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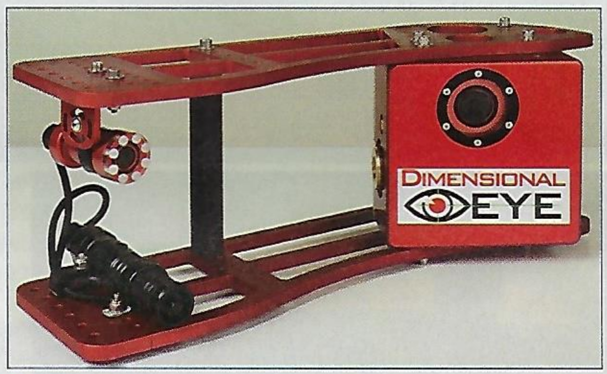
3D Subsea Survey On the Fly

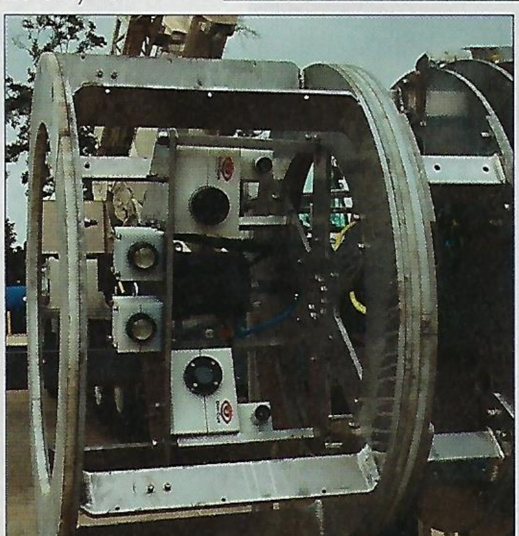
VLS Uses Laser, Camera for Point Cloud Surveying

By Arnauld Dumont

With the aging of oil and gas installations, requests for inspection and control of components are increasing rapidly in the industry to prevent failure, and some inspections need 3D as-built surveys before modifications can be done on an installation.

Optical measurement technologies have been used over the years for above-water surveys, while photogrammetry and laser scanning have been introduced into the subsea environment only recently. The main challenge for any kind of subsea survey is stability; even placing a tripod on the seabed might not be a stable option due to ocean currents. Photogrammetry provides the ideal solution: Not only is stability not an issue, but movement is actually required in order to get pictures from different angles. Moreover, thanks to the development of HD cameras, it is now possible to shoot video and extract high-quality images instead of shooting only still pictures.



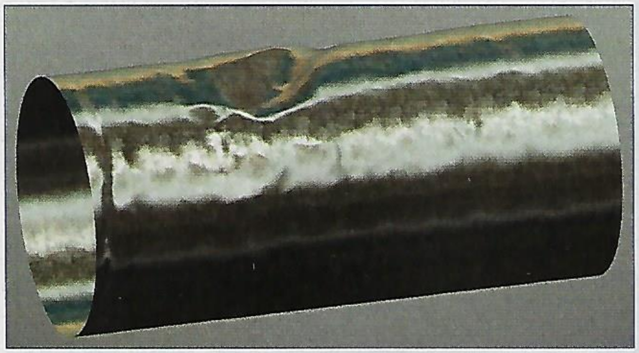


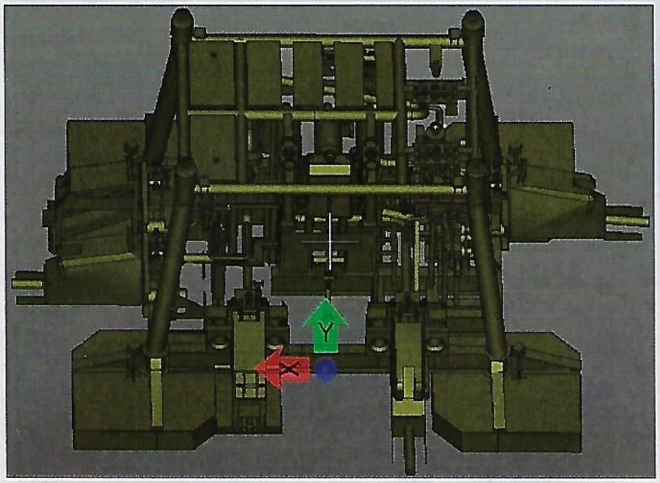
(Top) DimEye VLS system for divers. (Bottom) DimEye custom VLS system for subsea applications.

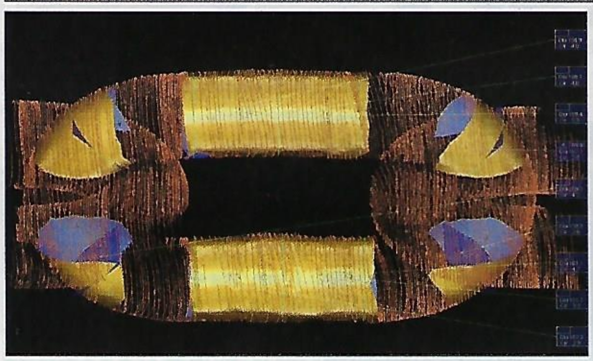
HD Cameras

The history and development of photogrammetry is linked to the development of cameras. Some cameras have been developed specifically for photogrammetry to be able to conduct accurate measurements on the images. These are called metric cameras. Measuring in this way requires doing at least three things: keeping the flatness of the film by adding a pressure/vacuum device; adding marks on the film fiducials in order to correct the optical distortions; and keeping the relative positions between the lens and the film as rigid as possible.

In 1994, the development of the first digital cameras marked the beginning of a new era, ushering in broader use of photogrammetry in various industries and the development of new processes and new methodologies. Logically, the development of cameras in order to be able to conduct measurements from images led to the development of CCDs (charged-couple device) sensors, pixels and software. Whereas it was difficult, if not impossible, to build a perfectly mechanical and optically stable camera, it seemed possible to correct all deformations by software, for example by working on camera self-calibration routines, which meant it was just a matter of waiting for the development of better cameras with better resolution and stronger optical and mechanical characteristics. Introducing these cameras to the subsea environment was then only a matter of creating the right canister and developing a communication interface suitable for ROVs. A typical example of such a camera is the 1Cam HD camera by SubC Imaging, which is broadly used now for subsea visual inspection and subsea 3D surveys.







(From top to bottom) Sample pipe-dent 3D CAD model. Sample 3D as-built CAD model (manifold). Sample mooring chain VLS survey and 3D analysis.

Unmanned Vehicles and Divers

Because photogrammetry doesn't require stability, it's very easy to conduct any survey directly from an ROV. The camera can be mounted either on the pan-and-tilt unit that is usually installed on the skid or on a small bracket at the end of one arm. In the past, shooting still images was quite time consuming and somewhat more complicated than shooting video. When shooting video, the ROV pilot simply needs to fly around or above the region of interest (ROI). There's a lot of flexibility for flight paths, with only a few basic rules to follow, such as being at a certain standoff distance (mainly depending on camera field of view and visibility), never changing the zoom position and being sure to get enough overlap between runs.

The photogrammetry rules are very easy to follow for an ROV pilot because they are very similar to what is required for a visual inspection. The rules are exactly the same for divers, AUV and UAV (unmanned aerial vehicle) pilots. The result is that ROV/AUV/UAV pilots and divers can conduct such surveys after short training, without any need for additional personnel or equipment.

Data Processing

Once the videos are captured, the files can then be sent for data processing. The photogrammetry process includes four main steps: preparation, digitalization, bundling, and 3D measurement or modeling.

Preparation consists of extracting relevant images from a video. This can be done automatically (extraction at a certain rate) or manually, depending on the complexity of the survey and the navigation conditions. For digitalization, common points are identified and measured on all images. This can be done automatically thanks to an image-processing algorithm, yet very often still requires human intervention, especially for underwater images. Once points and geometrical features (such as circles or cylinders, for example) are digitalized on all images, the 3D computation is launched. The outputs are the 3D coordinates of all the points and geometrical features, as well as the location and orientation of all camera positions. Depending on the output requirements, it is possible to either produce high-accuracy measurements of distances and angles or a full 3D CAD model.

VLS for Anomalies in 3D Mapping

When further modifications to mapping are required, creating a 3D as-built CAD model is necessary. Doing this provides the existing geometry and dimensions and allows for the design of new components that will fit in perfectly. It's also an essential tool for ROV/AUV/UAV navigation simulations and can help prepare divers for their subsea operations.

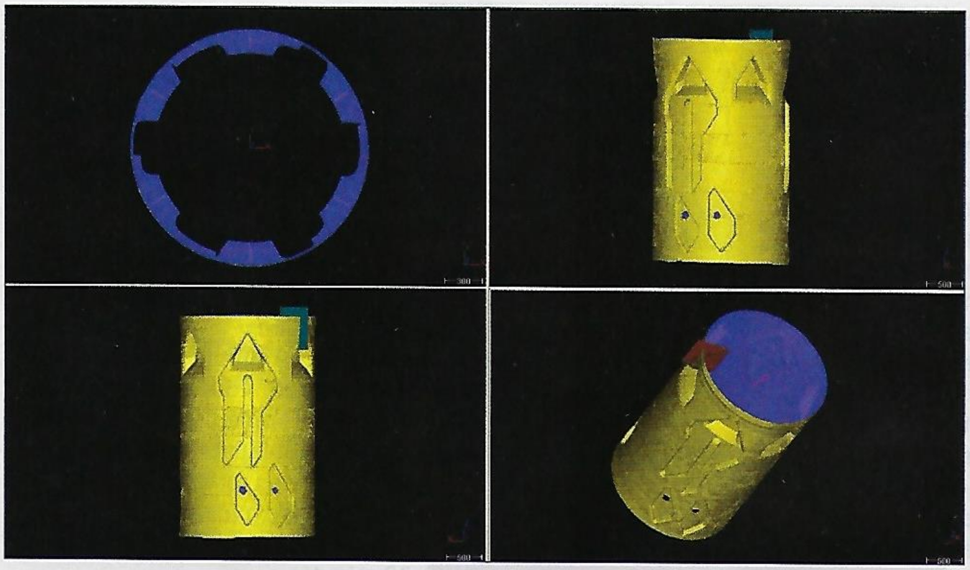
But when looking for an anomaly such as a crack or a dent, photogrammetry can only provide a few points and general dimensions (length, width, depth). It's almost impossible to measure many points on surfaces simply because the correlation of points between images is impossible; there are no details or texture.

This is why DimEye invented the VLS (Video Laser Scan). The idea is to rigidly mount a laser plane projector device with a camera at a certain distance and with a certain angle. Relative positions and orientations of the camera and laser are determined by calibration. Positions and orientations of the camera in space are computed by photogrammetry: On every single image, the laser plane intersects the subsea structure and generates a line that can be triangulated, giving potentially infinite points. When shooting a video from an ROV at slow speed, about 25 images per second are acquired, which allows the selection of the required density of laser lines on the object and, therefore, the final density of the point cloud.

In terms of operations, adding a laser plane projector is easy: The camera and the laser can be mounted on a small bracket at the end of an ROV arm, or they can be handheld by a diver.

Case Studies

Spool Metrology. Measuring the relative positions and orientations in space of two objects is a classic application for photogrammetry. Spool metrology involves measuring



Sample VLS survey and 3D analysis of subsea piles.

purposes to superimpose the CAD model on any picture of the same area previously corrected of all optical distortions.

Manifold. Like spool metrology, flying around a manifold with an HD camera allows the creation of a very accurate 3D as-built CAD model of the entire manifold. The standard achievable accuracy is 1/2,000 (i.e., 1-mm on 2-m dimensions), and this can be made even higher to fit the client's needs.

Flex Joint. Since the surface of a flex joint consists of black rubber, it is only possible to measure a few points by photogrammetry, which are not enough to create an accurate and dense mesh. DimEye's VLS technology was initially developed for flex joint 3D modeling.

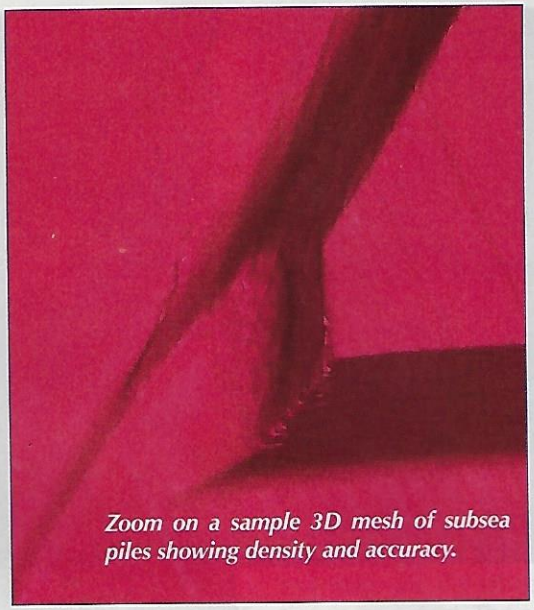
The VLS includes an HD camera and a laser plane projector. Three-hundred-and-sixty images (one every degree) are extracted for the 3D model, and in case of anomalies, additional images (and, therefore, laser lines) can be extracted, which will locally generate an even more dense point cloud.

Pipe Dent. Pipe Dent 3D measurement is the most straightforward application of the VLS technology: Scanning the dent through a single run generates a very accurate point cloud that can later be used for analyzing the dent's dimen-

the relative positions of flanges that could be separated by a certain distance and have relative orientation angles.

A photogrammetry survey simply requires flying from one flange to the other in a back-and-forth motion to minimize errors, then recording the corresponding HD video file. Images are extracted from the video for 3D processing, and the output is a 3D as-built CAD model that can be used for the design of the new spool, with the guarantee that it will fit perfectly. It is also possible for quality-check sions. These measurements can also be sent for finite element analysis (FEA) if necessary.

Mooring Chain. Measuring mooring chains is a difficult challenge. In order to achieve 360° of coverage, multiple ROV runs must be done from both "sides" of the chain. This process becomes complicated when environmental factors such as ocean currents and chain movements are taken into account. Conditions like this make ROV maneuvers intense. However, thanks to its high level of flexibility, the VLS technology makes it possible to capture HD video, generate accurate point clouds, measure general dimensions and determine the grip zone wear of each chain link to a submillimeter level of accuracy.


Zoom on a sample 3D mesh of subsea piles showing density and accuracy.

Piles. In 2016, DimEye was contracted to measure the interior of subsea piles in the Gulf of Mexico. A specific VLS sensor configuration was established in order to completely cover the internal surface and generate an accurate point cloud from which 3D analysis was carried out (such as cylindricity and ovality), as well as collision analysis. With a total of 768,000 images—48,000 per pile—this is the largest close-range photogrammetry project ever realized. (Before this, the largest was the 3D survey of the nuclear fuel reprocessing plant of La Hague, France, which produced close to 200,000 stereoscopic couples—a total of 400,000 images.) By processing 48,000 images on a single pile, it was possible to generate a high-density and high-accuracy cloud of about 14 million 3D points. The space between points (resolution) was less than 1 mm.

Economic Considerations

The economic impact of the VLS technology is significant for technical, operational and financial reasons. First of all, the data capture is very fast and reduces considerably the vessel time. Video shooting takes only minutes and is often already planned for visual inspection purposes. A typical spool metrology survey would take no more than 30 minutes.

Second, nonspecialists can carry out data capture after a short training on basic rules of photogrammetry and DimEye technologies. This means less people needed on the boat and less people involved in operations.

Third, the equipment is off-the-shelf, and HD cameras already integrated can be used without any problem. They can also very easily be rented from traditional suppliers of offshore equipment. There is no need for very expensive and sophisticated sensors that could only be used by high-level specialists.

Finally, data processing is becoming faster and faster thanks to the development of new high-performance cameras and the development of powerful image-processing algorithms.

New Developments

The future of 3D measurement by optical techniques such as photogrammetry and video laser scan will be driven by the development of the hardware and new methodologies associated with software development.

With the hardware being now mostly off the shelf, the technology will automatically benefit from any camera improvement. Video cameras now have 4K resolution and will have 6K or more in the future. Stabilization techniques will also help by allowing faster ROV speeds. Ongoing research on high dynamic range (HDR) video will certainly lead to the continuous improvement of images.

Software development will be driven by the market and customer requirements. Although data processing has become significantly faster over the last few years, there is still a demand for shorter time frames, including real-time results. This will require more automation through the development of more dedicated software, such as applications to be used by nonspecialists. **ST**

Arnauld Dumont is a surveyor-expert engineer and has been working for more than 25 years in the field of 3D measurement by photogrammetry and laser technologies in various industries (oil and gas, nuclear, aerospace, civil engineering). He managed 3D survey projects in the U.S., Europe, Africa and Asia and founded DimEye Corp. in Los Angeles back in 2009 with the goal of focusing on applications for inaccessible environments such as subsea, space and nuclear areas. Since then, DimEye has developed the innovative technology called VLS for subsea and aerial periodical inspection of infrastructure components and 3D as-built surveys.