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Precision System for Motion Path Parameters Measurement of Wheel and Rail Transport

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Abstract. In article the optic-electronic system of coordinates measurement is examined. Two circuits of system's construction are offered, their merits and demerits are specified. The substantiation of a system's measuring scheme construction is resulted. Theoretical errors of a distance measurement and cross-section vertical displacement of reference marks for the chosen scheme are analysed.

1. Main Principles

The problem of a motion path parameters definition (a distance up to reference marks, displacement on height, speed of movement) is solved effectively by optic-electronic measuring means [1-2].

The system for a motion path parameters monitoring can be necessary for automatic control of the transport robot or the control of a railway's condition.

The principle of a vehicle 3 (figure 1) motion path parameters measurement consists in definition of relative coordinates of motionless reference marks 2 which are located along a trajectory 4. Measurements are carried out by optic-electronic system 1.

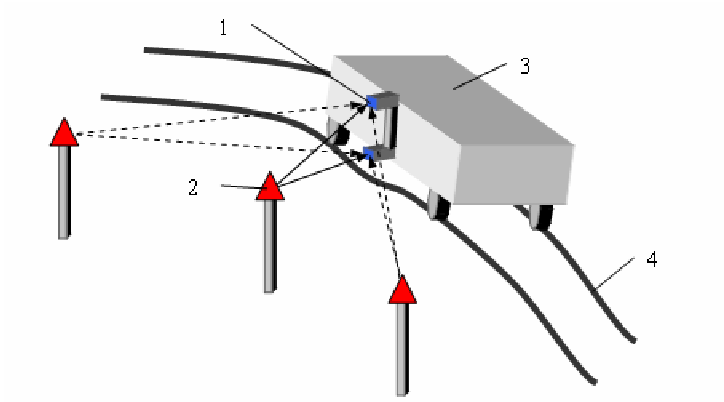

Figure 1. The principle of a vehicle motion path parameters measurement.

2. The measuring scheme

The given optic-electronic system has been realized under the scheme of an intrabase range finder [3] (figure 2).

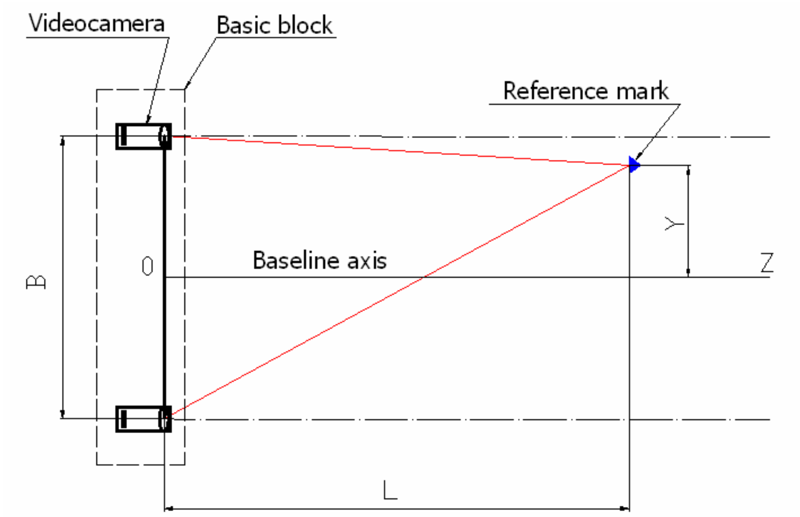

Figure 2. The measuring scheme.

2.1. Principle of functioning

When the reference mark appears in the mark's indicator (in figure 2 it is not shown) field of vision, the electric signal is developed. The signal acts in devices of infrared light-emitting diodes management and in the personal computer. Devices of light-emitting diodes management activate infra-red light-emitting diodes (in figure 2 are not shown), and light-emitting diodes highlight a reference mark. Objectives of both measuring channels build images of a reference mark on matrixes of photodetectors. Simultaneously with it the signal sent to the personal computer initiates synchronous preservation of the current images from matrixes in the operative memory. Displacement definition of a reference mark is carried out in two stages. In the beginning the program in the personal computer calculates vertical coordinates in pixels the power centers of reference mark images y'_1, y'_2 (figure 3). The algorithm of the power center's definition provides an error 0,1..0,01 sizes of an element photosensitive matrixes (pixel) [4] . Then coordinates y'_1, y'_2 of pixels are transferred in mm (the linear sizes of pixels are known). After that longitudinal and vertical coordinates of reference mark are calculated.

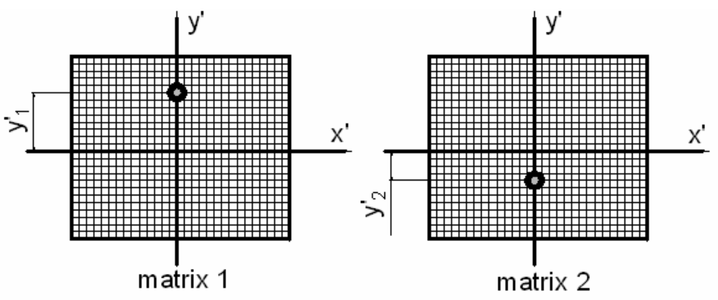

Figure 3. Images of reference mark on matrixes of the first and second videocameras.

Distance up to mark L and its displacement Y in a vertical plane are calculated under the following formulas:

$$L = \frac{B \cdot a'}{y_1' - y_2'}, \quad (1)$$

$$Y = \frac{B}{2}\left(\frac{y_2' + y_1'}{y_2' - y_1'}\right). \quad (2)$$

B – base, mm; a' - a back length of an objective, mm; y'_1, y'_2 – vertical coordinates of the first and second mark's images on a videocameras matrix, mm.

Advantage of the specified formulas is their simplicity. The direction of objectives optical axes in parallel baseline axis OZ is justified only when the measured distance is much more than sizes of system ($B \ll L$). The given system should measure distances in a range of 2000-7000 mm and cross-section vertical displacement in a range (-100) - (+300) mm concerning base line OZ. The base of system B is limited to size 300 mm. In these conditions at a direction of optical axes in parallel baseline axis ranges of measured vertical and longitudinal displacement much less required. Besides at an arrangement of matrixes symmetrically concerning optical axes the matrixes photosensitive area is involved in measurements not completely. It results in reduction in sensitivity of measurements. For maintenance of the necessary ranges and sensitivity of measurements it is necessary, that objectives optical axes have been inclined concerning a base axis, and matrixes of videocameras are displaced from optical axes of objectives (figure 4).

3. The modified measuring scheme

In the modified measuring scheme optical axes of objectives are inclined concerning a base axis of system. Thus, the optical axis of the top channel crosses a base axis on distance L_{01} from system, and the optical axis of the second channel crosses a base axis on distance L_{02}. The centers of matrixes are displaced from optical axes of objectives owing to what the zero of coordinates readout in both channels does not coincide with the centers of matrixes.

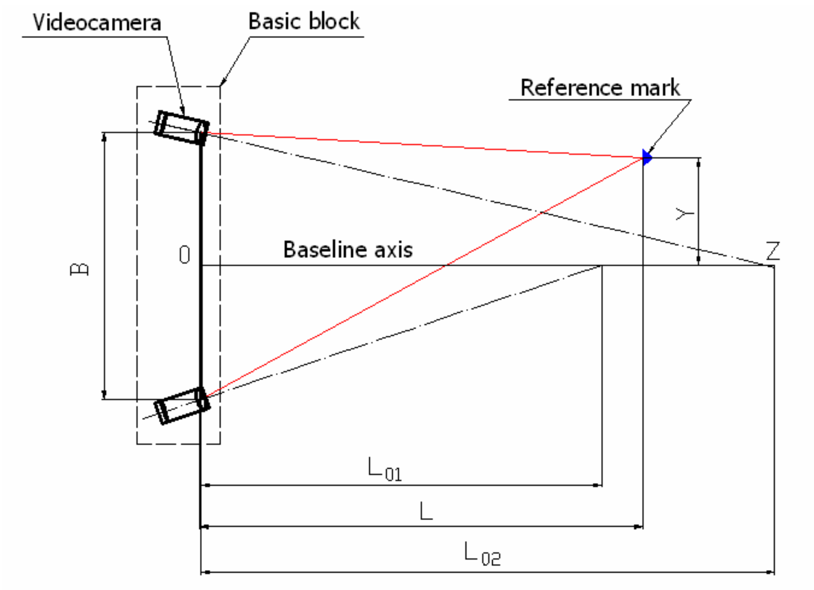

Figure 4. The modified measuring scheme.

The distance up to a reference mark and its vertical displacement from a baseline axis is determined under formulas:

$$L = L_{01} + \frac{y_2' \cdot K_1 + y_1' \cdot K_2 + y_1' \cdot y_2' \cdot K_3 + K_4}{y_2' \cdot K_5 + y_1' \cdot K_6 + y_1' \cdot y_2' \cdot K_7 + K_8} \quad (3)$$

$$Y = \frac{y_2' \cdot K_9 + y_1' \cdot K_{10} + y_1' \cdot y_2' \cdot K_{11} + K_{12}}{y_2' \cdot K_5 + y_1' \cdot K_6 + y_1' \cdot y_2' \cdot K_7 + K_8}. \quad (4)$$

K_1-K_{12} – the constant factors dependent on system parameters (distances L_{01}, L_{02}, back lengths of objectives *a'*, base *B*).

4. Measurement errors analysis

The analysis of formulas has allowed to estimate ranges and potential accuracy of measurements which system can theoretically provide with *B*=300 mm and *f'*=35 mm, a matrix with the greatest size 7.44 mm and the size of pixel 2.7 microns.

Figure 5 and figure 6 show dependence of images vertical coordinates on the videocameras matrixes in the first and second measuring channels.

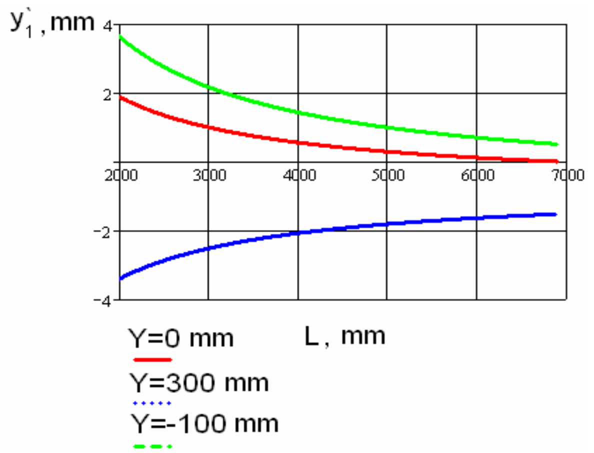

Figure 5. Dependence of image vertical coordinate on matrix in the first measuring channel.

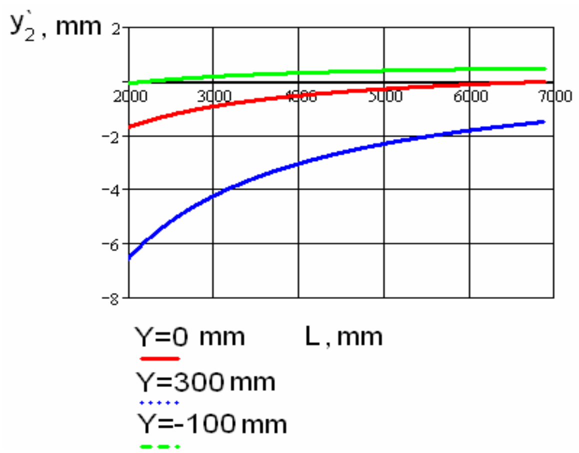

Figure 6. Dependence of image vertical coordinate on matrix in the second measuring channel.

Graphs on the figures 5 and 6 are made for different vertical displacement of object. Most effectively matrixes are used on near distances of measurements. From graphs it is visible, that at the size of a matrix of 7.44 mm the system should provide a required range of measurements on range and vertical displacement. However, that the range of measurements of vertical displacement is asymmetrical concerning a base axis, in the second channel it is necessary to displace a matrix from an optical axis of an objective on 3 mm.

On the figure 7 theoretical dependence of a distance measurement error for range of measurements 2000-7000 mm is submitted. From the graph it is visible, that the error on a distance of 7000 mm makes 2.6 mm. At the analysis of displacement calculation algorithm of a reference mark it was found out, that with other things being equal product *f'* and *B* for the set accuracy of measurements is size of a constant:

$$f' \cdot B = const\,. \quad (5)$$

Knowing this size and having set *f'* or *B*, under the formula it is possible to determine the second parameter.

In figure 8 dependence of a measurement error of vertical object displacement for the same range of measurements on distance is submitted. It is visible, that on all a range this error does not exceed 1 mm.

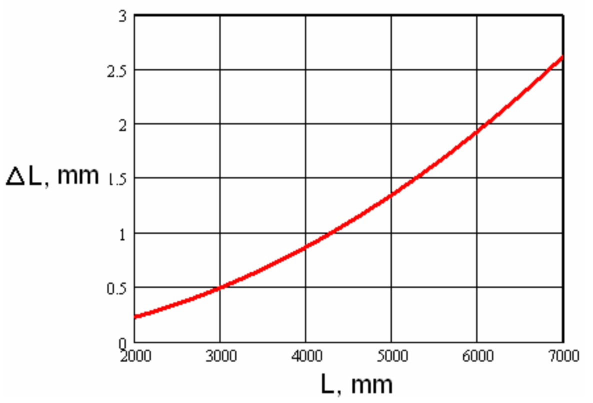

Figure 7. Dependence of a distance measurement error on a distance up to a reference mark.

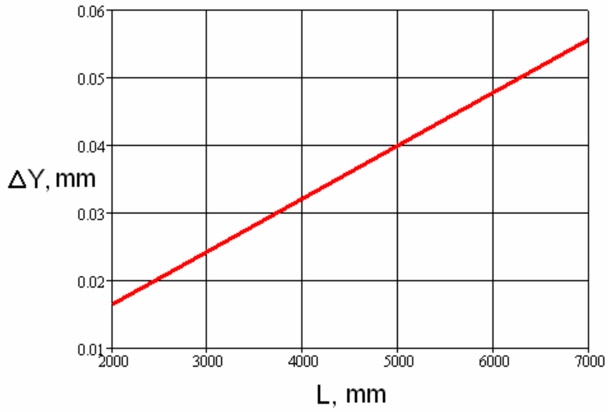

Figure 8. Dependence of a vertical coordinate measurement error on a distance up to a reference mark.

5. Conclusion

The optic-electronic system, allowing to measure a distance up to a reference mark and its vertical displacement is considered.

The analysis of a measurement scheme and algorithm of object coordinates calculation has yielded the following results:

- at an asymmetrical range of an object vertical displacement measurement an axis of videocameras should be asymmetrically inclined in relation to a baseline axis of system;
- to not cut down measured ranges it is necessary, that the matrix of a videocamera in the bottom measuring channel has been displaced from an optical axis of an objective on 3 mm (at f' =35 mm, B=300 mm, h_{matrix}=7.44 mm);
- the error of object cross-section vertical displacement measurement (0.55 mm on a distance 7000 mm) on the order is less than measurement error of its distance (2.6 mm);
- the expression (5), allowing to facilitate a choice of system parameters, is received.

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