Modeling the factors that determine the accuracy of the range measuring using active-pulse television measuring systems

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Abstract. The article describes the operation principles of the active-pulse television measuring system and the method of measuring the range by using it. The results of modeling and the effect of control impulse jitter and photodetector noise on the range measurement accuracy are presented. Based on the simulation results, the dependence of the range measurement error on the value of the jitter of the control pulses and the noise of the photodetector was established. A decrease in the accuracy of measuring the range with an increase in the jitter values of the control pulses and the noise of the photodetector was established.

1. Introduction
Remote range estimation is an important task for the modern objects positioning technologies. Existing methods and tools are capable to measure distances to objects under specified conditions with required accuracy.

Active-pulse television measuring systems (AP TMS) are devices that use the active method to determine the distance to objects. The main application of such systems is the detection and recognition of objects in difficult vision conditions (smoke, fog, rain, snow, etc.) by suppressing of the backscatter interference. Distance measurement in the AP TMS is provided due to the principles of their operation and design features.

The principle of operation of the AP TMS is shown in figure 1.

![Figure 1. The principle of operation of the AP TMS.](image_url)
The principle of based on the object illumination using a laser emitter and receive reflected radiation with delays corresponding to the light transition time to the object and back. Thus, the photodetector of the system receives reflected light only from objects of interest, while ignoring the reflection from the interference. This feature allows you to cut off backscatter interference in the form of reflected light radiation from dust, fog, snow, etc. [1].

The method provides visualization of space in the form of a narrow layer, while cutting off nearby interference and the background behind the object. The resulting image provides information about the reflectivity of the observed object and the distance to it [2].

The tasks solved by the AP TMS determine the main areas of application for such systems, which include the navigation of unmanned vehicles, ensuring the safety of driving vehicles in difficult visibility conditions, conducting search and rescue operations, terrain orientation and many others.

The authors of this work have previously developed a multi-zone ranging method (MZRM) for AP TIS, which is distinguished by the use of a normalized dynamic exposure of a photodetector in range [3, 4]. MZRM allows increasing the range of determining the distances to the observed objects with a given accuracy. The purpose of this study is to evaluate the influence of the noise of the AP TIS receiving path and the jitter of the illumination pulse duration on the accuracy of range measurement in MZRM.

2. Measuring the distance using AP TMS

The observed space layer of this system is often called the active zone of vision (AZV) [5, 6]. AZV describes the change in the distribution of light energy depending on the observation distance and the transparency of the medium in which the radiation propagates [7].

The AZV shape is a convolution of the illumination and strobing pulse shapes of the AP TMS photodetector. Thus, its form depends on the duration of these pulses and their shape. With rectangular pulses of equal duration, the shape of the AZV will be described by a "triangle" (figure 2), and in the case of inequality of durations - by a "trapezoid" [8].

Based on the operation principles, there are various methods for determining the distances, using AP TMS, can be implemented. One of these methods is the multi-zone ranging method (MZRM).

The multi-zone method assumes the integration of the photodetector exposures, which makes possible the wide dynamic range adjustment in order to determine the distances without changing the duration of the illumination pulse. The method is based on the formation of a number of specific AZV and their summation with a shift along the distance. Further, the resulting amount is divided by the first of these zones. The resulting linear section is used as a linear measurement function to measure the distance to objects.

Thus, the range sweep function is the dependence of the object brightness on its range. In other words, in MZRM, the range scan is realized by dividing the object brightness in the total zone by the brightness of the object in the first zone (figure 3).
3. Evaluation of the photodetector noise effect on the MZRM accuracy

During the AP TMS operation, the observed space resulting images are affected by the noise of the system’s optoelectronic receiving path. The main source of noise in the AP TMS optoelectronic receiving path is an electron-optical image converter (EOC) and a video sensor reading from the EOC. Thus, it is necessary to assess the influence of the AP TMS receiving path noise on the potential accuracy of measuring the range using MZRM. To assess the influence of the AP TMS receiving path noise, the MZRM was simulated and, when forming the counts of the local and total AZV, the counts of the additive white Gaussian noise were used. The Additive White Gaussian Noise (AWGN) – is a random process with a Gaussian probability density distribution, the main parameters of which are the mathematical expectation, which characterizes the mean value, as well as the standard deviation, σ, characterizing the scattering of values relative to the mean value.

To measure the range, the MZRM uses a frame with a total AZV and a frame with the first AZV. The shape of each of these AZV is described by an array of average frame brightness values corresponding to the distance within the AZV. Thus, in order to simulate the effect of AWGN on the MZRM range measurement error, it is necessary to add a random AWGN value with zero mathematical expectation and a given value of σ to each value of the frame arrays of the first AZV and total AZV.

The simulation was carried out for a 20-zone MZRM with an initial strobing delay of 50 ns. In this case, the duration of the illumination pulse was 30 ns, the strobing pulse of the EOC was 130 ns. The strobing delay step in the total AZV was 5 ns. Simulation was carried out taking into account the inverse square law for ranges from 8 m to 22 m.

The first stage was considered the influence of AWGN with σ = 1. Figure 4 shows the graph of the measuring function of a 20-zone MZRM with AWGN with σ = 1.
When measuring the distance to the object using AP TMS, according to the MZRM, its brightness is measured using two video frames; in this case, both the brightness of a single pixel in the image of the object and the average brightness of a certain area of pixels in the object image can be measured. Measurement of the pixels area average brightness in the object image leads to an increase in the signal-to-noise ratio due to a decrease in the noise level when the pixel values are averaged by a factor, $\sqrt{N}$, where $N$ is equal to the number of averaged pixels. So when averaging the brightness in an area containing 100 pixels, the noise level will be reduced by a factor of 10.

To numerically estimate the influence of the AWGN on the potential accuracy of measuring the range in a 20-zone MZRM, 50 simulation iterations were performed for the value $\sigma = 1$. Statistical processing of 50 dependences of absolute errors of range measurement was carried out by calculating the root mean square error (RMS) for the range with a step of 1 m in the range from 8 m to 22 m.

Figure 6 shows a graph of the dependence of the RMS of the measured range in a 20-zone MZRM on the distance at AWGN with $\sigma = 1$. 

Figure 5 shows a graph of the absolute error for 20-zone MZRM measurement function when AWGN $\sigma = 1$. 

![Graph of the 20-zone MZRM model measuring functions (\(\sigma = 1\)).](image)

**Figure 4.** Graph of the 20-zone MZRM model measuring functions ($\sigma = 1$).

![Absolute error graph of the 20-zone MZRM model measurement function (\(\sigma = 1\)).](image)

**Figure 5.** Absolute error graph of the 20-zone MZRM model measurement function ($\sigma = 1$).
4. Evaluation of the influence exerted by photodetector strobing and illumination pulses jitter on the MZRM accuracy

The frequency instability of the reference oscillator and the instability of the signal delay in digital circuits have a great influence on the accuracy characteristics of real equipment operating with short pulses and short delay durations between them. Random deviations of the edges positions of the generated pulses along the time axis are called jitter.

In the AP TMS, the image of the observed space is obtained through the formation and control of the parameters of short-time illumination and strobing pulses of the photodetector. In this regard, the images obtained with the AP TMS will be influenced by the temporal instabilities of the generated pulses, that is, the jitter of the illumination and strobing pulse durations, as well as the jitter of the strobing pulse delay. The duration and delay jitter is caused by the instability of the frequency of the reference oscillator, as well as the instability of the signal delays in digital circuits and circuits of the shapers of the output high-current and high-voltage illumination and strobing pulses of the AP TMS.

When measuring the MZRM range, the measurement accuracy can be influenced by the initial delay of the photodetector strobing pulse during the formation of the first and total AVZ in the corresponding video frames, as well as the duration of the illumination and strobing pulses of the photodetector. The jitter of the strobing pulse initial delay of the photodetector will lead to a random shift of the resulting measurement function in space relatively to the objects of interest. In this case, the measurement error will be proportional to the error value of the initial strobing delay.

When simulating the effect of illumination pulse duration jitter on the potential accuracy of measuring the range with MZRM, a positive or negative value of the duration correction from an equiprobable series limited by the jitter value introduced in the model was added to the illumination pulse duration.

The simulation was carried out for a 20-zone MZRM with an initial strobing delay of 50 ns. In this case, the initial duration of the illumination pulse was 30 ns, and the duration of the strobing pulse of the image EOC was 130 ns. The strobing delay step in the total AVZ was 5 ns. The modeling was carried out taking into account the inverse square law for ranges from 8 m to 22 m.

Figure 7 shows a graph of the 20-zone MZRM measurement function with a jitter of the illumination pulse duration equal to 1 ns.
Figure 7. Model measurement function graph of the 20-zone MZRM (jitter 1 ns).

Figure 8 shows a graph of the 20-zone MZRM measurement function absolute error with a jitter of the illumination pulse duration equal to 1 ns.

Figure 8. Model measurement function absolute error graph of the 20-zone MZRM (jitter 1 ns).

In order to numerically evaluate the effect of illumination pulse jitter on the potential accuracy of ranging with 20-zone MZRM, 50 simulation iterations were performed for the illumination pulse duration jitter value from 0.5 ns to 5 ns. For each jitter value, the statistical processing of 50 dependences of the absolute measurement errors on the range was performed by calculating the RMS over the range with a step of 1 m in the range from 8 m to 22 m. Figure 9 shows a RMS curves family graph with measuring range for the results of 50 simulation iterations of a 20-zone MZRM when the jitter of the illumination pulse duration changes from 0 ns to 5 ns with a step of 0.5 ns.
Figure 9. RMS dependency graphs of the range measurement for the results of 50 simulation iterations (jitter from 0 ns to 5 ns).

To present an assessment of the illumination pulse duration jitter effect in a more visual form, the RMS values on each curve from figure 9 were averaged over the range and their averaged values depending on the jitter value are presented on figure 10.

Figure 10. Dependence graph of the average RMS value on the jitter value of the illumination pulse duration

According to the simulation results, the jitter of the photodetector strobing pulse duration did not lead to any changes in the resulting measurement function of the MZRM.

Figure 10 shows that with an increase in the value of jitter, the RMS of the linearity of the range sweep curve increases. In modern systems, jitter values may not exceed 0.05 ns. It means that, for systems using this ranging method, the potential error in ranging does not exceed the order of a few millimeters.

5. Conclusion
An example of MZRM simulation is considered, taking into account the ABGS influence on the error in range estimation. A numerical assessment of the ABGS influence on the potential accuracy of range measurement when processing 50 dependences of absolute measurement errors on range showed an increase in RMS from 0.1 m to 0.45 m with an increase in distance from 8 to 22 m.
In the course of the work, the simulation and assessment of the influence of the jitter of the strobing pulses of the photodetector and illumination on the accuracy of the MZRM were carried out. A numerical assessment of the influence of the illumination pulse jitter on the potential accuracy of ranging in a 20-zone MZRM for 50 simulation iterations showed an increase in RMS from 0 to 0.125 m with an increase in jitter from 0 to 5 ns.

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