Statistical Analysis and Experimental Evaluation of Active-Pulse Television Measuring Systems Vision Zone Shapes

A Movchan, V Kapustin, M Kuryachiy and E Chaldina

Department of Television and Control, Tomsk State University of Control Systems and Radioelectronics, 47 Vershinin st., 634045 Tomsk, Russia

E-mail: mr.movchann@mail.ru

Abstract. The paper presents experimental results for obtaining the shapes of active-pulse television measuring systems vision zones, their statistical analysis, as well as comparison with the shapes of zones obtained as a result of modelling. A description of the active-pulse television measuring systems operation principle, and the main technical characteristics of the active-pulse television measuring systems prototype used in the experiment are given. It has been experimentally confirmed that the proposed mathematical models for the system's active vision zones description adequately and effectively describes the process of their formation, and can be used in the active-pulse television measuring systems design and development processes.

1. Introduction

When observing an object in pure transparent media active-pulse television measuring systems (AP TMS) are used. Operation principle of active-pulse systems based on highlighting the area with short pulses of infrared radiation and time gating of high-sensitive optical receiver using high-speed optical gate. In figure 1, AP TMS structural diagram is given.
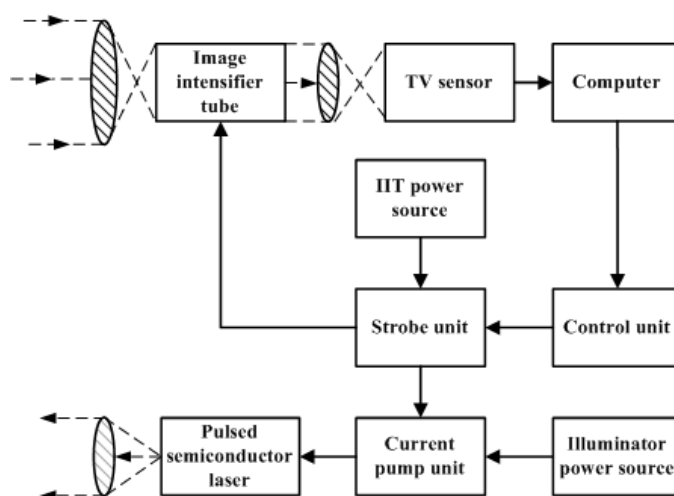

Figure 1. Structural diagram of AP TMS.

AP TMS base element is an image intensifier tube (IIT) [1], which besides its main function of amplification optical signal, also performs as high-speed optical gate. With equality of optical gate opening delay and duration of eradiated light optical pulse transition time to the object and back AP TMS operator will see the object image and surrounding area of space. The source of optical pulses in such systems can be the a pulsed semiconductor laser emitter (PSLE), and as the video sensor forming the image, a matrix of charge-coupled devices (CCD) or complementary metal-oxide semiconductor structure (CMOS) are used, optically conformed with the IIT [2].

Because of pulse functioning mode of the system in observation area of space active vision zone formation occurs, it contains objects of interest and limited area of surrounding space [3].

In order to determine form of AP TMS active vision zone it is necessary to perform emission source pulse convolution with optical receiver starting pulse. In case pulses are rectangular shape and having equal durations, active vision zone will be «triangular», and in case inequality of durations – «trapezoidal».

It is quite hard to get high-voltage rectangular pulses with nanosecond duration on practice, thus it is necessary to perform evaluation of AP TMS AVZ shape taking into account the length of highlight and IIT gating pulse duration fronts. High resolution AP TMS in terms of observing space depth is possible only with high accuracy and stability in delay duration and gating pulses duration formation [4].

Besides pulse front durations AVZ shape is affected by the attenuation of highlight optical signal when it passes through pure transparent media.

2. Experimental AP TMS active vision zones measurement evaluation

Active vision zone shape measurement experiment was carried out using AP TMS laboratory model, the appearance of which is shown on figure 5. The system includes: photo detecting device, highlighting device, personal computer (PC), PC pairing unit.
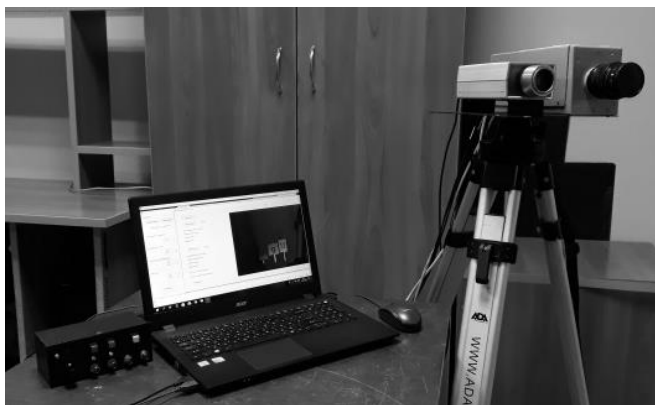

Figure 2. Appearance of AP TMS.

Figure 3. Appearance of observation path.

A system vision range is about 180 m, a vision angle of the system is limited by 12 deg., there is 842 nm wavelength infrared highlight illumination, the durations of highlight and IIT gating pulses are changing in a range from 30 ns to 120 ns, wherein a highlight pulse repetition rate can be from 50 Hz to 4950 Hz.

40 m long and 2.5 m wide corridor was used as observation path with distance mark plates at distances of 6 m, 7.5 m, 9 m, 12 m, 15 m, 18 m, 21 m, 24 m as observed objects. Distance mark plates are made of white paper with printed number representing the distance to it. In figure 6 there is an observation path.

In order to compare AVZ shapes at different distances, it is necessary to measure those shapes and carry out statistical evaluation.

In order to get AVZ shapes array through whole observation path, it is necessary to perform video shooting of mark plates with changing of IIT gating delay from 0 to 300 ns in 5 ns increments with IIT gating and highlight pulse durations of 100 ns. Next, there is a measurement of average brightness of mark plate's image fragments for each video frame, according to a certain IIT gating delay. Average brightness values obtained are indicators of AVZ shapes during the observation path. After that, the obtained AVZ samples are entered into the MATLAB software environment for graphing and subsequent processing for statistical analysis. Experimentally obtained AVZ shapes from given observation path are shown in figure 4.
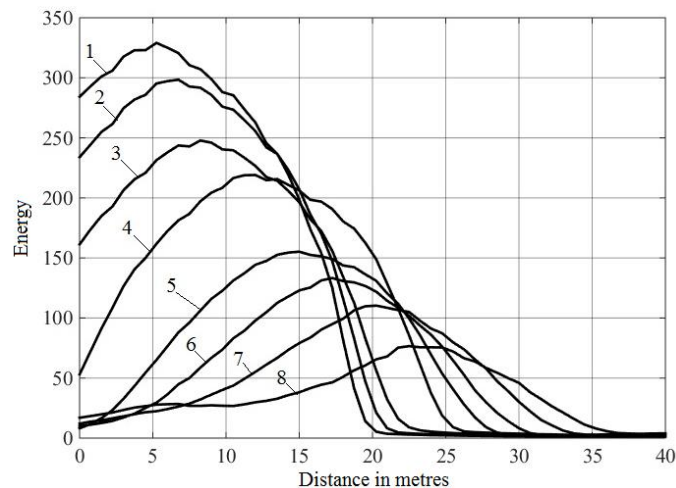

Figure 4. AVZ shapes on distances, m: 1 – 6 m; 2 – 7.5 m; 3 – 9 m; 4 – 12 m; 5 – 15 m; 6 – 18 m; 7 – 21 m; 8 – 24 m.

For further statistical analysis of AVZ shapes it is necessary to carry out normalization and combination of collected experimental data. Figure 5 demonstrates a graph of normalized and combined AVZ shapes.
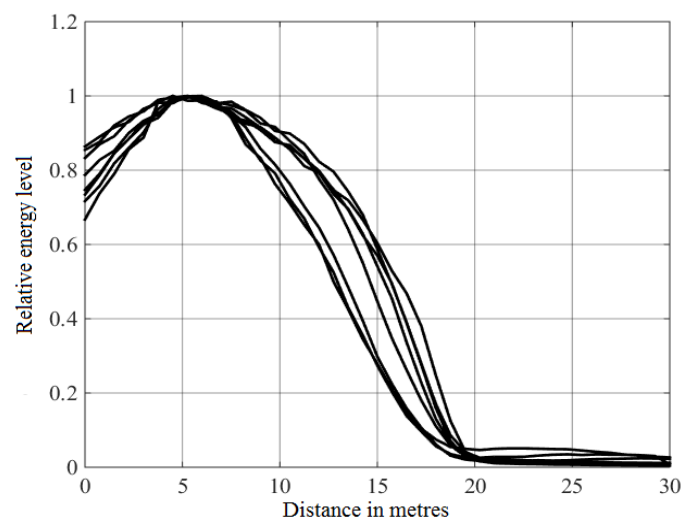

Figure 5. Graph of normalized and combined AVZ shapes.

One of the random value characteristics is its expected value. In this case, AVZ shapes are random. To calculate AVZ shape expected value one should use the following expression (1)

$$m_j = \frac{\sum\limits_{i=1}^{N} x_{ij}}{N} \qquad (1)$$

where x_{ij} – AVZ shapes indicators; N – number of zones.

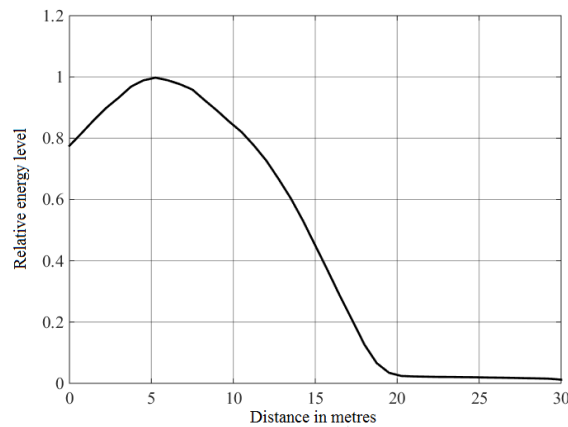Figure 6 shows the expected value of AVZ shape.

Figure 6. Expected value of AVZ shape.

For measuring the AVZ shape deviation one should use the expression for standard deviation (SD), represented below (2)

$$\sigma_j = \sqrt{\frac{\sum\limits_{i=1}^{N} (x_{ij} - m_j)^2}{N-1}} \qquad (2)$$

where x_{ij} – AVZ shapes indicators; N – number of zones; m_j – expected value.

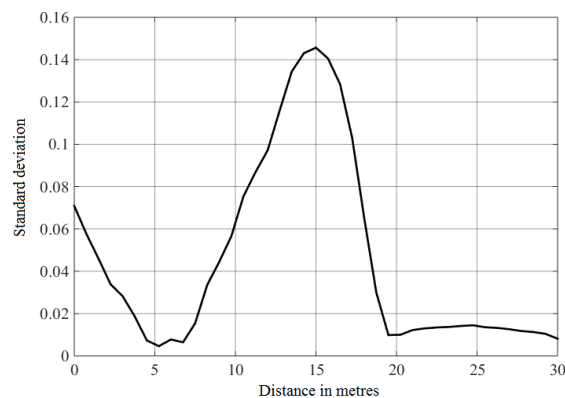Figure 7 represents values of AVZ shapes SD.

Figure 7. SD graph for AVZ shapes.

It is also interesting to compare gathered AVZ shapes with vision zone model obtained as a result of convolution of real optical highlight illumination pulse and IIT gating pulse. Optical highlight illumination pulse signal shape is shown in figure 8.

Figure 9 represents measured shape of IIT gating signal electric pulse. To calculate convolution idealized trapezoidal IIT gating pulse with duration of leading and trailing edges of 15 ns and flat top duration equal 70 ns will be used.
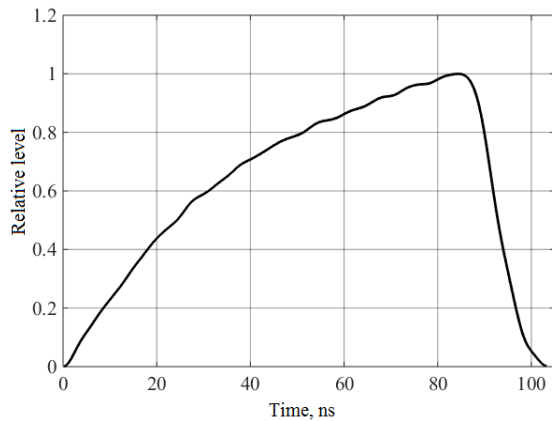

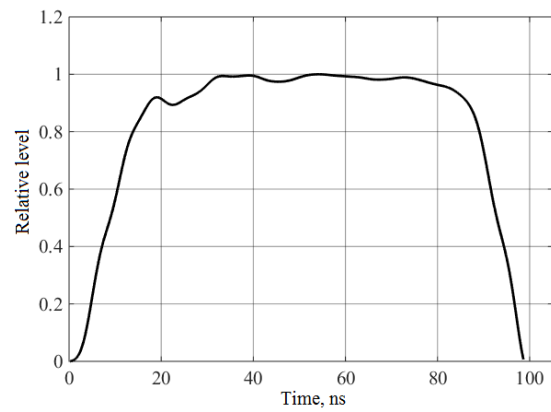**Figure 8.** Measured shape of optical highlight illumination pulse.

Figure 9. Measured shape of IIT gating signal electric pulse.

Figure 10 represents AVZ shape obtained as a result of modelling. IIT gating delay was equal 100 ns. It also represents AVZ shape, experimentally obtained at a distance of 15 m. It is interesting to compare space averaged AVZ (figure 6) and mathematic model of AVZ (figure 10), for this purpose it is necessary to make a shift of AVZ mathematic model to position of compared zones maxima alignment.
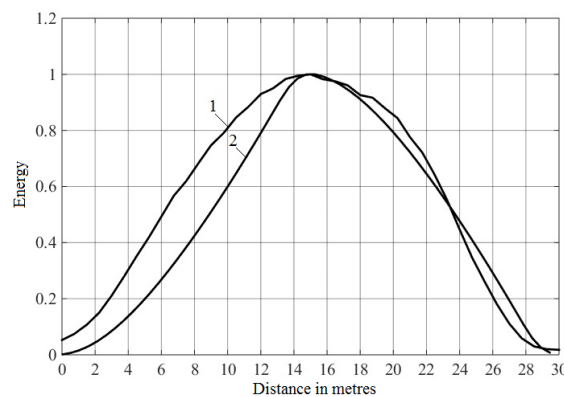

Figure 10. AVZ shapes graph: 1 –15 m distance (experimental data); 2 – model.

Figure 11 represents AVZ shape graphs built according to average value (experimental data) and model.
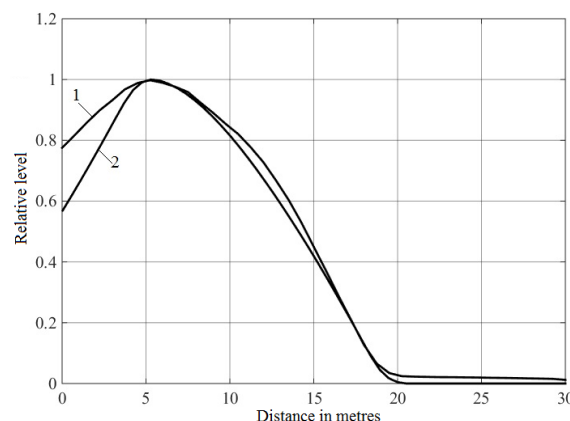
Figure 11. AVZ shapes graph:1 – average value
(experimental data);2 – model

Figure 11 shows that the space averaged AVZ matches quite accurate with AVZ model with given edge, a the same time it is some differences with leading edges, caused by the expansion of the zone leading edges, obtained on observation path and, as a result, contributing average value in AVZ shape.

3. Conclusion

During the experiment to obtain AVZ shapes of AP TMS, the athors determined vision zone shapes by using mark plates set on the observation path at different distances from 6 m to 24 m increments from 1.5 m to 3 m. Statistical analysis of obtained data was carried out, as well as the comparison with zone shapes, obtained as a result of modelling. Using results obtained it can be concluded that during zone shapes comparison by distance there were identified fluctuations of zone width, and averaged by distance zone shape also derives from zone shape obtained as a result of AVZ mathematic modelling, namely the largest SD of leading edge was 0.15, and for trailing edge 0.04. Results obtained during statistical and comparative analyses help to understand AP TMS vision zones formation processes and what is necessary for further development of methods and algorithms for precise measurement of distance using AP TMS.

References

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[3]   Kapustin V, Movchan A, Zaitseva E 2018 *Active-pulse television measuring systems for ensuring navigation of vehicles in difficult weather conditions* (Moscow: Transport systems and technologies)
[4]   Mishchenko N, Pustynsky I, Kapustin V 2016 *Methods and means of increasing the efficiency of actively pulsed television and computer systems for monitoring and ensuring the safety of objects* (Moscow: Tomsk: Tomsk State University of Control Systems and Radioelectronics Press) pp 42–46