Software tool for modelling active vision areas of tomographic systems

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Abstract. An algorithm for calculating the shape of the active vision area of active-pulse television measuring system is proposed and implemented in the MATLAB software. Methods for determining the range of such systems, implemented in this software environment, are described. The software environment corresponds to the operation of an active-pulse system with settings for illumination pulses duration from 1 ns to 250 ns and settings for strobe pulses duration from 1 ns to 500 ns, and the maximum observation depth of the vision area is 80 m.

1. Introduction
Modelling of various processes and systems is an important task in any scientific research. Adequate models gives an ability to solve problems of proposing new and testing known hypotheses of the system operation, predicting various processes, studying the systems functioning in extreme conditions, and also allow to briefly and accurately describe the processes and phenomena that characterize systems operation.

Due to the variety of some specific problems, much attention is paid to the development of systems using the active television method for distance determination. For experimental research, a laboratory model of an active-pulse television measuring system was developed and upgraded. (AP TMS) [1]. Illumination of space with short optical pulses, as well as pulsed reception of the reflected optical signal after a specified time, is the basic principle of AP TMS operation. A region of space visible by an active-pulse system has a certain depth, which depends on the duration of the illumination and gating pulses of the photodetector [2, 3]. Thus, the AP TMS realizes a layer-by-layer vision of space, therefore such a system can be called tomographic.

Typically, AP TMS is applied to detect and recognize objects in difficult vision conditions, due to the ability to suppress backscatter interference [4]. However, by using AP TMS it is additionally possible to implement distance measurement. There are various methods for determining distances, implemented by active-pulse devices.

In the process of studying the capabilities of the system under investigation, it became necessary to develop a model that simulates its work. To solve this problem, it was decided to use the capabilities of computer modelling.

The created software allows simulating the operation of the system under various conditions, setting the main parameters and displaying the work results in the form of graphs and numerical values. The main modules of the program are an active vision area (AVA) calculator and a simulator of ranging methods using AP TMS.
The purpose of this study is to develop software for modeling the principle of vision, methods for measuring range, as well as ways to control a photodetector in an AP TMS. This software is necessary to study the principles of operation of the AP TMS with its parameters variations in order to optimize them. The simulation results can be used to compare them with the results of real tests of the AP TMS.

2. AP TMS active vision area

To describe the operation of AP TMS, the definition of AVA is widely used, which is a region of space visible to the system. AVA describes the change in the distribution of light energy depending on the observation distance and the level of transparency of the medium in which the radiation propagates [5].

The algorithm for calculating the AVA shape is the setting of the initial parameters of the system, then the calculation of the pulses convolution taking into account the distance and propagation medium, and after all the output of the calculation results in form of the AVA shape. The AVA shape is the result of the convolution of the laser emitter illumination pulse and the gating pulse of the image intensifier tube (IIT). The type of AVA will depend on the values of the duration and shape of these pulses. Thus, with equal rectangular pulses, the AVA shape will be described by a "triangle", and in the case of inequality of durations - by a "trapezoid".

So, for the formation of the illumination and gating pulses of the IIT, the numerical setting of the durations of the fronts and peaks of these pulses is implemented. To obtain information about the observation range, an adjustment of the IIT gating delay is provided. These parameters are set in units of time, and the received pulses and the AVA curve are displayed in the program windows in the form of graphs. It also provides the ability to take into account the inverse square law with respect to the illumination device and taking into account the attenuation in a turbid propagation medium.

In this software, the convolution of the illumination device pulse and the IIT gate pulse is implemented using the built-in functions of the program used for simulation. The software implementation of the AP TMS AVA shape calculation was carried out using the MATLAB software. The graphical interface for AVA modelling is shown in Figure 1.

![Figure 1. Graphical interface for AP TMS active vision area shape modelling.](image)

The shapes graphs of the illumination and gating pulses of the photodetector are located on the right side of the interface. In the central part there is a window for displaying the AVA calculation result. The display of characteristic points of the area in separate fields allows you to speed up the process of analyzing the calculation results. The initial system parameters are set on the left side of the
window. The values of the energy level of the AVA curve graph are normalized. The loading of real IIT gating pulses and the illumination device of the AP TMS laboratory model with a predetermined gating delay has been implemented. The level of transparency of the propagation medium when calculating the AVA shape is taken into account as losses depending on weather conditions in the near infrared range with a wavelength of 850 nm.

3. Ranging methods implemented by software

Modelling algorithms for measuring distance in this program is implemented in the form of two methods used in AP TMS - a two-zone (TAREM) and multi-zone method for the range estimation (MAREM) [6].

TAREM is based on the using of two AVA with gating delay shifted by the duration of the illumination pulse. So, to obtain a linear dependence of energy on the distance, it is assumed to use a rectangular shape of pulses of the illumination device and a photodetector with the same duration, which allow, using the normalized amplitude difference in the first and second AVA, to measure the distance to objects of observation in the field of view of the device [7].

TAREM first stage is to form specific AVAs, obtained by convolution of the illumination pulse shape with the shape of the gating pulse. Obtaining AVA can be represented as:

$$X_m = \sum_{k=1}^{N} L_k \cdot G_{m+k}$$

(1)

where $X_m$ – AVA counts; $N$ – illumination pulse shape number of counts; $L_k$ – counts of illumination pulse shape; $G_{m}$ – counts of the IIT gating pulse shape.

The graph of range sweep curve describing the energy distribution depending on the distance to the intended object of observation is formed by weighting the energies of the intersecting sections of two displaced AVA and is described by the following expression:

$$Y_n = \frac{X_{2n}}{X_{2n} + X_{1n}} \cdot \frac{c}{2} \cdot (\tau_L + \tau_{D1})$$

(2)

where $Y_n$ – counts of the range sweep curve; $X_{2n}$ – trailing edge counts of the first AVA; $X_{1n}$ – leading edge counts of the second AVA; $c$ – speed of light; $\tau_L$ – optical pulse duration; $\tau_{D1}$ – gating delay duration of the first AVA.

The estimation of the potential accuracy of the range estimation using TAREM is performed by calculating the difference between the linear range sweep curve and the curve obtained from the model with quasi-real pulses.

The multi-zone method for the range estimation (MAREM) assumes the integration of the exposures of the photo-receiving device, which makes it possible to regulate the dynamic range of determining the distances within wide limits without changing the duration of the illumination pulse [8]. Thus, the simulation of MAREM involves the set of specific AVAs obtained by convolving the shape of the illumination pulse with the shape of the IIT gating pulse. The range sweep curve in MAREM can be described by the following expression:

$$Y_m = \sum_{n=1}^{N} \frac{X_{n}}{X_{n}}$$

(3)

where $Y_m$ – range sweep counts; $N$ – AVA quantity; $X_{n}$ – AVA counts; $X_{n}$ – AVA with maximum depth and minimum gating delay.
The estimation of the potential accuracy of determining the range according to MAREM is performed by calculating the difference between the ideal linear curve and the curve obtained as a result of modeling. The software-implemented algorithms for the range estimation and assessing their ultimate accuracy are presented in the form of an additional functional window to the application for AVA modeling. In this application there is an option "Range measurement", which opens an additional window. The graphical interface for modeling AP TMS ranging algorithms is shown in Figure 2 for the case of the nine-zone ranging method.

![Figure 2. A graphical interface for AP TMS ranging algorithms modelling.](image)

In this window there is a possibility to select the ranging algorithm (two-zone, multi-zone). The user can set two general parameters for each of the algorithms – a) distance step and b) observation interval.

Also, for each of the algorithms, it is possible to set the jitter of the illumination pulse duration, as well as the duration and delay of the gating pulse. The value of the pulse duration or delay increment is selected with a step of 0.1 ns according to a uniform distribution law. Values are selected from a range limited by a given number to the positive and negative ranges of its values.

For each method, you must specify the simulation parameters. The window of modelling parameters for the two-zone method is shown in Figure 3.

![Figure 3. Parameters of the two-zone method.](image)
The simulation parameters of the two-zone method are gating delays for each of the two zones. The window of parameters for modelling the multi-zone method is shown in Figure 4.

![Parameters of the multi-zone method.](image)

**Figure 4.** Parameters of the multi-zone method.

The parameters for modeling using multi-zone method are the selection of the photo-receiver gating method, the initial gating delay, the gating delay step and the number of areas.

The gating method determines the control mode of the photodetector, which is supposed to be the IIT. Thus, the photocathode gating method is carried out by changing the gating delay of the photocathode pulse and its duration during the formation of each AVA.

With the method of gating by the photocathode and MCP, the formation of AVA is carried out by shifting the MCP pulse relative to the photocathode pulse. In this case, the delay of the photocathode pulse relative to the illumination pulse is always equal to the set of initial gating delay. The pulse durations of the photocathode and MCP do not change in time and have a value of the hundreds of ns, depending on the required range of distance measurement.

The method using the photocathode with a shift is carried out by changing the delay of the photocathode gating pulse at a constant duration, which determines the range of the distance measurement.

The interface for modeling ranging methods in AP TMS provides for the output of AVA shapes graphs, range sweep, and linearity error. In addition, the values of the standard deviation (SD) of the error and the minimum SD of the error are displayed in meters. SD error clearly shows the deviation of the resulting curve from the ideal linear range sweep function.

4. **Conclusion**

As a result of this work, a software environment was created for calculating the active vision areas of tomographic systems. This environment allows you to explore not only the formation of the active vision area curve, but also to deeply explore the methods for determining the distance to objects using the AP TMS. The behaviour of the range sweep graphs and its linearity errors make it possible to evaluate the accuracy of the selected method for the given modelling parameters. The created software contributes to further exploration of the AP TMS capabilities.

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