in edge areas. Thanks to this geometry, the scanning speed is doubled in relation to the speed of rotation, enabling as yet unequalled scanning frequencies. Up to four identical laser systems per frustum and corresponding detection devices can be arranged around the deflection unit in a star shape to guarantee full coverage of all angles. The design ensures perfectly correlated data capture, both in terms of time and space, and enables the use of specially shaped laser beams. The beam propagates along a line to allow planar scanning and guarantee eye safety.

This will be the first cavity inspection system to measure all relevant parameters simultaneously, rapidly, and with high levels of resolution. Thanks to its perfect data synchronization, comparisons can be made with previous measurements allowing even small changes in a structure to be identified in good time.

CUTTING-EDGE TECHNOLOGY FOR TUNNEL INSPECTION: The geometry, wall surface structure, vegetation growth and wall moisture in tunnels are inspected every five years. Today, static laser scanners positioned at numerous points throughout a tunnel are predominantly used to measure geometries. A small number of systems perform these measurements from mobile platforms, usually on manually-driven inspection cars. Cracks and moisture are detected using cameras, while cavities are identified with a special hammer. All existing methods are time-consuming and labor-intensive, and require full closure of the structure – which has far-reaching economic consequences.

Collecting data from the air

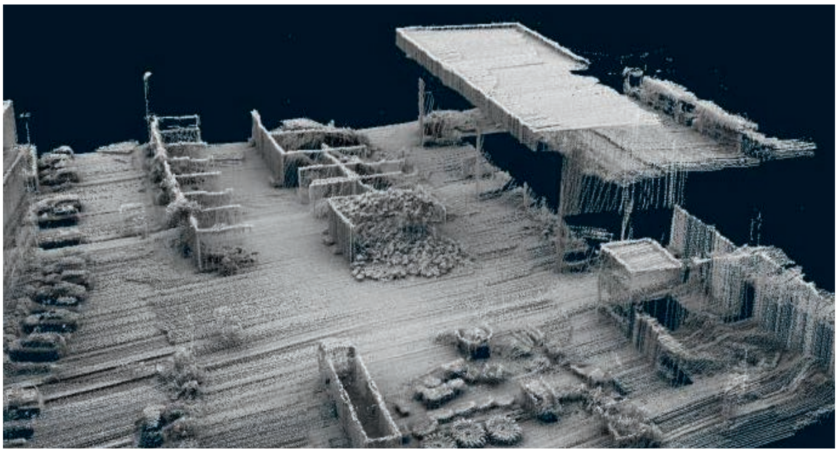
From impassable terrain to crisis-hit regions, UAVs (unmanned aerial vehicles) are the number one choice for use in locations where it could be dangerous for people to measure infrastructure. Mounted onto small, flying platforms, measurement systems are able to collect data about large areas and complex structures quickly and efficiently. Fraunhofer IPM has developed an innovative measurement system that enables UAVs to gather local geometry data.

Comprising a variety of modular components, the measurement device is able to position and locate itself locally without the need for external referencing systems like a GNSS (global navigation satellite system). This makes the solution particularly suitable for measuring obstructed and complex structures with little or no GNSS reception. It does so by capturing sequences of images very quickly and by using special algorithms. Depending on environmental conditions, the method has a relative accuracy of a few centimeters. The measuring component used in the system is an eye-safe laser scanner with a working range of 250 m. The scanner is combined with a multispectral camera system to form a powerful multi-sensor unit.

Small, lightweight and energy efficient

Above all, measurement solutions for use in UAVs must be lightweight, which places high demands on the system design. The size, weight and power consumption of the sensors, for example, must be kept within a narrow range. Fraunhofer IPM is continuously striving to optimize these sensors.

The scientists at the Institute are currently participating in two projects concerning the use of measurement systems on UAVs. The objective of the »MulDiScan« project is to better predict natural disasters such as floods, landsli-



Measuring complex structures from the air. A surface area of several 100 m2 can be measured, processed and visualized in less than ten minutes.

des and forest fires, making it easier to introduce preventive measures. This requires scientists to gather high-quality measurement data about vast swathes of land that are sometimes difficult to access, yet may indicate changes to the structural landscape. To achieve this aim, researchers from Fraunhofer IPM have joined forces with academics at the Albert Ludwig University of Freiburg to develop new methods of collecting and interpreting data.

As part of the »MonIs« project, which is being funded by the EU's Eurostars funding program, Fraunhofer IPM in collaboration with partners from Germany, Austria and Spain is developing a system for monitoring infrastructure such as railway tracks, roads and buildings. The measurement solution, which comprises a specially adapted UAV and a sensor system, is able to easily collect data at short intervals in challenging locations. Measurement systems fitted to UAVs have enormous potential. From rough or even inaccessible terrain to dangerous environments, they can be used to collect important data whenever it is impossible for measurements to be taken from the ground.

Ready for take-off: A STRABAG employee gets the drone ready to go. The data recorded are later automatically analyzed.

TIME-OF-FLIGHT MEASUREMENT OF LIGHT Collecting data from the air requires highly accurate geometrical measurements to be recorded using the time-of-flight method. This process records the time it takes for light waves or light pulses to travel from a sender to an object and back to a detector. The movement of a laser scanner and measurements taken in rapid succession create a large number of measuring points, which produce a 3D model of the surface under investigation.

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