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Finding the distance to the object using the method of spatial-temporal framing

***Abstract**. Range Gated Imaging cameras require to define of the image range. In the absence of the information about the location of objects, the choice of camera parameters can be very time consuming. Proposed new approach - it is a two-step procedure using the properties of spatial-temporal framing method, which can significantly reduce this time. An additional benefit may be the ability of the camera to work independently. The camera can be used for simultaneous positioning of many objects in geographical coordinates.*

***Streszczenie.** Kamery Range Gated Imaging wymagają definiowania zasięgu obrazowania. Przy braku informacji o położeniu obiektów dobór parametrów kamery może być bardzo czasochłonny. Zaproponowano nowe podejście – jest nim dwuetapowa procedura wykorzystująca właściwości metody kadrowania przestrzenno-czasowego, która może istotnie skrócić ten czas. Dodatkową korzyścią może być zdolność kamery do samodzielnej pracy. Kamerę taką można wykorzystać do jednoczesnego pozycjonowania wielu obiektów we współrzędnych geograficznych. (**Wyznaczanie odległości do obiektu z użyciem metody kadrowania przestrzenno-czasowego**).*

Keywords: active imaging, image auto-segmentation, distance measurement.
Słowa kluczowe: aktywne obrazowanie, auto-segmentacja obrazu, pomiar odległości.

Introduction

The introduction of a semiconductor camera in the second half of the twentieth century has revolutionized the research and development of many branches of industry and the services sector. According to the common opinion the image supplied by the camera is only a projection of three-dimensional space onto a plane. Thus, the information about the spatial relationships in comparison to the registration of objects on the image is lost. But, spatial information may be solved by using eg. photogrammetric analysis of images from two cameras.

However, the vision information systems increasingly turn to advanced imaging techniques. RGB-D and ToF cameras can be included to this group [1]. One of the main advantages of this type of cameras is the ability to obtain the information about the distance to the objects registered in the image. Such cameras use different mechanisms of spatial information acquisition. Therefore different ranges and resolution of these cameras are obtained.

However, there is a group of ToF cameras, which captures images in a very specific way. This is called - Range Gated Imaging (RGI) [2, 3, 4]. This solution does not get back the distance to the object. The distance must be defined before the acquisition of the image.

This approach may create some problems in a situation where we do not know the distance to the objects in the scene of our interests. The specific properties of this imaging by the method allows to visualize the object and determine the distance to it through hardware-based scene auto-segmentation. The necessity of defining the distance to an object caused that this type of devices requires cooperation with other systems, eg. Radar [5]. It provides with the necessary coordinates of the object (including the required distance). The example of such a system has been shown in Figure 1.

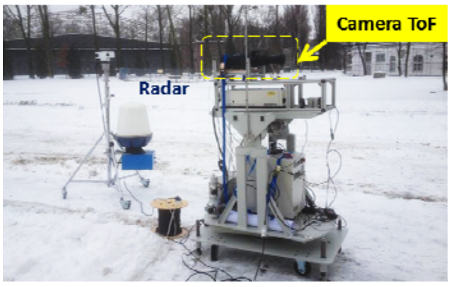

Fig.1. The RGI system with radar

The systematic scanning area as a function of distance is an alternative to this type of camera. However, this mode of operation is time-consuming and inefficient. The solution of the problem is an adaptive area scanning. This requires the use of specific properties of used imaging methods. The proposed solution is a recipe to make distance measurements to objects with the use of techniques of active imaging.

It is worth emphasizing that the method of spatial-temporal framing was used to study the problem of determining the distance to the object observed in the scene. The tests were conducted by means of the Laser Photography Device (LPD) developed in IOE WAT.

ToF cameras – spatial framing

Among the ToF (Time-of-Flight) cameras, we can distinguish two main groups of devices. The first group is usually the camera with a relatively low QVGA resolution. However, using these cameras, you can directly obtain information about the distance of each pixel of the image. In the case of the method of phase (pulse) the greater precision (range) of the measurements can be obtained. Generally speaking, these cameras work as laser rangefinders (phase or pulse) but instead of a single detector we have to engage a whole range of detectors. Cameras are active because the use of laser illuminators.

Lasers can be pulsed or phase depending on the method of operation of the sensor. The source can be implemented as a single radiating element (for pulse solutions) or a diode array (for phase solutions). Pulse solutions are characterized by a greater range of the observation. On the other hand, phase cameras work on shorter distances but offer a greater precision in determination of the distance. The example of such a miniature phase device is presented in Figure 2.

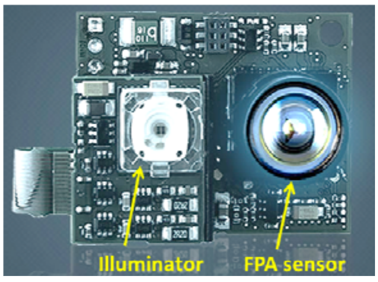

Fig.2. Phase ToF camera – PMD Photonics

The PMD camera parameters:
- type of Sensor: PMD PhotonICs® 19k-S3,
- framerate: ≤ 90 fps,
- field of View: 90° × 68°,
- illumination Wavelength: 850 nm,
- dimensions: 37 × 30 × 25 mm,
- power Supply: 5 V @ 500 mA,
- range: 100 cm.

The second group of ToF devices uses spatial framing - Range Gated Imaging. An important advantage of this method is the possibility to obtain the images with higher resolutions up to SXGA. However, the distances to objects are given in the form of a range distances at which objects can be observed. In addition, the object can be seen in the image only when it is in the "range of observation" defined in the camera.

The studies on this type of imaging methods have been conducted in IOE WAT since 2005. They have resulted in the development of methods of spatial-temporal framing and the unique description of this method which connects both problems of time and space imaging [6,7]. After obtaining adequate funding it was possible to develop experimental Laser Photography Device in 2012.

As the name of this device suggests one of the key elements is the nanosecond laser illuminator. This solution is based on the pulse laser. Optics allows for proper illumination field adapted to the field of view of the receiver. Another important component of the camera is fast shutter speed of sensor. Image intensifier with adjustable time was used for the construction of the shutter. In this way it is possible to control the shutter at the level of single ns. Figure 3 shows the developed (jointly with HADRsoft) experimental camera.

Fig.3. ToF camera - Laser Photography Device

Below are shown the most important parameters of the device:
- image resolution: 1360(H) × 1024(V) pixels,
- MTF resolution: 60 lp/mm,
- field of view: 2,46°,
- spectral range: 532 nm,
- the laser Energy: 1 mJ,
- pulse time: 2 ns.

What differentiates this solution from commercially available cameras RGI? It is for example 14-bit sensor but mainly, open design enable cooperation and synchronization with any lasers. Key time parameters: shutter 3 ns and system clock 1ns which translates into the possibility of obtaining the depth of observation < 1 m and spatial step 15 cm.

Characteristics of the method of determining the distance

The basic problem of the use of devices RGI is a need to approximate knowledge of the distance to the observed objects. If this information is not available from other devices, eg. radar or laser scanner, we can get it from the analysis of a sequence of images taken by LPD at different settings of range observation.

The most important for the operation of the LPD camera are three parameters: lighting time, waiting time and time of detection. They unambiguously define the range and the depth of observation**:**

(1) $$R_{START} = 0.5 \cdot c \cdot T_w$$

(2) $$\Delta R = 0.5 \cdot c \cdot (T_d + T_i)$$

where: R_{START} – distance to field observation, ΔR – depth of field observation, ***c*** – speed of light, T_w – waiting time, T_i – illumination time, T_d – detection time.

These equations define the observation space.
If we assume that:
- we have a large range of observation (distance range)
- the lack of initial information about the approximate position of the object,
- we use the minimum depth follow-up (ensuring maximum accuracy and resolution positioning)

the process of finding an object can be very time consuming.

The basic thing is just to minimize the time of the process. The proposed solution has two phases and is based on:
a) sequential and adaptive narrowing range of observation - the method of successive approximations,
b) using the analysis of space-time frame - energy analysis.

The method of successive approximations

Algorithm distance measurement works similarly to the successive approximation. The module comparing the binary images for different ranges of observation performs the function of a comparator. Such a solution is possible because the method carries out image segmentation. In other words, objects are visible only if they fulfill the distance condition. If the object is beyond the scope of spatial, eg. it is closer or further - it is not registered by the image - as it is presented in Fig. 4.

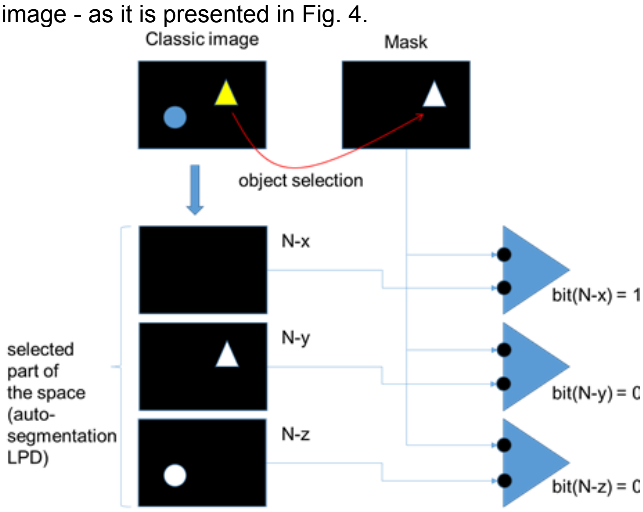

Fig.4. Possible results of the images comparator

The next steps of the algorithm precise the range of distance in which an object is present. From a technical point of view, control of the entire process is carried out by changing the depth and distance of observation. Every distance is chosen adaptively based on the comparison result of the comparator. The depth of observation shall be halved compared to the previous step (Fig. 5).

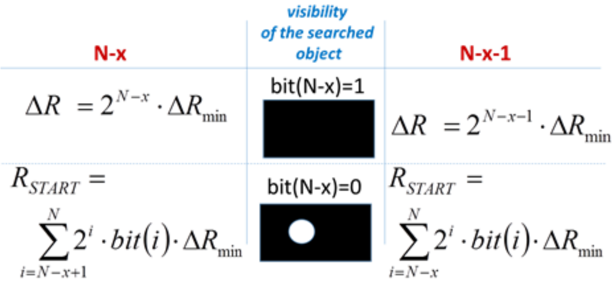

Fig.5. An example of successive approximations (N-x → N-x+1)

The procedure ends with a "best approximation" when reaching a minimum depth of observation. The equation of the best approximation is present below:

(3) $$R_x = \sum_{i=0}^{N} 2^i \cdot bit(i) \cdot \Delta R_{\min}$$

where: R_x – distance to the object, ΔR_{min} – the minimum depth of observation.

Energy analysis

The minimum achievable depth of observation is larger than the minimum step distance. More accurately determine the position of the object it is possible by analyzing the intensity of the object. This is done in the neighborhood of the point best estimate.The method of spatial-temporal framing provides the important information. The intensity of pixels of an image is a function of the position of an object inside the space-time frame as shown in Figure 6.

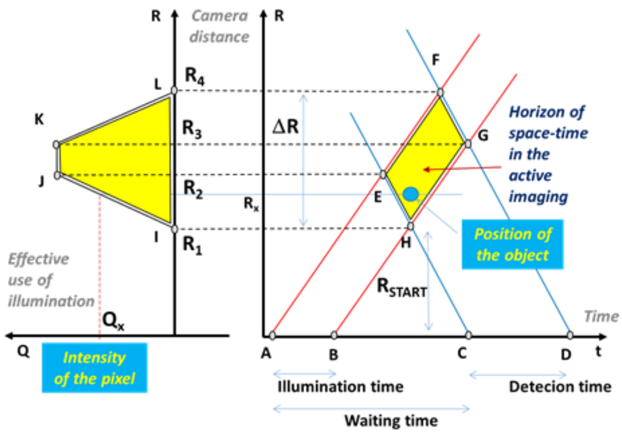

Fig.6. Spatial-tempral frame

At a minimum depth of the observation, the frame is moved spatially forward and/or backward (by a few positions), with a minimal step. Distribution of pixels intensity belonging to the observed object is analyzed. Analytically determined the maximum of the distribution can specify the location of the object with an accuracy better than the minimum step of observation.

Functions describing the boundaries of the space-time horizon are linear:

(4) $$EF \rightarrow c \cdot t$$

(5) $$GH \rightarrow c \cdot t - T_i$$

(6) $$EH \rightarrow -c \cdot t + T_w$$

(7) $$FG \rightarrow -c \cdot t + T_w + T_d$$

where: EF, GH, EH, FG – the boundaries of spatial-temporal horizon.

Changing the intensity of the pixel is a linear function of its position relative to the spatio-temporal frame:

(8) $$Q_x = \begin{cases} 100 \cdot \dfrac{R_x - R_1}{R_2 - R_1}\% & for \quad (R_1; R_2) \\ 100\% & for \quad \langle R_2; R_3 \rangle \\ 100 \cdot \dfrac{R_4 - R_x}{R_4 - R_3}\% & for \quad (R_3; R_4) \end{cases}$$

where: Q_x – effective pixel intensity, R_x – distance to the object, R_1, R_2, R_3, R_4, – characteristic points of the spatial horizon.

The graphical way to find a position of the object using energy analysis are shown on Figure 7.

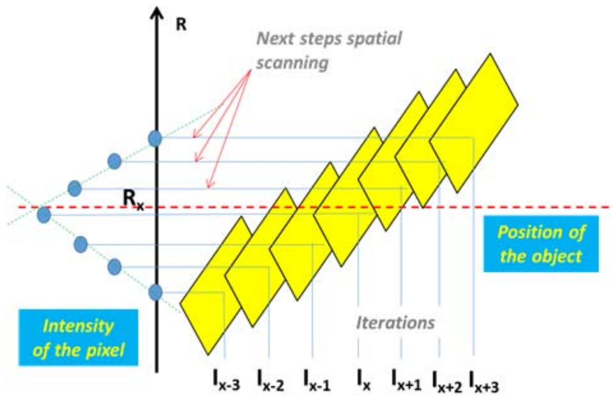

Fig.7. The Determination of the position based on the energy analysis

Examples of results

The main configuration of the device used for the tests are shown in Figure 8.

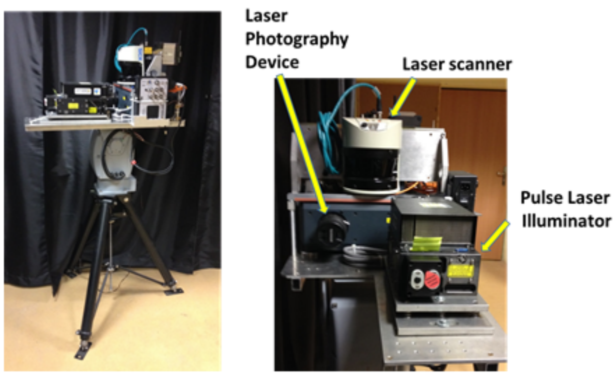

Fig.8. Configuration LPD system

The scene selected for testing included the objects positioned at different distances. The maximum distance to the objects ~ 200 m (Fig. 9).

In a first step (successive approximation) the following initial parameters of the system were used:

- distance to field observation ~ 115.2 m,
- depth of field observation ~ 115.2 m,
- illumination time = 2 ns,
- detection time = 766 ns,
- N = 7.

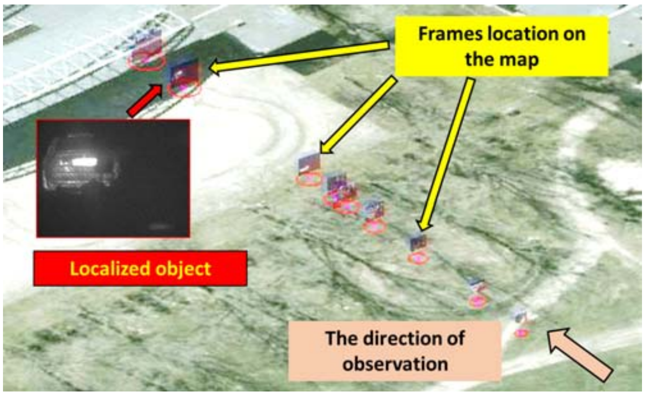

Fig.9. Google map terrain tests

As a result of the sequential narrowing of the depth of observation the images with different information content were obtained. The examples of some iteration of the measurement procedure have been shown in Figure 10.

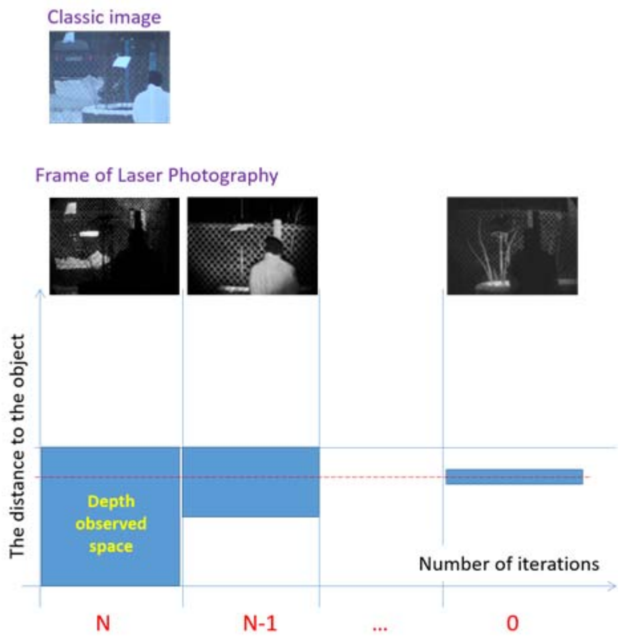

Fig.10. Visualization procedures of successive approximations

In the second stage (energy analysis) the initial parameters of the system as a result of the stage of successive approximations were adopted:

- "the best approximation" ~ N_i[0,1,1,1,1,0,1,0] = 84.6 m,
- depth of field observation ~ 0.9 m,
- detection time = 4 ns,
- step scanning space ~ 0.15 m.

As a result of the sequential movement images have been obtained with slightly different information content (in a visual sense). But the essence of this stage is the analysis of average intensity of pixels assigned to the selected portion of the object. The examples of the selected sequences with the energy analysis have been shown in Figure 11.

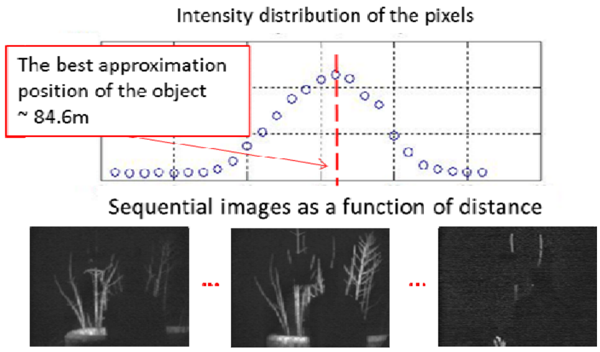

Fig.11. Visualization procedures of energy analysis

Summary

Initial tests carried out with LPD (at distances of several hundred meters) showed that the main positioning algorithm (successive approximation) allows to obtain the best approximation of +/- 0.5 m. The extended version of the algorithm with the analysis of the intensity can get approximations to the level of +/- 0.08 m. Jitter of the system clock < 0.1ns did not affect the measurement results. The most significant limitations are related to the shutter ~ 3 ns and the time laser pulse ~ 2 ns. The possibility of shortening of these times and improving the shapes of the rising and falling slopes will improve the accuracy of positioning objects using the proposed method.

So advanced imaging technology, will not be probably used to determine the distance to individual objects. However, in the case of simultaneous positioning of a larger number of objects, the method could be applied. In addition, using information from navigation sensors, there is the possibility of determining the position of the observed objects directly in geographic coordinates. The most practical application of the proposed method is related to its use by the LPD. The rapid positioning of objects offers the ability to work independently without the assistance of external measurement systems.

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REFERENCES

[1] Remondino F., Stoppa D., TOF Range-Imaging Cameras, *Springer-Verlag,* Berlin (2013)
[2] Andersson P., Long-range three-dimensional imaging using range-gated laser radar images, *Opt. Eng., 45*, (2006), *no 3,* 034301
[3] Lelièvre, Bonnie D., Introduction to Active imaging, *Sylviane Obzerv Technologies* (2011)
[4] Laurenzis M., Christnacher F., Monnin D., Long-range three-dimensional active imaging with superresolution depth mapping, *Optics Letters,* Vol. 32, (2007), No. 21, 3146-3148
[5] Piszczek M., Kowalski M., Karol M., Rutyna K., Zarzycki M., Szustakowski M., Laser photography device – spatial parameters of imaging*, Acta Physica Polonica A*, Vol. 124, (2013), No. 3, 550-553
[6] Piszczek M., Metadata in a LPS, *Acta Physica Polonica A*, Vol. 122 (2012), 858-861
[7] Piszczek M., Kowalski M., Laser photography in selective space imaging and navigation, Jerzy Sąsiadek (red.), Wydawnictwo monograficzne Springer: *Aerospace Robotics – GeoPlanet: Earth and Planetary Sciences,* (2013), 35-49