Estimation of Bilateral Facial Symmetry Deviation Using a Stereoscopic Computer Vision System

A. B. Murynin*, V. F. Krychenkov, I. A. Matveev*, V. D. Kuznetsov***

**Computer Center, Russian Academy of Sciences, ul. Vavilova 40, GSP-1, Moscow, 117967 Russia*
e-mail: murynin@spiritcorp.com; tanacom@space.ru
***OOO Prozrenie Ophthalmology Center, ul. Elektrozavodskaya 12B, Moscow, 105023 Russia*

Abstract—The task of measuring bilateral facial symmetry deviation using stereoscopic images of human faces is considered. The stereoscopic computer vision system is developed for the diagnostics of squint in early childhood in order to prevent probable disabilities. The required accuracy of measurements is estimated. It is shown that the developed algorithms ensure a sufficient accuracy of measurements for anthropometric points in the neighborhood of the eye sockets. A complex method that uses both raster and vector templates of facial features is proposed for finding the exact positions of low-contrast reference points on a face. The methods have been tested on patients with different forms of squints.

URGENCY OF THE PROBLEM

The acuity of remote stereoscopic vision is vital for the survival of most higher animals. An animal cannot get food or hunt effectively without a pair of eyes that function jointly. The natural selection exists in human communities as well. However, here it reveals itself only when choosing a profession or a way of life in general. For instance, for pilots, topographers and many others, this ability is an indispensable attribute in their professions.

Quantitative and qualitative parameters of human vision are checked in medical practice, as a rule, on the basis of verbal replies. While most vision parameters can be improved by medical or optical methods at any age, stereoscopic vision can be corrected only up to a certain age in childhood. Moreover, the older the child, the more difficult and longer the treatment, which is provided till the age of seven to ten years.

Horizontal ocular movements are governed by the Herring law; i.e., as early as in the prenatal developmental phase, the child elaborates a dynamic stereotypy of equal impulsing on the horizontal muscles of the right and left eyes. If the positions of the eyes on the right and on the left get onto horizontal planes that are spaced along the vertical line by more than 2 mm, then intolerable doubling in the vertical direction arises. The compensatory movements of ocular muscles responsible for the vertical eye orienting are insufficient to correct for doubling.

The anatomic asymmetries in the positions of the right and left eyes are, first of all, caused by the displacement of the right half of the skull relative to the left in the sagittal plane (forward or backward displacements). The bones that form eye sockets have different degrees of mobility and distinct "preferable" directions of shift in the cartilaginous joints. In particular, the orbital process of the zygoma always shifts not only sagittally, but necessarily upwards or downwards as well, because it is joined with the temporal bone in a skewed manner.

Determining the relative depths of the positions of the orbital points on the right and on the left, one can diagnose the positions of the eyes along a vertical line. Up to a certain level of accuracy, this can be done by the simplest instruments. The purpose of this study is to develop an algorithm for fast diagnosis of the extent of asymmetry in the position of the eye sockets both in depth and in height.

The urgency of studies in this field is connected with the possibility of diagnosing and preventing such diseases as squint, ocular torticollis, nystagmus, progressive myopia, astigmatism, asthenopia symptoms when reading, and intolerance to bright light in early childhood. This is especially important for younger children because the measurements are performed in fractions of a second and no contact with the child's face is required.

EXPERIMENTAL BACKGROUND

The verification of the hypothesis on the interrelation of ocular diseases and skull asymmetry was carried out in the Center for the Recovery of Vision by Yu.A. Utekhin's method in the Children and Teenager Rehabilitation Department of the Veshnyaki Complex Center for Social Services, and is conducted at present in the Prozrenie Ophtalmology Center in cooperation with the Department of Complex Systems, Computer Center, Russian Academy of Sciences. About 50 patients were examined in the course of this verification. Intolerable skull asymmetries were observed to be characteristic of patients with squint, progressive myopia,

Received October 25, 2000

Original Text Copyright © 2001 by Pattern Recognition and Image Analysis. English Translation Copyright © 2001 by MAIK "Nauka/Interperiodica" (Russia).

nystagmus, and bright light intolerance. The principal feasibility of measuring skull asymmetries with a stereoscopic computer vision system was tested for ten patients. In particular, verification via digital photogrammetry was carried out for two patients in the Laboratory of Aerospace Methods at Moscow State University [1].

The interrelation of skull asymmetry and certain ophthalmic diseases was stressed in [2]. However, the authors do not give a definite answer to the question as to which of above phenomena is primary. Our studies provide enough evidence in favor of the hypothesis that structural skull asymmetries are primary and not vice versa. Therefore, the skull asymmetries must be diagnosed in early childhood. Taking into account that the verbal diagnostics of stereoscopic vision distortions is not possible for such patients, the remote measurements of symmetry abnormality become the principal tool in the diagnosis of possible stereoscopic vision distortions.

The results of preliminary research make it possible to set a task of developing hardware and software systems designed for further clinical examination on a larger scale. The authors propose to use stereoscopic computer vision systems that were originally developed as face-recognition applications [3]. The hardware system is shown in Fig. 1. It is a compact system equipped with a set of mirrors for human face positioning; an infrared lighting system ensures uniform illumination. The software complex is tailored to the processing of stereoscopic images of human faces [4, 5].

Since most regions on a human face are low contrast, the system is designed so as to ensure special illumination conditions for certain facial regions. This facilitates the process of finding the corresponding points on the left and right images (see Fig. 2).

On the other hand, the task set in this paper leads to a number of specific requirements for the accuracy of algorithms used to recover three-dimensional surfaces of objects from stereoscopic pairs.

Fig. 1. Face examination by a stereoscopic computer vision system.

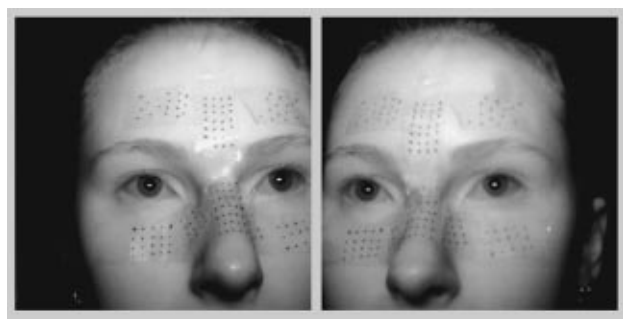

Fig. 2. A stereoscopic pair of images taken under special illumination conditions.

ALGORITHMS AND THEIR ACCURACY

According to the results of the conducted research, bilateral asymmetry is diagnosed by selecting those points in the orbital and frontal regions which are reliably identified on photographic images. The measurements are made for several main anthropometric points in the region of the eye socket, forehead, and nose. The difference in the distances of selected points from the three coordinate planes is taken as a measure of the asymmetry. The first plane is determined as an expected position of the plane of bilateral symmetry (the sagittal plane), two other planes are perpendicular to the first one (the frontal and horizontal planes). The frontal plane is used as a reference when measuring the differences in the depth positions of points; the horizontal plane is a reference plane when the differences in the vertical positions of points are measured.

The maximum permissible error in recovering depth variations for facial points is 1 mm. Facial relief is recovered via the relief computation based on the disparity of corresponding points. Since we need depth variations (i.e., the differences of the depths of points on the image) and not the absolute values of the depths, the exact distance to an object does not matter, and it can be assumed that the disparity is converted into depth variations without introducing any error. Let us estimate the maximum permissible error in the determination of the disparity (in pixels).

Let d be the error in the determination of depth variations, l be the error in locating a point on the object (in mm), B be the stereo base, D be the distance from the object to the camera, α be the angular aperture of the camera, N be the pixel aperture of the camera (the number of pixels in the image). From geometrical considerations, $l/d = B/D$; i.e., the error in locating a point on the original object is $l = Bd/D$. The distance on the object that corresponds to one pixel is $\mathbf{s} = \alpha D/N$; therefore, the error in locating a point in the image is the ratio $l/s = NBD/\alpha D^2$. If d is the maximum permissible error in the determination of depth variations, then the obtained quantity is

the maximum permissible error in the determination of disparity in the image.

The corresponding points are found by using the correlation algorithm that introduces noise of its own (the methodic error), whose value is half of a pixel at most. Therefore, the algorithmic noise in the determination of disparity is one pixel. The measurement error (due to distortion, blurring, etc.) in the system under consideration is likewise equal to one pixel. The sum of these two errors should not exceed the maximum permissible error; therefore, all other things being equal, the required image size N must satisfy the following inequality:

$$N > \frac{(e_{\text{alogor}} + e_{\text{optic}})\alpha D^2}{bd}.$$

For the system under consideration, the algorithmic error $e_{\text{alogor}} = 1$, the optical error $e_{\text{optic}} = 1$ mm, $b = 120$ mm, $d = 1$ mm, $\alpha = 1/4$ rad, and $D = 300$ mm. This allows us to estimate the required resolving power of cameras, $N > 375$. The system is equipped with cameras whose resolving power is 512 pixels; this makes it possible to measure depth differences in the positions of points accurate to 0.7 mm.

As was noted above, the task requires that the exact positions of several anthropometric points in the orbital region could be found. Special data processing algorithms must be worked out for this purpose.

The existing methods can be subdivided into two groups. One of them uses raster templates, the other uses vector templates. The main drawback of raster template-based methods is that they are capable of indicating the exact positions only for high-contrast characteristic points. At the same time, these methods are reliable enough in the selection of regions in which the object to be found is located. The recognition methods based on vector templates use *a priori* knowledge of the object to be found (to be more precise, the knowledge on the shape of this object). The drawbacks of this approach are the high time complexity of algorithms and the possibility of errors of the second kind (false object identification). Therefore, as a rule, the search area is not much larger than the object's size, and the detection of the object in this domain is guaranteed. At the same time, the method makes it possible to determine the boundaries of the object and its elements in the image.

The foregoing shows that the optimal approach to the search for low-contrast characteristic points that represent stable object elements in the image is to apply the search based on raster templates (either through the entire image, or a hierarchical search, e.g., the search for the face on the image, the search for the eyes on the face) first, and then to refine the object boundaries by using vector templates.

The fact that original images are stereoscopic is also taken into account. Once the search based on vector templates is completed, the next step is to verify the correlation between the areas that were found in the image; this correlation may reveal discrepancies in the results for distinct images in the stereoscopic pair. Based on the results of numerical experiments, we have chosen the following version of the scenario for the algorithm. A single measure of the similarity of templates is introduced for the entire stereoscopic image and the correlation between the extracted areas on parts of the stereoscopic image is incorporated into the formula of this measure. Thus, in distinction to the measure that is defined for the monoscopic image, the measure for the stereoscopic image includes the measures of correlation between the template and the image for each frame of the stereoscopic image, and also the measure of correlation between the positions of the templates and/or the measure of correlation between extracted areas on the frames of the stereoscopic image. In the framework of this approach, the position of the object of search on the stereoscopic image that is corrected by the vector template becomes a final one. This method yields better results and is more reliable than the preceding ones, provided that the common measure and the coefficients of measures of correlation are appropriately chosen.

CONCLUSIONS

In this paper, we have demonstrated the principal feasibility of using the stereoscopic computer vision system to measure the facial bilateral symmetry deviation with the purpose of diagnosing the human stereoscopic vision disturbances caused by bone and muscle asymmetry. It is shown that the hardware and software tools used ensure the required accuracy in detecting anthropometric points on the face. The main directions of further research in the field of designing the automated systems for the diagnosis of stereoscopic vision disturbances in early childhood are outlined.

REFERENCES

1. Knizhnikov, Yu.F., Gel'man, R.N., and Krychenkov, V.F., Application of Digital Photogrammetry to the Diagnosis of Stereoscopic Vision Pathologies, *Geodeziya i Kartografiya*, 2000, no. 6.
2. Greenberg, M.F. and Pollard, Z.F., Ocular Plagiocephaly: Ocular Torticollis with Skull and Facial Asymmetry, *Ophthalmology*, 2000, vol. 107, no. 1, pp. 173–179.
3. Murynin, A.B., The Automated Stereoscopic Image-Based Face-Recognition System, *Izv. Ross. Akad. Nauk. Teoriya Sistemy Upravleniya*, 1999, no. 1.
4. Matveev, I.A. and Murynin, A.B., Identification of Objects on the Basis of Stereo Images: Optimized Algorithms for Surface Recovery, *Izv. Ross. Akad. Nauk. Teoriya Systemy Upravleniya*, 1998, no. 3.
5. Kuznetsov, V.D., Matveev, I.A., and Murynin, A.B., Identification of Objects on the Basis of Stereo Images: Optimization of Information Space, *Izv. Ross. Akad. Nauk. Teoriya Systemy Upravleniya*, 1998, no. 4.