LASER OPTRONIX

AquaLynx the gated system of underwater laser vision

TECHNICAL REQUIREMENTS AQUA LYNX SYSTEM

Pos.	Parameter	Typical Value	Minimum or maximum value, if applicable
1.	Increase of *detection* range of the white disk with a diameter of 300 mm in passive mode, in comparison with the detection range zw by means of a standard method. Comparison conditions. 1. zw is the depth at which a white disk with a diameter of 30 cm barely may be seen when an observer is at shade side of ship and look down on the disk through air into water. 2. The system is dipped into the water including input and output windows.		not less then 1.1 times
2.	Increase of *detection* range of the white disk with the diameter 300mm in gated mode, in comparison with detection range zw of the disk by means of a standard method. Comparison conditions. See point 1 of the table.		not less then 2.1 times
3.	Range, in passive mode, within the white disk may be *identified* in comparison with the identification range by means of a standard method. Comparison conditions. See point 1 of the table.	equal to the standard method	
4.	Increase of the *identification* range, in gated mode, within the white disk may be identified. Comparison conditions. See point 1 of the table.		not less then 2 times
5.	Type of laser	Nd^{+3}: YAG solid-state	
6.	Pulse duration. (full width at half of maximum, FWHM)	7 - 10 ns	< 10 ns
7.	Pulse repetition frequency	0,2 Hz	> 0,18 Hz
8.	Pulse energy	35 mJ	> 25 mJ
9.	Wave length	0,54 μm	

10.	Sensitivity of gated TV camera	10^{-4} lx	
11.	Angle of view in water	5-30 degrees	
12.	Resolution	350 TV lines	> 320 lines horizontal >200 lines vertical
13.	Thickness of the viewed water layer, in gated mode	Controlled from the computer in steps from 2 m to 10 m	Smallest thickness must be < 3 m
14.	Distance settings of the distance from camera to viewed water layer in gated mode	Controlled from the computer in steps from 3 m to 100 m	Shortest distance must be < 3,5 m
15.	Maximum possible visible distance in absolutely clear water	100 m	> 30 m
16.	Minimum possible visible range	3 m	< 3.5 m
17. 17.1 17.2	Power consumption Underwater part of the system Ship's equipment	 80 W 100 W	 < 100 W < 120 W
18.	Power supply of ship's equipment	220V; 50Hz	
19. 19.1. 19.2.	Overall dimensions inside underwater equipment dimensions of illumination unit dimensions of receiver unit	 150 mm (diam) x 300 mm (length) 150 mm (diam) x 500 mm (length)	
20.	Weight of contents inside underwater equipment	Max 15 kg	
21.	Complete weight of underwater part of the system, excluding cable	30 kg	< 45kg
22.	Complete volume of underwater part of the system	Two steel or aluminium alloy tubes located on a metal frame, each tube has diameter 165 mm and length 600 mm, which gives a typical displacement of 25 litres	displacement volume: < 35 litres
23.	Operating temperature range, water temperature, t		-5 < t < 25 degrees centigrade
24.	Operating temperature range, air temperature, a		-10 < a < 30 degrees centigrade
25.	Storage temperature range, s		-10 < s < 40 degrees centigrade
26.	Cable length between the ship's equipment and	80 m	> 60 m

	underwater unit		
27.	Depth rating of underwater unit	80 m	> 60 m

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There are two basic parameters that characterize an underwater vision system: limiting distance and resolution. The principal limit of the limiting vision distance is exponential light decay with distance (L) **$I \sim I_0$ exp(-□L)**, caused both by light absorption (□) and scattering (□) in medium in such a way that index of decay □ is equal to the sum of indexes of absorption and scattering **□=□+□**. The light decay in water depends on the radiation wavelength and has a characteristic minimum in a green-yellow range of spectrum. The existence of the green-yellow window of transparence in water determines the optimum spectral range of light sources and receivers. Table 2 represents typical mean values of □ corresponding to minimum of spectral response for various regions.

Special feature of water is its significantly greater decay in comparison with atmosphere **(□$_{water}$/□$_{atm}$)~10^3**, that is a result of the fact that density of water is greater that of atmosphere by factor of 10^3. Therefore is the vision distance in atmosphere can reach tens of kilometers, in water in can be tens of meters and exceeds 100 meters in a pure water.

Existing underwater vision systems can be separated into two classes, passive systems operating under natural illumination at shallow depths, and active systems using additional light sources operating both in a continuous and pulsed mode. The present report describes a newly developed system of underwater vision that can operate in a passive mode and in an active mode, exactly, in an active-pulsed mode with a temporal gating or temporal cut-off of a back scattered background. In the matter of fact, when using an active illumination it is necessary to solve problems with the suppression of a background illumination connected with the light scattered back in the medium. This share of light reduces the signal-to-noise ratio, image contrast and limits the maximum accessible vision distance. A scheme of back scattering suppression is based on the spatial selection of zone of observation (see fig. 1). The selection is carried out either by geometric spacing of the light source and receiving camera or by the temporal cut-off of the background signal when using pulsed light sources. In a mode of operation with temporal cut-off of the back scattering interference, the receiving camera is always shut and opens only at the moment when

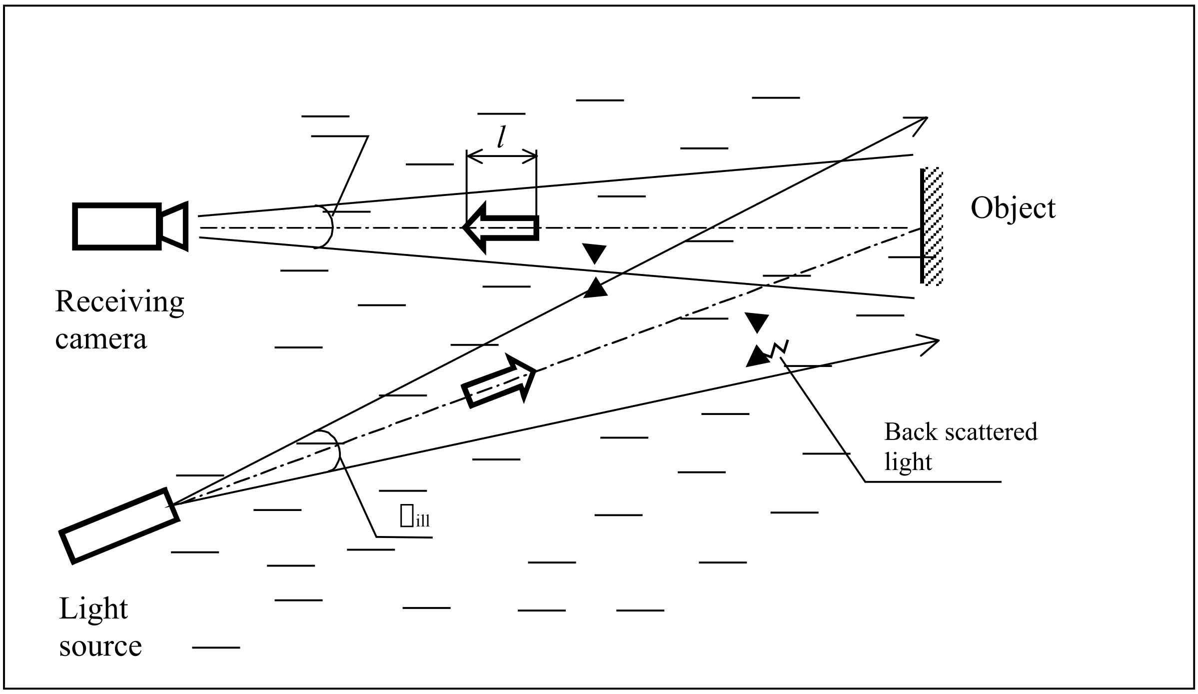

Fig. Scheme of back scattering suppression based on the spatial selection of zone of vision

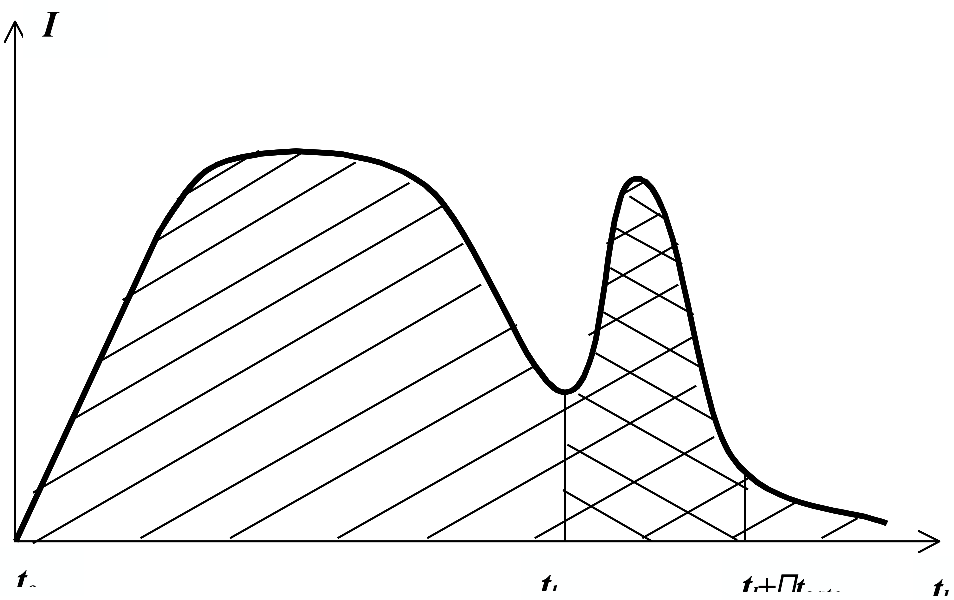

Fig. 1. Time dependence of light intensity on the receiving camera gating.

a useful signal enters. This is the mode that is realized in the vision system under consideration. Let us take a look at the mode. A light pulse with a duration of t_u, spatial length of $l=c\ t_u$, propagating with an illumination angle $\square_{ill}$, is emitted at the moment of time t_0 (see fig. 1). As the light pulse is propagating in water a light share, defined by the receiving angle $\square_{rec}$, is scattered back from the illuminated layer of water and falls into the receiving camera. But during all this time the receiving part of the camera is shut and only at the moment of time t_1, when a useful signal reaches the camera it opens and stay opened for a duration of the gate pulse $\square t_{gate}$. Therefore, only a layer of water of $\square l=l/2\ c\ \square t_{gate}$ in depth at the distance of $L=l/2\ c\ t$ can be seen. Varying a delay between the moment of light pulse emitting and the moment of the camera opening t_l, one can vary the distance to the zone of viewing. It can be easily seen on the fig. 1, that at presence of the gate the signal-to noise ratio is increased by factor of (S/s), where S is the total area under the curve of the medium back scattering signal, and s is the area under the curve of back scattering at the time range of (t_l, $t_l+\square_{tgate}$).

The underwater vision system consists of three main parts (see fig. 2), namely, the emitting part, the photo receiving part and a unit of image recording and processing.

The emitting part incorporates an emitter itself, a power supply unit and a cooling unit. The light emitter is a Nd+3:YAG solid-state laser with frequency doubling (l=532 nm) encapsulated in a sealed metallic housing with dimensions of 70x70x500 mm3. An optical system provided at the emitter exit allows to vary the angle of illumination from 60o to several minutes. Distilled water is used as a coolant.

The photo receiving part consists of an image intensifying tube with a micro channel plate (MCP), conjugated with a CCD camera.

The receiving camera is capable of operating in two modes, passive and active.

The image processing system is made on the base of a IBM PC compatible computer. The image is entered by means of a standard image input/output board.

Basic system parameters are represented in Table 1.

Table 1

	CAMERA	MONITOR	LASER
Weight, kg	3	7.5	12
Dimensions, mm (LxHxW)	170x160x105	310x215x215	380x90x275
Power supply	12 V (from the monitor)	AC 220 V, 50 Hz	AC 220 V, 50 Hz
Resolution	400 TV lines	450 TV lines	-
Field of view	60^o F=14/2.3 14^o F=37/1.1	-	-
Minimum illumination	0.002 lx		

The system was tested in the optical pool of the Institute of Physics of Belorussia. During the tests special test objects with black and white hatching were used as objects of viewing to estimate the system resolution. Maximum pool length is 40 meters, that factor defined the range of controllable delays.

Investigations of the system performance in various media showed that the limiting vision distance could be represented as $□ = □L_{lim} = 8$, where □is optical density of water.

Or $L_{lim} = 1.8\ z_w$, where z_w is the depth at which a white disk of 30 cm in a diameter is not seen. In a number of publications it was suggested to represent a relationship between the depth of the white disk disappearance out of view and the index of light decay as $□z_w = □$. A value of 4.7 - 5 is considered to be the most probable value for □. Table 2 represents typical values of zw and maximum accessible vision distances for various regions, resulting from the experimentally obtained data for $□L_{lim} = 8$.

Table 2

REGION	$□(m^{-1})$	z_w(m)	L_{lim}(m)	L'_{lim}(m) (estimated)
Baltic Sea	0.5	9.4	17	28
Black Sea	0.3	15.6	28	44
Open Ocean	0.1	47	84	113
Sargassian Sea	0.07	67	120	153

Also shown in Table 2 are simplest estimations for the limiting vision distance at the camera sensitivity of 10^{-4} lx under the conditions of total suppression of the back scattering, that corresponds to the mode of gating and taking into consideration of only a single back scattering when the process of light decay in water can be described by the law of Booger. In this case, taking into consideration a geometry of illumination and registration, the illumination on the photocathode can be represented as follows:

$$E = 680 \frac{P_0 \rho e^{-2\varepsilon L}}{\pi \theta^2 L^2} g^2 \qquad \textbf{(1)}$$

Where P_0 is the source power (3 MW),

ρ - reflection factor (0.5)

θ - angle of illumination (0.5^{o})

L - distance to the object

g - lens aperture (0.5).

Numerical values used in **(1)** correspond to the conditions of the experiment.

Results of calculations using (1) show that the increase of energetic parameters of the system (sensitivity of photo receiving camera or light source intensity) of 10 times leads to the increase of the parameter $\tau = \varepsilon L$ only by a unit. It means that for water having ε=0.1 m^{-1} the distance increases by 8 meters and by 2-3 meters for ε=0.3 m^{-1}. This condition should be taken into account in the design of vision systems in order to choose an optimum source energy and sensitivity of the photo receiving camera.

In addition to the maximum accessible distance of vision a vision system is characterized by the quality of image. The image quality is defined by the system resolution and image contrast. The resolution of the camera is 400 TV lines at the contrast level of 0.1. For example, when operating in water with ε=0.36 m^{-1} or z_w = 25 meters, the resolution drops down to 250 TV lines.

Use of the suppression of back scattering allows to double the vision distance as a minimum in comparison with a static vision mode at the same active illumination.

The video signal outgoing from the camera is a standard broadcasting signal. This gives an opportunity to record the image by means of a video tape recorder simultaneously with a visual control. Additional signal processing is provided to improve the image quality. For this purpose a computer based system of image input and processing was developed. The additional signal processing allows to increase the image contrast and pick out a useful information against a background of interferences.

At present the developers work hard on the problems of vision system resolution increase and reduction of power consumption and dimensions and weight of the system.