Development of a series of interchangeable optical tips for a video endoscope

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Abstract. In this work a design of four different optical tips for video endoscope is presented. In particular, the report presents the results of the calculation of optical systems with normal (50˚) and wide (80˚) field of view (FoV) for direct (0˚) and side (90˚) view. All tips have simple to manufacture design and produce good image quality. The results of image simulation are presented.

1. Introduction
Nowadays stereoscopic machine vision systems are widely used for various industrial and medical applications [1-4]. Devices of this type provide object visualization as well as measurements of its geometrical parameters. Industrial applications of stereoscopic vision include remote visual inspection [5-7] of different hard-to-reach objects, for example tubes, engines, heat exchangers, turbines.

In papers [8-10] we presented the developed miniature stereoscopic machine vision system for non-destructive testing that provides high-quality images and the novel calibration algorithm that allows accurate three-dimensional (3D) shape calculation. The optical layout of the designed system and the photo of its prototype are shown on figure\textsuperscript{1}.

The system consists of the basic objective (1) and the removable stereoscopic tip (2). The important feature of the designed system is that the aperture stop A is placed between the objective 1 and the tip (2). Constructively it is part of the objective. This allows us to minimize the diameters of the optical components. The prism is used to form two images of the same observing object from different points of view on the single sensor.
The main optical characteristics of this system are presented in table 1. The obtained image quality is enough to reconstruct 3D structure of the tested object and to get the accuracy of geometrical measurements about 50 μm.

### Table 1. Optical parameters.

| Stereoscopic system parameters                      |
|---------------------------------------------------|
| Working distance (WD)                             | 5 – 40 mm                     |
| FoV (in a single channel)                         | 45°                          |
| Magnification                                     | 0.25 – 0.06                  |
| F/#                                               | 11                           |
| Resolution (@ WD = 15 mm)                         | 40..100 lines per mm         |

| Basic objective parameters                        |
|---------------------------------------------------|
| Working distance                                  | 40 – 100 mm                   |
| FoV                                               | 15°                          |
| Focal length                                      | 4 mm                         |
| Magnification                                     | 0.1 – 0.04                   |
| F/#                                               | 8.5                          |
| Resolution (@ WD = 45 mm)                         | 50..90 lines per mm          |

| Sensor parameters                                  |
|---------------------------------------------------|
| Resolution                                        | 1280 x 720                   |
| Pixel size                                        | 1.4 μm x 1.4 μm              |
| Image area                                        | 1.819 x 1.033 mm (1/9”)      |

The formation of a stereoscopic image of inspected object and the measurement of its geometrical parameters is a function, in many cases necessary, but it is not so often used in endoscopic testing as a simple visual inspection. In this regard, the task of expanding the functionality of the developed video endoscope seems to be relevant. For this reason, several interchangeable optical tips are designed, which, when used in conjunction with the basic endoscope objective, provide various of its optical characteristics.

### 2. Interchangeable optical tips design

We have developed four types of tips for direct and side-view with different FoV: 50° and 80°. They are presented in figure 2. T0-15 (figure 2 (a)) is direct-view tip with angular magnification of 0.3 that provides the endoscopic FoV of 50°. This tip consists of a single quasi-afocal thick lens. In combination with the right-angle prism, it becomes a side-view tip T90-50 (figure 2 (c)).

**Figure 1.** Prototype of the stereoscopic endoscopic optical system: optical scheme (a) and photo (b).
Figure 2. Designed endoscopic tips (a, c, e, g) and corresponding image simulations (b, d, f, h).
Actually, it is possible to obtain more than 50˚ FoV with single lens, but it causes a significant complication in its manufacture because of its small radii. That is why the next direct-view wide-angle tip T0-80 (figure 2 (e)) has a two-lens design. It is also quasi-afocal.
T90-80 (figure 2 (g)) is a side-view wide-angle 80˚ tip with angular magnification of 0.188. It is the most complicated of the designed tips. To avoid the large size of the prism, the diverging lens is located in front of it.
All tips have a working distance WD = 10-50 mm which is convenient for inspecting most types of technical objects. Actually, all designed tips could be re-adjusted or recalculated without significant changes for another working distance if necessary.
Figure 2 (b), (d), (f), (h) shows the results of image simulation for the endoscopic system using the corresponding designed tips. Simulation was performed in ZEMAX software. The object was placed at the distance WD = 20 mm. We could see that all tips produce good image quality. Images obtained with tips T01-50 and T90-50 look the same because of there is no difference between these tips except the prism. T90-80 consists of 3 lenses and has better aberration correction than T0-80, therefore images in figures 2 (f) and 2 (h) show different distortion.
Optical resolution of the endoscope using the designed tips is almost the same for all tips. For image center, the resolution varies from 70 to 100 lines per mm within the working distance range. For the image margin, the resolution is from 45 to 70 lines per mm. It is quite enough for the tasks of visual inspection.

3. Conclusion
Presented interchangeable optical tips produce high image resolution (up to 100 lines per mm) and significantly expand the functionality of the developed endoscopic device for non-destructive testing of technical objects and, as a result, make it commercially more attractive.

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