

# Laser Photography Device — Spatial Parameters of Imaging

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Laser photography device is an imaging device developed in the Institute of Optoelectronics, Military University of Technology and it is an example of modern image acquisition device. The laser photography device allows to define a 3D observation scene thanks to short-time scene illumination and image acquisition method. This device works according to time–spatial framing method. In the paper, basics of time–spatial framing method are explained. Special attention is given to time parameters of device and their influence to spatial parameters of registered images. In this paper the laser photography device and results of chosen experiments are presented and described. Experimental results presented in the paper show the potential and possibilities of using the laser photography device as a camera for observation and measurement applications.

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## 1. Introduction

Modern vision systems offer great observation–measurement possibilities and play huge role in the recent information systems. One of the most interesting vision devices available on the market are time-of-flight (ToF) cameras [1, 2]. A characteristic feature of these active imaging devices is the ability to measure distances to objects. We can distinguish several types of ToF cameras according to the method of acquisition of spatial information. One of the methods is range gated imaging, which offers the ability to selectively register imaging information. Special property of the range gated imaging consists of the possibility to register image for defined distance and depth of observation [3, 4]. Registered images are not just a projection of angular observation range but are a representation of precisely defined three-dimensional fragment of space.

The laser photography device (LPD) developed in the Institute of Optoelectronics, Military University of Technology operates according to the time–spatial framing method [5]. This method is one of the most sophisticated solution amongst imaging techniques. The range of observation of the LPD is strictly connected with the conditions of propagation of electromagnetic wave. When operating in standard atmospheric conditions with using high-energy nanosecond laser pulses and nanosecond shutter, it is possible to register images on distances below 1 km with the spatial resolution below 1.5 m.

## 2. Method characteristics

The key elements of most of recently used imaging technologies are the characteristic parameters of method. These parameters are mainly responsible for the observation–measurement capabilities and potential applications of method. The characteristic parameters of the time–spatial framing method are: a method of scene

illumination (short-time laser pulses  $T_i \approx 10^{-8}$  s) and a method of light detection — fast shutter  $T_d \approx 10^{-8}$  s. The most important aspect of this method is the proper settings of time relations between emitted and detected electromagnetic wave propagating in the measurement space with the speed value  $c \approx 3 \times 10^8$  m/s. According to the basic equation  $R = cT$  connecting the path of wave (laser pulse)  $R$  with time  $T$ , there is a possibility to register imaging information from the precisely defined fragment of space and time interval [6].

The fact of using the laser radiation, and the accurate relationship between time and space of imaging, was the reason of naming the method time–spatial framing method and laser photography.

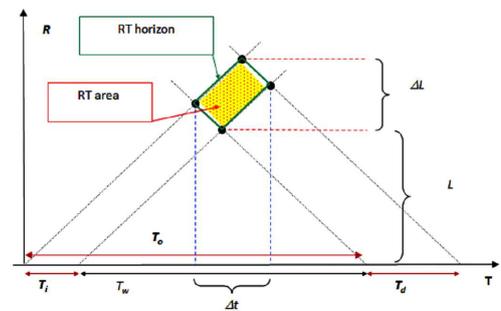


Fig. 1.  $R$ - $T$  diagram.

For better understanding, the time–spatial framing method in the  $R$ - $T$  diagram was proposed (Fig. 1). This diagram connects the information of time and space of imaging in a 2D graph.

Basic dependences:

- Time period of registered events  $\Delta t = 0.5(T_w + T_i)$ ;
- Distance to observation area  $l_{\min} = 0.5cT_w$ ;
- Depth of observation area  $\Delta L = 0.5c(T_d + T_i)$ .

Because of higher precision and easier hardware implementation, the  $T_w$  parameter (waiting time) was replaced with a  $T_0$  parameter (delay time).

$$T_0 = T_w + T_i. \quad (1)$$

Based on above equations, one can conclude that definition of distance and depth of observation area can be realized in many different ways depending on times  $T_i$ ,  $T_0$  and  $T_d$ .

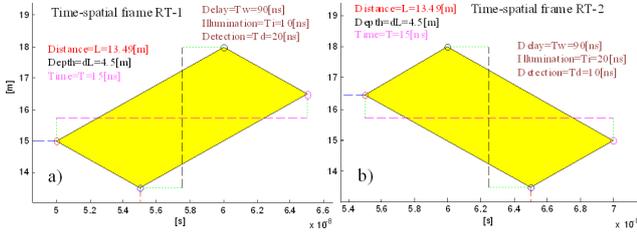


Fig. 2. Examples of time-spatial frames.

Examples of time-spatial frames in various configurations  $T_i < T_d$  and  $T_i > T_d$  are presented in Fig. 2. Apparently, Fig. 2a and b presents the same time-spatial frame. In terms of space both figures are the same but the registration took place in different time intervals in reference to the beginning of time of illuminator pulse.

From a point of view of acquisition of spatial information it is irrelevant, but besides the time gap, these two acquisitions are different because of the energetic deficit effect in variant  $T_i > T_d$ .

### 3. Device characteristics

Theoretical analysis helped us to define the key components of the camera (Fig. 3) using the time-spatial framing method:

- a) laser illuminator,
- b) image acquisition module,
- c) time parameters driver,
- d) camera controller.

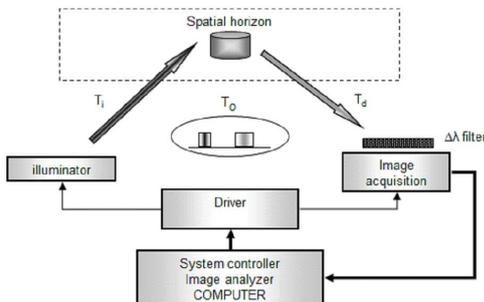


Fig. 3. Key camera components.

### 3.1. Illuminator

The laser photography device requires a pulse illuminator with parameters defined by the time-spatial framing method. The key illuminator parameters are short pulse duration time (few nanoseconds) and high energy light pulse [7]. The bigger the laser pulse energy is, the bigger distances and objects of bigger angular sizes the LPD can register.

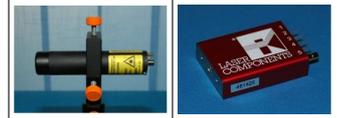
The LPD can operate in two configurations — mobile and stationary. A mobile version is dedicated to work in shorter distances (potential future applications — hand-held observation equipment e.g. binocular, gunsight or rocket system target illuminator) and uses semiconductor lasers.

The device is equipped with two semiconductor lasers with adjustable pulse duration (pulse laser diodes). Parameters of semiconductor lasers are listed in Table I.

TABLE I

Parameters of semiconductor lasers.

Wavelength	850 nm	905 nm
power	100 W	220 W
pulse duration	15–30 ns	30–100 ns
max. trigger repetition	20 kHz	5 kHz



In stationary version, dedicated for long-distance operating, high-energy laser is used. This laser offers a maximum energy of 360 mJ and it is operating at the second harmonic (532 nm) with nanosecond pulse durations (3–6 ns) and a TOP-HAT beam profile. Parameters of laser illuminators are controllable according to the requirements of the time-spatial framing method.

### 3.2. Image acquisition module

One of the most important elements of the LPD is a MCP (micro-channel plate) [8]. Thanks to this element it is possible to open a shutter for a very short time  $\approx 3$  ns. Another very important properties of the MCP is high sensitivity, amplification of image (10000 cd/m<sup>2</sup>/lx) and extension of image glossing time. Image is registered by a synchronous camera module equipped with CCD ProgressiveScan sensor with the resolution of 1360 × 1024 pixels.

### 3.3. Driver module

The image acquisition method of the LPD requires to use a driver module for synchronization of modules of illuminator and image acquisition. A prototype driver module can generate controlling signals with the resolution of 1 ns with jitter < 0.2 ns.

All of elements of the system — the MCP, the camera, a controlling module, the semiconductor laser illuminator and a PC-computer are mounted in one housing. This



essential LPD verification tests are shown in Fig. 5 and Fig. 6. These tests were run to verify the time–spatial framing method used in the LPD.

Figure 5 presents how the extension of waiting time influences the displacement of spatial frame. Modification of detection (presented in Fig. 6) time shows how the spatial frame is expanding during the rise of detection time. All the test results confirm the possibility of modifying

spatial parameters of registered frames by proper control of the image acquisition parameters.

### 5. Summary

The most important parameters of the laser photography device are presented in Table II.

TABLE II

The main LPD parameters.

Image resolution	1360( <i>H</i> ) × 1024( <i>V</i> ) pixels		
MTF resolution	60 lp/mm		
Field of view (FOV)			
— for optics 105 mm	11.04°		
— for optics 500 mm	2.46°		
— for optics 2800 mm	0.38°		
Bit resolution	14-bit		
Spatial resolution			
— min. observation distance	16 m — for 532 nm illuminator	0 m — for 850/905 nm illuminators	
— min. depth of observation	1.2 m		
— minimal distance growth	0.15 m		
— minimal depth growth	0.15 m		
— spatial jitter	1.5 cm		
Spectra range of illuminators	532 nm	850 nm	905 nm
Max. energy	360 mJ		
Max. power		100 W	200 W
Pulse duration	5 ns	10–30 ns	8 ns

The experimental results confirmed the possibility of building the fully functional camera working with the time–spatial framing method. The results of experiments also proved the ability of device to register images of precisely defined fragment of three-dimensional space.

Future devices and optoelectronic systems using this method of acquisition of imaging information can find many applications as observation–measurement tools.

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