NON-CONTACT AND NON-INVASIVE METHOD FOR MEASUREMENT OF HEAD POSTURE IN NEUROLOGY

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Abstract: Head posture can be influenced negatively by many diseases of the nervous system, visual and vestibular systems. This article explains our method of non-invasive and non-contact head position measurement by only two cameras mounted opposite each other. By this way we could avoid an influence on patients during the time of measurement of the inclination (roll), flexion (pitch) and rotation (yaw) of the head. This is very important advantage for medical doctors because they can apply various examinations which need open space in front of a face.

Keywords: head posture, neurology, inclination, rotation, flexion, fuzzy logic.

1. Introduction

Quality of head posture of patients can inform us about disorders of the nervous system, visual and vestibular systems. In many cases, the abnormalities of head position can be small and hardly to be observed. In clinical practice, it has been possible to quantify only those deviations that are well visible. Despite the fact that an accurate method for measuring the head postural alignment could contribute to diagnosis of vestibular and some other disorders, this has not been systematically studied. The main reason of that is that all designed systems for the study of motion are expensive and unpractical. Hence, the main neurologists' request is that measurement and analytical system must not have any influence on patients. All present-day sophistic systems use intricate expensive sensors for detection of motion in 3D space but these sensors are difficult to apply and fixed without any influence on the head of the patient. The goal of our study is to design the way of accurate analyses by two cameras and special software for accurate determination of head posture.

2. Background

At the present time, the use of an orthopedic goniometer is the standard way how to evaluate angles simply and rapidly in clinical practice. But there are some limitations, especially in the case of head posture measurement. Because of the combination of three components of movement, it is problematic to use only the goniometer.

An expert, who has experiences with angle evaluation in head posture measurement, could serve possible solution as well. But the main characterizations are the same for the method mentioned above.

In Ferrario, V.F. et al, 1994 [1] a new way of integrated method based on the photographic technique, radiography technique, cephalometric measurements and photographic measurements was described. The subjects were photographed and X-rayed in the same room. The set of standardized landmarks was traced on all the records. In all photographs, the predefined soft tissues were traced, and the angle between the soft tissue marks and true vertical was calculated. The same angle was calculated on the cephalometric films, and the difference between the two measurements was used to compute the position of the soft and hard tissues. The main drawback is the exposition of patients to X-ray and is a relatively time consuming procedure.

In Ferrario, V.F. et al, 1995 [2] the new method based on the television technology was developed as a faster method than conventional photographic analysis. The subject's body and face were identified by the 12 points. Based on the image analysis program, the specified angles were calculated after the digitalization of the recorded films.

Hozman, J. et al, 2004 [3] proposed new method based on the application of three digital cameras with stands and appropriate image processing software. The new method of non-invasive head position measurement was designed for use in neurology to discover relationships between some neurological disorders and postural alignment. Pictures of the head marked on tragus and outer eye canthus are taken simultaneously by three digital cameras aligned by laser beam. Head position was measured with precision of $0{,}5^0$ in three planes (rotation-yaw, flexion-pitch and inclination-roll).

3. Measurement Methods

In the original method, three cameras are required for determination of head position. The frontal photograph is used to evaluate the coronal head tilt (inclination). A digital camera is situated on a special stand so that its position corresponds to the physical horizontal. The anatomical horizontal was defined by the following ways: If the measured subject does not suffer from an eye disorder that effects position of eyes, the connecting between eye pupils can then be considered as anatomical horizontal. Otherwise, the anatomical horizontal is defined by white rounded marks. See Fig.1.

The position of eye pupils or attached marks is then evaluated in the digital image using Hough transform. The angle between anatomical and physical horizontal is determined by angle between vector *v* which is given by camera position and vector *u* that represents coordinates of points evaluated in the image. The angle is calculated as follows (1):

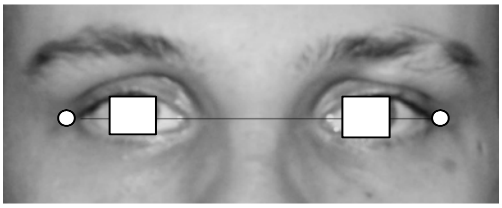
$$\theta = arccos\frac{u \cdot v}{|u| \cdot |v|} \quad (1)$$

where

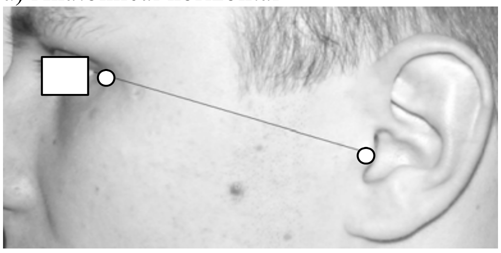
$$u = \left(a_{1x} - a_{2x}, a_{1y} - a_{2y}\right),\ v = (1,0).$$

The same method was used for evaluating the tilt in sagittal plane (flexion) using a profile photograph. The flexion value was measured relatively as the inclination of the connecting line between tragus and exterior eye corner.

The circumvolution extent (rotation) of the head is evaluated from the difference between tragus coordinates in the left-profile and right-profile image (Fig.2). These images were captured at the same time using two cameras and the cameras were situated on the same optical axis which is parallel with the frontal plane subject.



a) Anatomical horizontal



b) Anatomical axis

Figure 1: Anatomical horizontal and axis.

The coordinates of the left and right tragus are automatically evaluated by finding the centre of the white rounded mark attached on the tragus, using Hough transform. The tragus coordinates correspond to the coordinates of the maximum in an accumulator from the Hough transform.

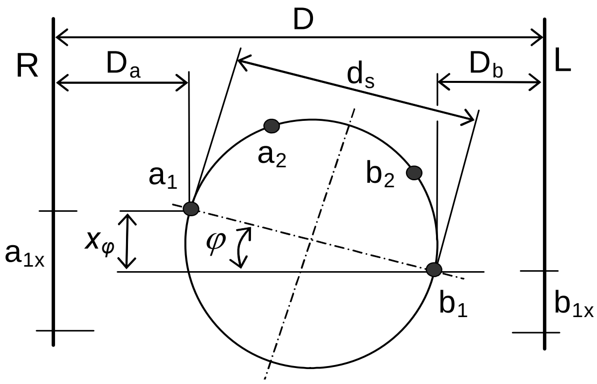


Figure 2: Geometry used for measuring the head position.

After evaluating coordinates of tragus in captured images, the angle of the head rotation is calculated as following (2):

$$\varphi = arcsin \frac{\left(a_{1x}[pixel] - b_{1x}[pixel]\right) \cdot const}{d_s[mm]} \tag{2}$$

where

$$const = \frac{ccd[mm] \cdot \left(\frac{D[mm]}{2} - \frac{d_s[mm]}{2} \right)}{f[mm] \cdot s[pixel]}.$$

The a_{1x} and b_{1x} are x-axis coordinates of tragus in the right-profile and left-profile images, d_s is diameter of the head and *const* is a constant converting the distance between tragus coordinates from pixels to millimeters. The quantity *ccd* is width of the CCD sensor given by the camera's manufacturer, D is distance between the CCD sensors (cameras), f is the focal length of the camera lens and s is the x-axis size of image.

From the description of method mentioned above used in the first generation of the measurement system [6] follows that the last method of angle determination is based on circular movement approximation. In the next step of modification we had to find a way to measure all mentioned angles by only two cameras. The main reason for that is requirement of neurologists to clear the front space where camera was used to evaluate the coronal head tilt (inclination). For evaluating the inclination we applied the same method which was used for evaluating the rotation:

$$\phi = arcsin\frac{\left(a_{1y}[pixel] - b_{1y}[pixel]\right)\cdot const}{d_s[mm]}. \qquad (3)$$

The a_{1y} and b_{1y} are y-axis coordinates of tragus in the right-profile and left-profile. The calculation of the *const* has to respect the modified quantities for y-axis, i.e. *ccd* is height of the CCD sensor given by the camera's manufacturer and *s* is the y-axis size of image.

The result of the mentioned modification of measurement (system) is that neurologists can apply other clinical equipment in frontal plane in the face of the head. We found out that last modification of system allows measuring the position with precision 0.5^0 in the all three planes as well as the system has used three cameras.

If we consider the large motion of head between the two cameras we should respect the changes of distance between the CCD sensors (cameras) and the head D_a, D_b (Fig.2). Hence, the determination of angles is little difficult. The measured distance *D* between the CCD sensors (cameras) can be calculated by the formula

$$D[mm] = D_a[mm] + D_b[mm] + d_s[mm]\cdot cos\,\varphi \qquad (4)$$

where the angle of the head rotation is

$$\varphi = arcsin\frac{a_{1x}[mm] - b_{1x}[mm]}{d_s[mm]}.$$

The distances D_a, D_b between the CCD sensors (cameras), for example the right sensor and head is determined by assumptions:

$$a_x[mm] = a_x[pixel]\cdot\frac{D_a[mm]\cdot ccd_x[mm]}{f[mm]\cdot s_x[pixel]},$$

$$a_y[mm] = a_y[pixel]\cdot\frac{D_a[mm]\cdot ccd_y[mm]}{f[mm]\cdot s_y[pixel]}$$

where the parameter a_x (in pixels) is the distance between x-axis coordinates of tragus and outer eye canthus and the parameter a_y (in pixels) is the distance between y-axis coordinates of tragus and outer eye canthus in the right-profile images. The quantity ccd_x is width and ccd_y is height of the CCD sensor given by the camera's manufacturer and s_x is the x-axis size of image and s_y is the y-axis size of image. In the case of flexion/extension of anatomical horizontal axis we can also assume that

$$a[mm] = \sqrt{\left(a_x[mm]\right)^2 + \left(a_y[mm]\right)^2}.$$

Then, by considering the pythagoras theorem, the D_a is given by

$$D_a[mm] = \frac{a[mm] \cdot f[mm]}{\sqrt{\left(\frac{a_x[pixel] \cdot ccd_x[mm]}{s_x[pixel]}\right)^2 + \left(\frac{a_y[pixel] \cdot ccd_y[mm]}{s_y[pixel]}\right)^2}}$$

The formula for the projection of distance between the points a_1, a_2 in the right image is

$$a[mm] = a_s[mm] \cdot cos\,\varphi$$

where a_s is a real measured distance between the points a_1, a_2 marked on tragus and outer eye canthus.

We determined the angle φ from mentioned formula (4) but the derivation of the angle is complicated and the final derived formula is complex. That is why we used the software MAPLE (Maplesoft) for solution and we do not present the complex applied formula we could apply in computational algorithms in this article.

The last mentioned method which respects change of distances D_a,D_b and was tested but we found that accuracy of determination of angles is not better than the application of original method which uses two cameras and which is computationally faster. Reason of this finding is the negligible effect of changes of D_a and D_b in comparison with the total distance D. That is why we finally applied in the new computational algorithms the formula (1) for determination of flexion, the formula (3) for determination of rotation and the formula (4) for determination of inclination.

4. Results of measurement

The designed method was tested in clinical practice and preliminary experiments indicate the effectiveness of these methods [7]. For easy control of the new system, a user interface was created (Fig.3).

The first set of data was measured on 30 volunteers. Measured data show that a healthy subject holds their head aligned with physical coordinate system in the range ±5 degrees. Statistical analyses of this sample show that all values (inclination, flexion, rotation) are in normal distribution.

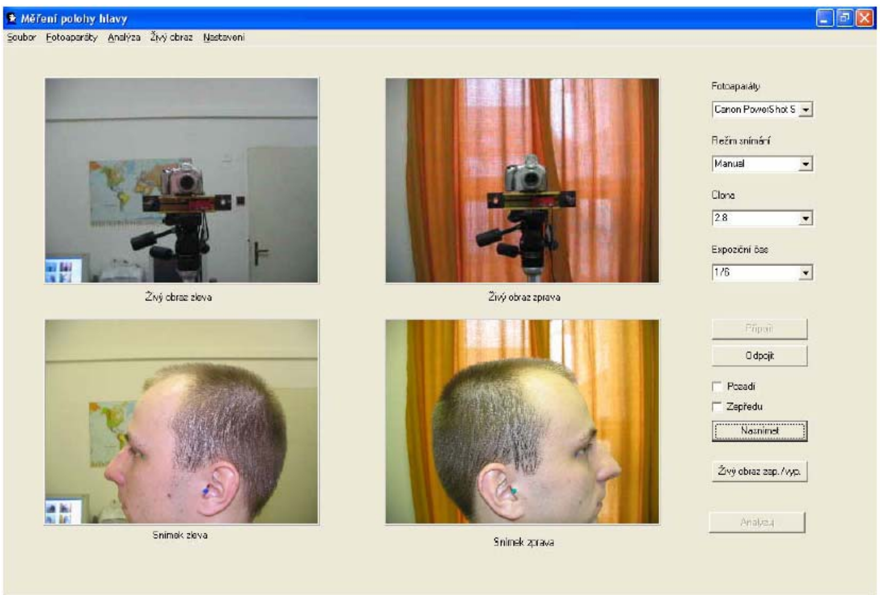


Figure 3: User interface of developed software.

5. Application of AI for identification of disease of patient

In the next step of our research we are going to apply tested methods of artificial intelligence. By our designed system and information from neurologists we can determine the sets of angles which represent characteristic states of head. This is a very important revelation because we can apply analytical method for determination and prediction of states of patient. According to the theory of fuzzy logic and neural network we designed these analytical methods:

- Fuzzy logic system uses set of fuzzy sets for determination of linguistic description of the state of head.

- Trained neural network system uses the time series of measured angles for prediction of state of patients.

Fuzzy logic system

As a simple example on how fuzzy sets we can use, consider the following situation: We found that a healthy subject holds their head aligned with physical coordinate system in the range ±5 degrees. Hence, the problem is to automatically determine the state of patient and inform medical doctor. The angles of rotation, flexion and inclination are described by linguistic form where the range ±5 degrees is linguistic "healthy". We can determine other ranges of angles according to actual information from neurologists about angles which are corresponding to the typical diseases. The advantage of application of fuzzy sets to identification of diseases is identification by table of fuzzy logic rules pre-set for all three characteristic angles (rotation, flexion and inclination). It means that we can determine output variable according these rules. For example, I will formulate the one production rule for healthy subject [*if* θ = *"healthy" and* φ = *"healthy" and* ϕ = *"healthy" then s = "healthy"*] and linguistically it is described by the statement: If the angle of flexion matches to the angle of healthy subject and angle of rotation matches to the angle of healthy subject and angle of inclination matches to the angle of healthy subject then the state of patient matches to the healthy state.

We can design other complex rules according to requirements of medical doctors. For the determination of output variable of the state of patient we have to design an inference mechanism. We will use Mamdani implication [8] for determination of output represented by single output fuzzy set and for defuzzification of this output fuzzy set I will use one of the most common methods: middle of maximum, centroid, largest of maximum. The method of defuzzification transforms the output fuzzy set to crisp output variable value. Described method of identification uses fuzzy sets and this designed principle of analysis represents a typical example of application of fuzzy expert system. Design of this fuzzy logic analytical tool can be created by Matlab Fuzzy Logic Toolbox.

Neural network system

The previous scheme allows direct identification of state of patient. For the prediction of state of patient, an input of momentary value can not be only used in the neural network but we have to analyze the time series representing previous sequence of values of the analyzed head posture [9]. A great advantage of neural networks is the ability to learn according to patterns. After learning, neural networks are able to represent and reflect hidden and strong nonlinear behaviour and relations with disturbance in the training set.

The prediction of time series can be realized only by trained neural network. For the training neural network, past time interval of behaviour of monitored quantity will be used.

Neural network will learn according to the past time series representing the training set of input/output. Past time series will represent the input data and time series in future will be expected as output information. This way of learning of neural network is called learning with teacher and we will fill the teaching set for learning only with relevant values. For prediction, we can use different sorts of neural network as are backpropagation NN, ART NN, Markovov's NN, etc. We choose backpropagation NN because this sort of NN is integrated into almost all special software applications.

We will create a training set directly from the time series. The input will be a certain number of measured values of angles and the desired output will be a certain number of measured values of angles in a predefined distance from the input time series. The input part of the time series is called a window and the output part of the time series is a predicted value. We create items of the training set by shifts of this window in the time series. If we require a sequence of predicted values (i.e. trend) we will also use for the output more values from the window of time series. For testing we will have to keep part of measured past time series. That means we will not use this chosen time series as items of the training sets but we will use this part of time series for checking of how much the neural network has learned.

We will divide acquired time series into learning series, validation series and testing series. These three series will partially overlap each other. We will use learning series as a data sequence for learning and modifying of neural network. Validation series will be used for determination of deviation. This deviation will be calculated as a diversity between answers to validation series of neural network and real output included in validation series. We will use this calculated deviation as criterion for the end of learning. We will use testing series for testing of learned neural network after the learning is finished. This set will simulate future values which have not been seen by neural network in the process of learning. I can tell that learning sets are for the identification of model, validation series are for model checking and testing series for usability test of the model.

In the described way, the learned and tested neural network will be able to predict the values of angles of head posture. We will feed the windows of time series (past and present time series of values) into input of neural network and these NN will compute output values representing predicted values or sequence of values. The only necessary condition for using this method is the existence of sufficient accuracy of values in the past time series and sufficient size of this time series (i.e. training set).

6. Conclusion

We designed the special calibration equipment and tools and implemented SW procedures for the evaluation of measured data. Above all, the new analytical methods of implemented SW procedures were described in this article.

A result of this study is a recommendation to use two identical digital cameras as a sufficiently accurate system for determination of inclination, flexion and rotation of head in neurological practice. This system is also cheaper in comparison with sophistic systems which use accelerometers, magnetometers and gyroscopes. Nevertheless, the largest advantage is non-invasive and non-contact way of measurement without application any sensors but only with application of small cheap one-use markers. The mentioned way of measurement of head posture could be applied as well in other engineering, medical and science areas.

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