ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/12314005.1137841

THE SYSTEM OF MEASUREMENT OF UNDERWATER OBJECTS WITH THE VISUAL METHOD

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Abstract

This material presents the results of works implemented so far at the Department of Underwater Works Technology of the Polish Naval Academy in Gdynia within the project No. O N502 274039 focused on an attempt to prepare theoretical assumptions for the visual diagnostics system for underwater objects. The main accomplishments until now have been the preparation of a mathematical model allowing specification of dimensions of photographed underwater objects and construction of a prototype underwater photogrammetric camera together with software used in frame analysis. Moreover, the project involved carrying out experiments resulting in an initial assessment of the prepared method. Currently obtained results indicate that the measurement method under verification based on a light model constitutes a rough measurement method. Relative uncertainties regarding the measurement of linear quantities at average amount to 10%. What has a significant impact on the size of this error is the fact of defining nodal points in relation to figures and segments analysed in a given frame with the use of a cursor manually controlled with a computer mouse. This leads to the conclusion that 'manual' introduction of nodal points for the examined figures constitutes the weakest element of the verified measurement method and its modification will be the main objective of further research. It is expected that the CYKLOP camera and the application prepared for its operation will constitute a system for a technical assessment of underwater objects on the basis of visual research. This will be an important leap in relation to the quality of the visual examination of underwater objects, as the methods used so far allowed only qualitative assessment of objects. The constructed system will, on the other hand, enable obtaining both qualitative and quantitative data.

Keywords: *underwater works technology, underwater photogrammetry, technical diagnostics*

1. Introduction

The essence of the research project No. O N502 274039 under implementation since the year 2010 rests in the attempt to work out an efficacious method for a remote specification of dimensions or a size of damage of underwater objects with the use of a visual system aided with a laser or sonar system mounted on a remotely operated abyssal vehicle (ROV). In prospect, the method is to allow visual assessment of technical state of underwater objects at a full scope of operational depths determined by constructional parameters of a given vehicle.

The issues discussed within the project combine elements of underwater work technology, technical and visual diagnostics, as well as underwater photogrammetry. At the phase of project implementation in 2010, a number of analyses were conducted with the aim of particularizing the problem area. One of them, for instance, dealt with analysing underwater objects from the point of view of technical diagnostics, which provided a new classification of underwater with assigned target functions and structure parameters within the aspect of visual diagnostics. Further analysis concerned the current state of technology of remotely operated vehicles (ROV) based on vehicle constructions available in the world as of the year 2010. The results showed that nearly 60% of all the operated ROVs at that time served only as observational vehicles, which means that their main task rested in conducting underwater situation assessment based on a supplied visual system. This confirmed the right direction of research proposed by the project – working out new visual system constructions to be installed on ROVs. Another examination involved defining the current state of underwater photogrammetry. The tests were performed by analysing synaba cards from research projects realised since 1999 and bibliographic-abstract Internet databases specifying the contents of Polish scientific publications (articles published since 1998). The synaba card analysis showed that in the period between 1999 and 2010, there were 50 research projects realized in connection with photogrammetry. The majority of them concerned the use of photogrammetry in geodesy (44%), in agriculture (24%), and engineering photogrammetry (16%). The other areas where photogrammetry was used included forestry (8%), medicine and monument examination (6%). The synaba card database indicated only one project related to underwater photogrammetry, i.e. 2% of all the research projects realized in the said period, and it is the project that is discussed in the presented material. As for technical diagnostics, the database indicated 148 projects realized in the years 1999-2009, among which none tackled the issue of underwater object diagnostics. The analysis of databases containing full publications of selected magazines showed, on the other hand, that within the last 5 years none of the authors whose works were noted in the analysed databases defined their research areas as underwater photogrammetry or visual diagnostics of underwater objects.

The above analyses showed that the development of underwater photogrammetry in Poland stopped in the first half of the 1980s at the level of analogue photography with the use of classic photographic cameras taken by divers to smaller depths. This was practiced mainly in connection with underwater archaeology.

2. Assumptions of the prepared method

The mathematical model was prepared for an optical system lens – illuminator – water; the model accounts for the parameters of the camera's internal and external orientation and allows the determination of flat coordinates of a photographed object on the basis of a single photograph:

$$X = \frac{D(x cos\varphi cos\chi - y cos\omega sin\chi - sin\varphi)}{-x(sin\omega sin\chi - cos\omega sin\varphi cos\chi) - y(sin\omega cos\chi + cos\omega sin\varphi sin\chi) + f cos\omega cos\varphi}, \quad (1)$$

and:

$$Y = \frac{D[x(sin\omega sin\varphi cos\chi + cos\omega sin\chi) + y(cos\omega cos\chi - sin\omega sin\varphi sin\chi) + f sin\omega cos\varphi]}{-x(sin\omega sin\chi - cos\omega sin\varphi cos\chi) - y(sin\omega cos\chi + cos\omega sin\varphi sin\chi) + f cos\omega cos\varphi}, \quad (2)$$

where:

D – distance from photographed object,
-f – focal length of the camera, '-' means that the photograph is made in positive position,
ω, χ, φ – direction angles of the camera's spatial orientation,
X,Y – coordinates of the object,
x,y – coordinates of the photograph.

Whereas the scale of a photograph is expressed with the following equation:

$$\frac{1}{\lambda} = \frac{f}{D}\left(cos\upsilon - \frac{y}{f} sin\upsilon\right)\sqrt{\left[\left(cos\upsilon - \frac{y}{f} sin\upsilon\right) cos\phi + \frac{x}{f} sin\upsilon sin\phi\right]^2 + sin^2\phi}, \quad (3)$$

where:

λ – photograph scale,
F – focal length,
D – distance between the photographed object and the projection centre,
X – abscissa of a point in the photograph,
Y – ordinate of a point in the photograph,
Φ – bearing angle of a section in the photograph,
υ – photograph's bearing angle.

The key parameter for calculating the equations is the image distance of a photogrammetry camera [5], which is unknown for the prototype prepared and constructed within the project, as the optical system supplied together with CMOS converter has been enriched with an illuminator.

Moreover, the entire camera together with the casing operates in aquatic environment, whereas the camera manufacturer specified the value of image distance for a system operating in the air.

The specification of image distance of a camera operating under water has been conducted on the basis of experiments applying horizontal method for determining image distance [3, 4]. The method allows an experimental specification of horizontal angles in the field and distances in the photograph [4]:

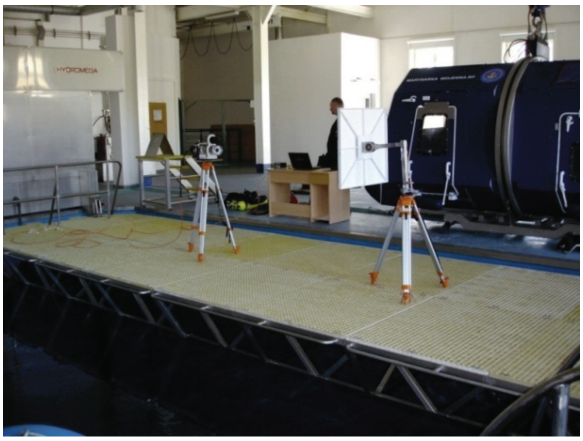
$$f = \frac{k(x_2 - x_1)}{x_1 cot\alpha_1 - x_2 cot\alpha_2}. \quad (4)$$

The equation (4) helps to determine the actual focal length of an optical system. In order to compare its value with the data provided by the manufacturer for CMOS converter, the said data need to be transposed into an equivalent focal length for an analogue optical system [2]. The remaining parameters necessary for solving the equations (1), (2) and (3) are obtained by measuring angles with the use of inertial sensor installed in an underwater photogrammetric camera. Initially, it was planned to delimit the distance between the object surface and the projection centre (D) with the use of a laser rangefinder. For this purpose researchers conducted an analysis of application of laser radiation sources for performing distance measurements under water. Its results showed that the optimal source is a tuneable laser operating within the wave length range from 540 to 670 nm. However, the application of this method may be inconvenient due to frequent presence of detritus (marine snow) in sea water, which leads to significant measuring errors. [1]. For this reason, it was decided to apply a hydroacoustic meter for determining the D value. Further activities allowed to work out a method for the evaluation of dimensions or sizes of damage of underwater objects with the use of a light model placed on a researched object with the use of a laser matrix coupled with the lens of an underwater photogrammetry camera and the software used in the analysis of digital photographs obtained in an aquatic environment. The light model laid out by laser is used to generate a triangulation network allowing the measurement of objects visible in a given frame.

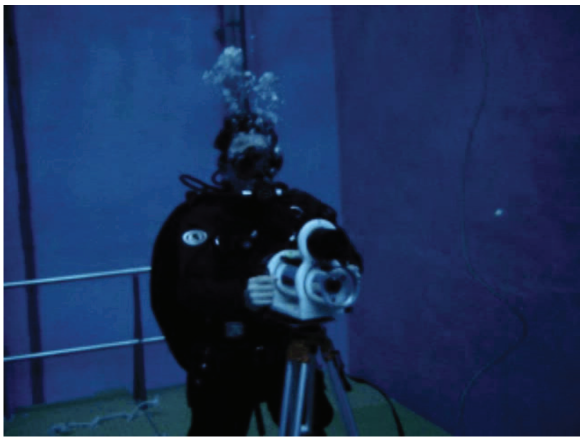
3. The research

The research was performed by courtesy of the Polish Army Training Centre for Divers and Scuba Divers (Gdynia, Poland) in a special diving pool with the depth of 10 metres, equipped with a moveable platform enabling regulation of depths at which the measurements were taken.

Before experiment commencement, a specially constructed for this purpose CYKLOP (Fig. 2) camera used in the measurements and a test board were mounted on the moveable platform over the water surface. The distance between the plane of the lens and the board was set at 2000 mm. After level verification and correction the entire platform with the prepared measuring station was immersed to the depth of 5 metres (Fig. 1).



A



B

Fig. 1. Measuring station used in the experiment A – before platform immersion to the depth of 5 metres, B – a diver operating the station at the depth of 5 metres

A *B*

Fig. 2. Underwater photogrammetry TV camera CYKLOP: A – complete working set, B – tarnsportive complete set

In the course of tests carried out under water the test board with flat objects of known and unknown geometric dimensions was filmed. The obtained frames were then analysed with the use of Skala software prepared within the project (Fig. 3). Exemplary measurement results are presented as Fig. 4.

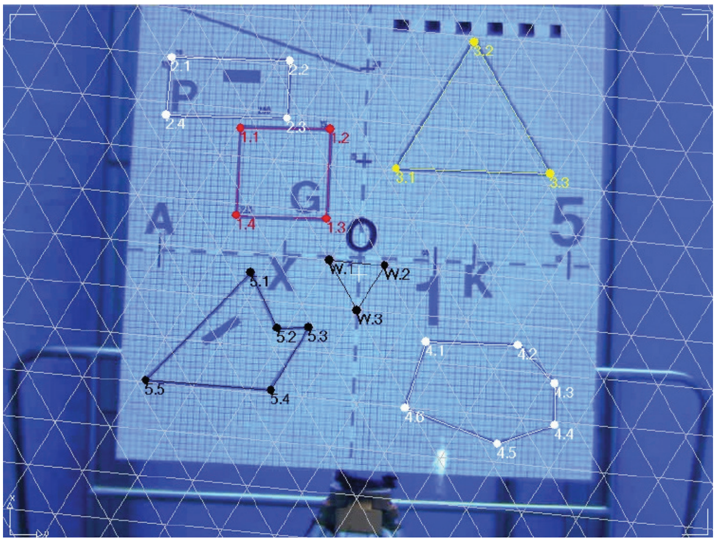


Fig. 3. An exemplary frame obtained with the use of Skala software

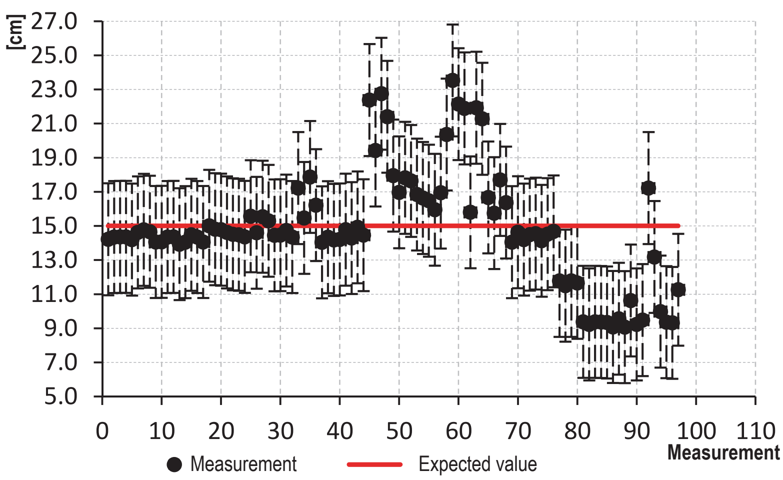


Fig. 4. An exemplary distribution of measurement results for the vertical section of figure G with analytical method ($\sigma_x = 3.3\ cm$)

4. Conclusions

The conducted tests constitute the basis for undertaking further experiments aimed at the verification of the prepared mathematical model. Currently obtained results indicate that the measurement method under verification based on a light model constitutes a rough measurement method. Relative uncertainties regarding the measurement of linear quantities at average amount to 10%. What has a significant impact on the size of this error is the fact of defining nodal points in relation to figures and segments analysed in a given frame with the use of a cursor manually controlled with a computer mouse. By way of example, the measurement scale for the vertical segment of figure G calculated by the software in a single measurement series ranged from 0.0482 $\frac{cm}{px}$ to 0.1293 $\frac{cm}{px}$. The standard pixel size for the Windows system is equal to 0.26458 mm, whereas the standard picture definition for this system is 96 dpi. This means that each 1 mm of the frame displayed on the screen consists of ca. 4 pixels, and consequently even the slightest cursor movement of 1 mm may introduce an error in calculations amounting to ca. ± 0.2 cm for the scale 0.0482 $\frac{cm}{px}$, and ca. ± 0.5 cm for the scale 0.1293 $\frac{cm}{px}$. For the expected value equal to 15 cm the error reaches from 1.3% to 3.3% of the measured value, i.e. from 13% to 33% of the values observed in error measurements. As we may easily deduce, cursor movement of 2 mm will cause an increase of the said values and reach from 26% to 66% of the error value. This leads to the conclusion that '*manual*' introduction of nodal points for the examined figures constitutes the weakest element of the verified measurement method and its modification will be the main objective of further research. It is expected that the CYKLOP camera and the application prepared for its operation will constitute a system for a technical assessment of underwater objects on the basis of visual research. This will be an important leap in relation to the quality of the visual examination of underwater objects, as the methods used so far allowed only qualitative assessment of objects. The constructed system will, on the other hand, enable obtaining both qualitative and quantitative data.

Acknowledgement

Scientific work financed from educational funds as an own research project No. O N502 274039.

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