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TRIANGULAR 3D LASER SCANNING IN UNDERWATER PHOTOGRAMMETRY

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ABSTRACT

The use of triangular 3D laser scanning may significantly enhance the visual inspection of underwater objects. In these days of high demand for accurate information, exclusively photographic documentation is not enough, as it is geometrically flawed.

The authors of this article are trying to present the rudiments of laser scanning, a modern means of measuring, which is reliable, relatively easy to use and works in accordance with basic good measurement practices. With the use of a laser beam, a point model of the measured object is generated with a resolution that is adapted to the requirements. A well performed scan will cover the entire surface of the measured object with no information gaps, as is often the case with photographic documentation which focuses solely on key details. Photographic documentation is now already being replaced by Structure from Motion technology, the latter being an alternative to laser scanning, which creates a textured 3D model from the collection of photographs of the object with similar accuracy, but with more time required.

Key words: laser scanning, underwater imaging, underwater visual inspection.

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INTRODUCTION

Speaking of modern trends in geometrical measurements and location in a broad sense one must not forget about photogrammetry and remote sensing, which have existed for years but are still treated as futuristic creations. The field in question reflects the current way of thinking, according to which, the presence of human beings in on-site measurements (often in adverse conditions) should be minimised and reduced to the post-processing phase, even if this comes at the cost of collecting less data.

The world has now come to terms with the ubiquitous satellite techniques which are successfully in operation on land, in the air and most importantly for us, in the sea. With their assistance we are able to lead ships on waters that are not easily navigable, erect off-shore constructions with sub-metre precision or lay foundations for underwater navigation. Another rational measure after our measurements have been tied in globally, as everything now requires georeference, is a transition from direct to remote measuring.

With respect to the specificity of the marine medium, this course of development was discovered long ago and is now gradually being implemented in underwater technology. This is corroborated by increasingly efficient multibeam sonars that are used not only in hydrography, but are also utilised as implements for engineering measurements, for instance: BlueView 3D - by Teledyne.

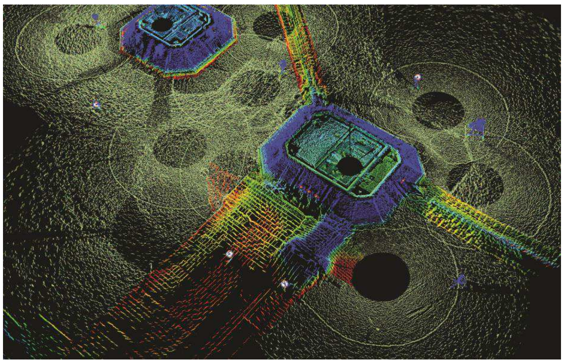

Fig.1. A point cloud generated by a BlueView 3D multibeam sonar.

Another course of development of photogrammetry and remote sensing is the use of light as a specific gauge. In the case of photogrammetry, which is a passive technique that uses reflected light, we reproduce a beam of light rays allowing for the imperfections of the optical system, so that we can reproduce the image in two or three dimensions, depending on whether we are dealing with single or multi image photogrammetry. In order to cover the entire object in question a sequence of photographs with the camera in various different positions is required, so that the photographed object overlaps on the consecutive photographs, and then the photos are oriented against each other with the use of identical points.

Remote sensing with the use of light is nothing else but the so- called LIDAR (Light Detection and Ranging), which is the detection and determination of the localisation with the use of a generated ray of light. According to recent research of 2G Robotics, a producer of underwater inspection systems, laser scanning produced a 100 times higher spatial resolution than in the case of a multibeam sonar [2].

Fig. 2. A point cloud generated with the ULS 500 laser scanner [2].

It is important to note, however, that even a cursory glance at the information on photogrammetry and remote sensing will clearly determine a hierarchy of popularity. With regard to all the media hype about drones, amplified by the ISOK (IT System for Protecting the Country against Emergencies) government project which involves a LIDAR generated Digital Elevation Model as one of its products, photogrammetry and aerial remote sensing are indisputably leading the way.

Although not comparable in terms of popularity and reserved only for people who are engaged in architectural surveys, terrestrial photogrammetry is developing due to the Structure from Motion (SfM) technology, which is used for range imaging from photographs, with the assumption of their mutual overlapping.

Underwater photogrammetry is apparently the least frequently mentioned form of photogrammetry in generally accessible publications, regardless of the fact that it involves the least friendly type of environment for man, and by being such, it is relegated to the ranks of being considered almost a recreational activity [3]. Therefore, each additional contribution in the development of advanced techniques that facilitate reliable documentation of underwater objects is not solely *l'art pour l'art.* – an act of expanding general knowledge, but it may also be beneficial for compiling new geospatial data and minimising risks in underwater planning and carrying out tasks.

The authors of the present article will demonstrate the effects of their engineer's thesis titled: "*Verification of a 3D scanner's usability for underwater photogrammetric measurements*" prepared under the supervision of Marek Przyborski, PhD, Eng, an associate professor of Gdańsk University of Technology, head of the Chair of Geodesy at Gdańsk University of Technology and Cpt. Adam Olejnik, PhD, Eng, head of the Department of Underwater Works Technology of the Polish Naval Academy.

The research that contributed to the completion of the abovementioned thesis was conducted at the Department of Underwater Works Technology of the Polish Naval Academy in Gdynia as part of a project co-financed by the National Centre for Research and Development No: POIG.01.04.00-22-069/13 pt.: A modular, remotely controlled system for the analysis of aquatic environments and underwater objects as part of the Innovative Economy Operational Programme Measure 1.4 Support for Targeted Projects,

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ISSUES AND AIM OF THE RESEARCH

The choice of remote sensing for underwater measurements is dictated by several equally important reasons: completeness of the collected data, rate of their registration, adjustment of the data for CAD processing, as well as the comfort of the measuring team itself, which additionally inspires considerations of combining remote measuring with a remote measuring platform.

In spite of having unquestionable advantages that are proved by numerous terrestrial and aerial applications, laser scanning has limitations that are typical for systems that rely on light, which makes its one-to-one application in the submarine environment challenging – one of the reasons being the anticipated range of the measurement.

The tenacity of the marine medium comprises several different physical factors, such as changeability of the environment itself and little predictability. The most frequently quoted parameter that poses the greatest challenge for all those who plan and perform underwater works is hydrostatic pressure. It is worth noting the cost and complexity of adjusting the equipment for work at even shallow depths. The difficulty lies in creating a structure that protects vital electronic elements against water at a pressure higher than a falling raindrop. The evidence for that was shown in the initial problems that the people involved in the openrov.com initiative experienced. At first, it was an open project which later became a commercial production of small remotely operated observation vehicles.

For surveying shipwrecks or mapping elements of infrastructure which lay in deeper depths, the prolonged exposure of working divers is potentially dangerous to life and health, not to mention its high cost. The hardships of submarine exploration may be encapsulated in the following comparison: 12 astronauts had the privilege of traversing the surface of the Moon, but only 3 people have reached the deepest place to be explored on our planet – the Challenger Deep. However, they did not have the possibility of walking freely on the seabed. It provokes a deep reflection on the necessity to perform most underwater works at great depths (over 50 m below the sea level) with the application of submarine vehicles, considering all the research regarding the harmfulness of diving [3-5].

Yet another factor that directly affects the quality and feasibility of accurate measurements is the clarity of the water. The deterioration of visibility is significantly influenced by bioseston and abioseston – that is particulates of biological and non-biological origin respectively drifting in midwater. Bioseston, or in other words plankton, drifts in midwater on account of its structure, although its specific weight is similar to the specific weight of water, but abioseston, especially when the underwater works are conducted close to the sea bottom, occurs by resuspension, in other words by disturbing the seabed, in this case as a result of operating propellers of underwater vehicles, movement of divers' flippers or the uncontrolled dropping of tools.

Remotely operated vehicles may become alternative platforms for performing underwater remote sensing. The range of their works is very wide and includes support or replacement of the diver, or operating as a platform for vision technology, 'their popularity stems from the fact that they contribute to the increase of safety standards and have a direct impact on the effectiveness of performed tasks. Interestingly, now nearly 60% of all operated ROVs in the world are observation vehicles'. [6]. Thus, their main task is the evaluation of submarine situations based on TV images.

Therefore, the machine vision that is mounted on this device will be one of its most basic on-board systems. Unfortunately, standard TV images with no geometric points of reference enables only quality evaluation – good/bad, object in place/not in place. Optical systems based on the measurements made by an active scanner may become an extension to on-board systems of visual diagnostics [3,6,7].

On account of an insufficient amount of accessible reliable research on underwater laser scanning, the authors have chosen primarily to confirm the usability of a 3D scanner for underwater measurements by analysing the reliability of test object mapping. Realising that ready-made commercial solutions are in operation, it was decided that a device which is not originally suited for underwater measurements, and only a demonstration of technology, would be used. Additional objectives relate to characteristics of the received product, namely a point cloud, that is its density and uniformity, as well as determination of the effect of the aquatic medium and the construction of the device on the measurement results.

DESCRIPTION OF MEASUREMENT TECHNIQUE

A Matter & Form triangular 3D scanner, a compact device for making point clouds and models of 3D objects with the maximum diameter of 18 cm and height of 25 cm, was adopted as a measuring device. After the scanner has been set up, it is composed of a vertical scanning part, as well as a horizontal part with a revolving dish that enables measurements of the entire object. The scanning element of the device is manoeuvred along a vertical threaded screw, enabling the scanning of the object in its full range of 25 cm in height.

The dish in the horizontal part is a round, rubber (for better stability of the object) element upon which the scanned object is mounted. Next, by turning the dish by angle value, default (1.5 deg) or defined by the software user, it is possible to spread the beam evenly across the surface of the entire object. For the purposes of the test, it was not necessary to swim around the object and place the measuring system there, as needs to be done under actual operating conditions.

Additionally, within the casing there is a DC power port and an USB port for connecting the unit to a computer.

Fig. 3. Matter & Form triangular scanner [8].

The operating principle of the scanner may be presented as obtaining the spatial structure of a visible object from photographs taken by a camera, which make a two-dimensional rendering. For this purpose, a method of optical triangulation is used, which is supported by the laser beam. Each change of position of the projected laser beam is gradually imaged and then recorded.

This system is based on simple trigonometrical relationships. In order to solve the issue of measuring spatial coordinates of points, one only needs to determine two angles (α, β) and the length of the baseline (figure 4). The angle of the α laser beam incidence and the distance between the diodes of the laser emitter and the optical centre of the camera are familiar and follow entirely from the structure/geometry of the measurement system. The β angle at which the reflected and diffused laser beam has been recorded by the CMOS sensor, which is indispensable for calculations, is in turn dependant on the distance of the scrutinised object to the measurement system *z* and is dynamically determined in each measurement [%quote]. The next step only consists in calculating the missing angle between the incident beam and the reflected γ beam, as well as the shift of the recorded point from the measurement system *z*, with the following equations:

$$y = 180° - (a+b)\ [°] \qquad (1)$$

$$z = (D * sina * sinb)/(siny) \qquad (2)$$

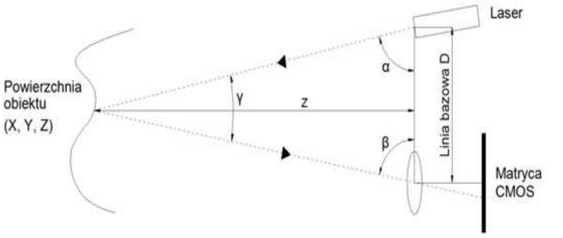

Fig. 4. Method of Optical Triangulation.

The optical system (measurement system) is composed of two diode lasers (fig. 5) (LED array of unidentified dimensions) characterised as: 'safe for the eye, with a spatial pulse length between 100 and 200mm' [technical dialogue with the producer].In relation to a significant disparity and asymmetry of the beam that is typical for this type of technology, which might affect an essential measurement feature, namely the high-precision illuminating of a part of the object, the lenses used most probably create a beam of much better properties, yet still burdened with some energy losses.

The simplest and least expensive solutions that were most likely to be used in the Matter & Form scanner beam formation are effected through spherical lenses.

According to the operating theory of a triangular scanner, laser diodes are placed on both sides of the recording unit (a camera) at differently set angles (Fig.5). The application of two lasers in a different geometrical configuration in place of one, as in a classic arrangement, is meant to accelerate the measurement, reduce blind spots that are not lit with a single beam and increase precision by a twofold determination of coordinates.

The module that records the image is equal in terms of hierarchy in the optical system. In the case of Matter & Form scanners the recording of the image is effected through a Logitech camera originally adapted as a webcam.

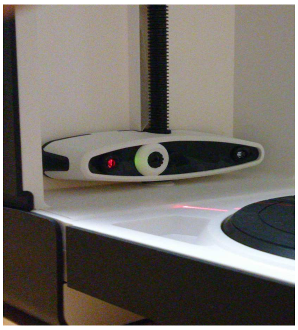

Fig. 5. The structure of an optical system [own research].

The last element that is responsible for collecting data is the computer together with the dedicated Matter & Form software. On account of the fact that the scanner is a device which only performs a measurement, it needs a superior unit that would be responsible for the calibration, recording and the first visualisation of the measurement and its residual processing. Thus, the velocity of processing raw data depends solely on the parameters of the computer's processor, the support by a graphic unit and the velocity of write/read from random access memory RAM. The connection is effected through the USB wire mentioned earlier while discussing the scanner.

The measurements were taken by simulating a scenario in which the built-in scanner in the system had been adjusted to taking underwater measurements, a situation which prompted the use of various experimental transparent shields in order to simulate the viewing ports through which the device would need to look in an underwater environment.

Initially, while conducting a number of trials, sheets of sodium calcium glass and a sheet of acrylic glass (plexiglass) were used to simulate the presence of such a viewing port, but without allowing for the impact of the marine environment. This served as a verification of the device itself, a test to check if it was capable of overcoming a transparent obstacle positioned in front of the laser beam.

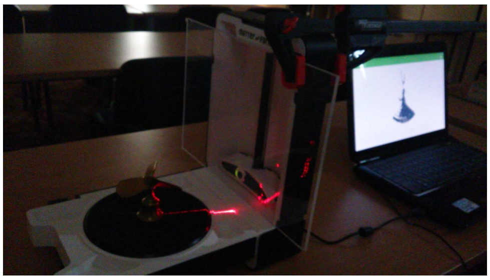

Fig. 6. Measurement through a sheet of plexiglass [own research].

In the following measurements, for the purpose of examining the properties of the medium when penetrated by a laser beam, glass containers of varying size and geometry were used which was later directly reflected in: varying thicknesses of water positioned between the optical system and the object, as well as varying the shape of the viewing port.

A verification of the measurement method was performed by measuring a single object which imitated a brass screw propeller. The object was small enough for its entire surface to be scanned. At the same time it was complex enough in terms of geometry and had a number of details that enabled an accurate examination of the device and the measurement method's potential. There were four series of tests conducted, after each series, the environment the studies were conducted in were modified, so that with each step it became closer to the environment of target implementation, i.e. a measurement by remote operation with an underwater device.

In the first series with emptied vessels, a measurement taken in a small cuboid aquarium showed better results with respect to the number of measured points, their coherence and number of errors. During the rotation of the scanner, the walls of the aquarium formed a flat-wall viewing port, which was not an obstacle for a scanner, as with the earlier measurements through a pane of glass and plexiglass. Errors occurred only at a specific angle of incline of the aquarium walls (both the longer and the shorter one), which were probably due to the angle of incidence of the rays of both laser beams and the angle at which the incident beam was being recorded by the camera. Of course, in the places where walls meet up, which are opaque themselves, the laser beams did not reach the object (a screw).

In the case of a cylindrical vessel with the diameter of 18 cm, the errors mentioned before, the coherence of points and the possibility of an unambiguous interpretation were at a lower level than in the small aquarium. One could observe an occurrence of a number of points recorded on the surface of the vessel and dispersed points that were difficult to interpret; it is possible that this was the result of the optical system being utilised – the vessel acting as a convex-concave lens which has dispersing properties, but equally the optical imperfections of the vessel's glass from which it was made could have been to blame.

Fig. 7. Measurement in a round vessel in a series of measurements without water [own research].

As all the trials without water were successful and the results did not vary from each other significantly, it was impossible to determine a right choice of the appropriate viewing port for the next stage of the experiment. In the following two measurement series, the possibility of measuring an object submerged in water (distilled and sea water) by the scanner was examined. In spite of initial concerns about the limitations that follow from optical properties of said created systems – the presence of water, the refraction of a beam at the border of two mediums, the distance between the transparent viewing port and the optical system of the scanner, the course of measurements was correct and the points were recorded.

The cylindrical vessel in this case behaved much better than the cuboid aquarium. First of all, the screw was imaged accurately so that it was possible to recognise the object (fig. 8). However, a large number of erroneous points were recorded (dispersed). In the case of the aquarium, although they were coherent in places, the points may have been interpreted as elements of a real image of the propeller that was being examined only with the previous knowledge of the scanned object (fig. 9). Following the aforementioned conclusion, it was only the cylindrical vessel that was accepted for the sea water experiments.

In the last series of measurements (sea water) (fig. 10), according to the experiments with distilled water, the screw was imaged correctly. However, one could observe the appearance of some points at the bottom of the vessel that were previously unrecorded, which was most likely to be an effect of sedimentation of particulates, as well as a fair amount of points within the vessel which was an indication of much lesser clarity (fig. 11).

The fourth series of measurements was a reference series conducted in order to faithfully render the screw, which also served for the purposes of comparison as a reference model. The vessels were disposed of and the screw was laid on the scanner dish, as if taking standard measurement as per the methodology indicated by the scanner's producer. The course of the measurement was more than successful and the screw was recorded very accurately (fig. 12), whereas the received density of points enabled a reliable evaluation of accuracy and correctness of other measurements in a relevant software.

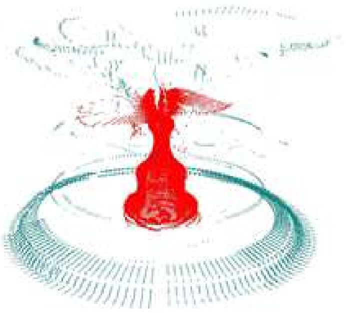

Fig. 8. The scan of the object in a cylindrical vessel with distilled water [own research].

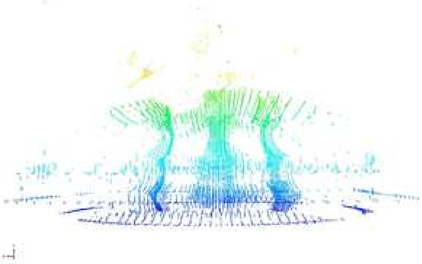

Fig. 9. The scan of the object in an aquarium with distilled water [own research].

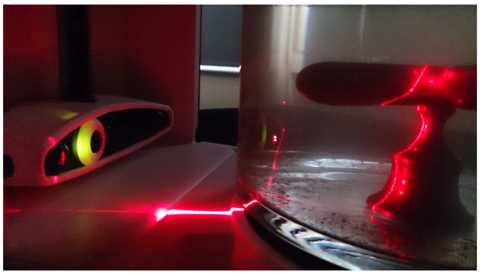

Fig. 10. Measurement in sea water [own research].

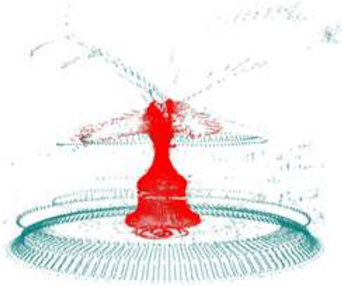

Fig. 11. The scan of the object in a cylindrical vessel with sea water [own research].

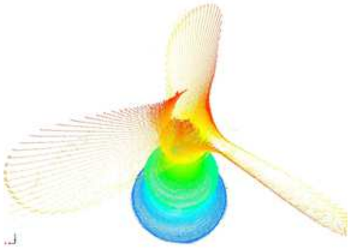

Fig. 12. The scan of the object which serves as a reference model in the following part of the experiment [own research].

Two computer programs that are suited to working with 'point clouds' were used in the course of data processing: RiScan Pro and Cloud Compare. The former, which is not a tool for visualisation, dimensioning and filtration, served as a source of graphic documentation of the obtained object and the preliminary determination of the faithfulness of the image through taking measurements of characteristic dimensions and the elimination of evidently erroneous points. (Fig. 13).

It is worth noting that, as a default, the programme imported the point cloud with units given in metres, whereas in fact they were milimetres. This was due to the lack of possibility to define the units of measurement at the level of exporting from the Matter & Form software in the *.ascii format.

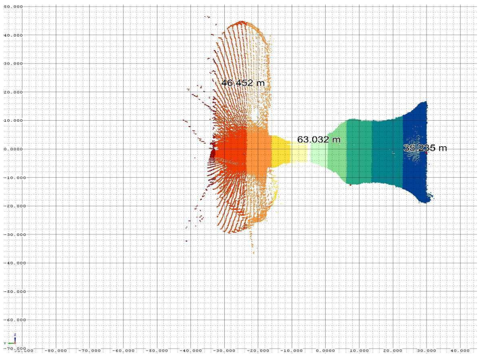

Fig. 13. Dimensioning in the Riscan PRO software [own research].

Cloud Compare, as the name suggests, is a programme that enables the detection of changes in 'point clouds' of identical objects. This task consists in fitting one cloud to another with the use of the least square approach from two sets of data and automatically finding the differences with previously marked data sets i.e. the cloud, which is an object of reference. The programme enables visualisation of the result in the form the RGB distribution of colours laid on the points: the closer to the colour blue, the smaller the deviation of the shape, and conversely, the closer to the colour red, the larger, together with the distribution of densities of individual results (fig. 14).

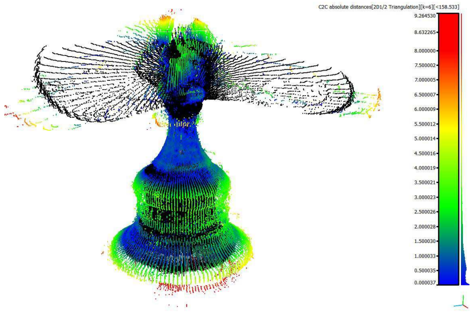

Fig. 14. Comparing in the Cloud Compare software [own research].

CONCLUSIONS AND FURTHER RESEARCH

Verification of the 3D scanner for the suitability for underwater photogrammetric measurements was successful. We were able to achieve satisfying results having at our disposal equipment that was not adapted to this type of works. This provided the basis for concluding that the used technology can be applied in larger scale works, e.g. in surveying and diagnostics of submarine infrastructures. According to the authors, in the light of the accuracy of the achieved results, such a measurement system would ideally complement the measurements taken with multi-beam ultrasonic probes in the case of objects that require an increased precision of detection.

From the point of view of optics, the best results were achieved with flat viewing ports. The best solution in the laser measurement system adapted to measurements taken in an aquatic environment would be a viewing port in the form of a flat parallel plate from acrylic glass strictly adhering to the emitter of the beam and the lens of the camera. The plates would be an integral part of a watertight casing of the scanner that would protect it from water. A negative effect of the plates on the measurement may be simply removed, as the measurement device can be calibrated. Calibration should be performed before each measurement so as to take into account the effect of the quality of the water and the thickness of the water layer in the case of the inspected object being placed at a larger distance from the measuring device.

A complex geometry of the object proves to be problematic in optical measuring systems. In the course of scanning a particular section, one must pay attention to the position of the optical system of the scanner in relation to the scanned surfaces and the number of existing edges. In cases when either the entire or part of the object under scrutiny is inclined (more than 45°) parallel to the optical axis, the so-called *slide* of the laser spot ensues. When this happens, the spot is expanded and distorted. In triangular systems the detection of points is still possible, but this phenomenon influences their recorded number.

The number of points formed during the measurement, which has a direct impact on the accuracy of the obtained image, may be increased through the use of cameras of higher resolutions according to the idea that more pixels will mean more recorded points. However, it needs to be noted that higher resolution of the recorder itself will not have an effect on the obtained accuracy as the discrepancy of the laser beam is very high. This leads to the expansion of the visible beam on the surface and thus loss of its linear/punctual nature. It makes the detection of relevant points harder, as more of the area is lit with saturated light and the light which is refracted at the surface of the object.

Therefore, it is a good idea to reduce the width of the emitted beam which will greatly improve the situation. According to the authors, a very high resolution of the camera in combination with a sufficiently thin laser line would provide sufficient accuracy and precision to a great majority of the possible applications for submarine diagnostics, as well as accurate determination of edges.

Future development of contactless submarine measuring technology should benefit from comparisons with a point cloud made with laser scanning, and a point cloud generated with the use of photogrammetric techniques (only photos) (fig.16), forming a reconstruction of points made by a multiple spatial resection. Such developments are possible thanks to the Structure from Motion technology mentioned earlier, i.e. the accurate photographic documentation of a submerged object, overlapping consecutive photographs, and with the application of a high resolution camera. This occurs for the corresponding pixels on the consecutive recorded images (Fig. 15).

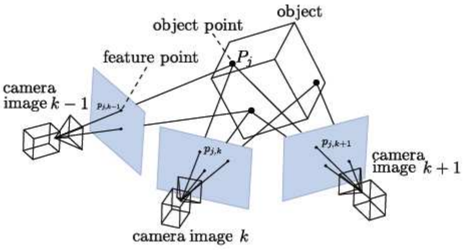

Fig. 15. The principle of the SfM technology operation [9].

Fig. 16 A fragment of a point cloud generated from underwater photographs [10].

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