Precise Advanced Head Posture Measurement

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Abstract: - In this paper we describe advanced contactless method for the precise posture head measurement using two digital cameras with a special stand. Three main important requirements are needed for the successful measurement. The method is designed for use in neurology to discover relationships between some neurological disorders (such as disorders of vestibular system) and postural head alignment. The main goal of this study is to compare possibilities of the method with callibration and validation tests. It means with the special accurate protractor in case of the head inclination and head flexion/extension and with the stepper motor including planet gearbox in case of the head rotation. The results are presented for all cases. It was experimentally checked that the accuracy of this method in order of tenths of degrees and therefore this method satisfies the general physicians´ requirement for the accuracy of the measurement about 1-2°.

Key-Words: - Head posture, posture measurement, postural head alignment

1 Introduction

Objective was to develop a technique for precise posture head measurement or, in other words, for measurement of the native position of the head in 3D space. The technique was supposed to determine differences between anatomical coordinate system and physical coordinate system with accuracy from one to two degrees in case of tilt and rotation. Similar technique has not been developed up to this time such that it could be widely and easily used in neurological clinical practice although it could have an important use in this field because there are a lot of neurological disorders that affect postural alignment position of head [1]. Head posture is influenced by many diseases of nervous system, visual and vestibular systems [1]. These can be divided into several groups:

- Cervical blockades and diseases of cervical spine often cause abnormalities of the head position in the wide range.
- "Movement disorders" from the group of dystonias. For them, the abnormal position of affected body segments is typical. Disorder of the head alignment that is known as torticollis is the most frequent dystonia at all. In this case, the abnormal position of the head corresponds to activation of affected muscles. See Fig. 1.
- Paralyses of eye muscles also often cause a compensative position of the head when the insufficient function is compensated by a tilt of the head in direction of the affected muscle.

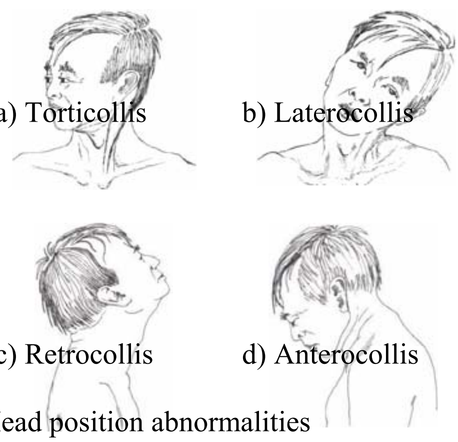


Fig. 1: Head position abnormalities

In many cases, the abnormalities of the head position can be small and hard to be observed. In clinical practice, it has been possible to quantify only those deviations that are well visible (up to this time). Despite the fact that an accurate method for measuring the head postural alignment could contribute to diagnosis of vestibular and some other disorders, this issue has not been systematically studied. There are only a few works concerning the head posture, but it was investigated e.g. from the point of view of orthodontics and dentofacial orthopedics or plastic surgery. Detailed survey of these methods is given in chapter 2.

Another similar studies (that have been published) are focused on differences of head postural alignment in different genders and age categories [2] or compare means between a normal sample and a sample of people with cervical pain [3] but the techniques described in these studies are not useful clinically and don't allow measuring the rotation of the head. We present a new technique that allows us to get all needed values comfortably and quickly by evaluating digital images. Our study is focused on relation of the head position to neurological and eye disorders including relation to subjective perception of vertical by control and patient samples.

2 Background and Related Works

The following overview serves as enumeration of the applications related to the available technology during the last twenty years. This enumeration is not exhaustive but the most important papers are included. At the same time it is evident that technology advancement implies new methods of the head posture measurement from the various viewpoints. From this point of view the following overview is commented.

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

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

The following methods are typical by the using of some tools or technology.

In Young, J.D., 1988 [4] the main principal of this approach is based on using three mirrors and special patient´s head markers (bands). The resulting images are taken with the camera. After this a set of lines is drawn with respect to the reference points and adjacent known vertical or horizontal line. The last step is measurement of the relevant angles with a protractor. Head tilt (inclination), head turn (rotation) and chin elevation or depression (flexion/extension) is evaluated. One drawback is the wide variation in cranial configuration found between patients and associated with age.

In Murphy, K.E. et al, 1991 [5] the main aim of this paper was to describe a system for measuring and recording cranial posture in a dynamic manner. Measurement of the declination and inclination was performed by inclinometers attached to the spectacle rims. Inclinometer is an instrument for measuring angles of tilt, elevation or inclination of an object with respect to gravity based on the accelerometers. Processing of the inclinometer voltages was performed by the adaptive data logger. The inclinometer was calibrated with a 30º plastic visor and a perpendicular spirit level.

In Ferrario, V.F. et al, 1994 [6] an integrated method based on the photographic technique, radiographic technique, cephalometric measurements and photographic measurements was desribed. The subjects were photographed and X-rayed in the same room. The set of standardized landmarks was traced on all the records. On all photographs, the soft tissue Fandwork Nasion and the soft tissue Pogonion were traced, and the angle between the above mentioned 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. These new values were compared with the values previously observed in the standard cephalometric orientation. The main drawback is exposition of patients to X-ray and relatively time consuming procedures.

In Ferrario, V.F. et al, 1995 [7] the new method based on the television technology was developed as method faster than conventional photographic analysis. The subject's body and face were identified by the 12 points. All subjects were pictured using a standardized technique for frontal views of the total body and lateral views of the neck and face. After 20 seconds of standings, two 2-second films were taken for each subject. Based on the image analysis program the specified angles were calculated after the digitization of the recorded films.

In Galardi, G. et al, 2003 [8] objective method to measure posture and voluntary movements in patients with cervical dystonia using Fastrack was developed. The Fastrack is an electromagnetic system consisting of a stationary transmitter station and four sensors.The head position in the space was reconstructed (based on the sensor signals) and observed from axial, sagittal, and coronal planes.

Hozman, J. et al, 2004 [9] proposed new method based on the application of two digital cameras with stands and appropriate image processing software. We described the new method of non-invasive head position measurement. The method was designed for use in neurology to discover relationships between some neurological disorders (such as disorders of vestibular system) and postural head alignment. Pictures of the head marked on tragus and outer eye canthus are taken simultaneously by two digital cameras aligned by laser beam.

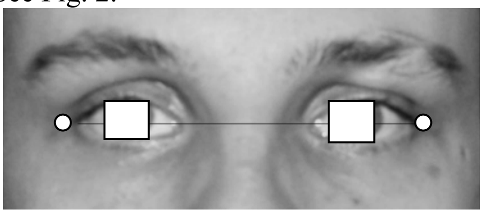
In Hozman, J. et al, 2005 [10], second generation of the system described in [9] was presented. The first results are shown measured on 31 normal subjects.

In Cerny, R. et al, 2006 [11] second advanced generation of the system was described in [10]. Head position was measured with precision of 0,5º in three planes (rotation -yaw, flexion-pitch and inclination-roll). Mean values of the head position (100 healthy controls): retro flexion 21,7º; inclination to the right 0,2º; head rotation to the left 1,7º.

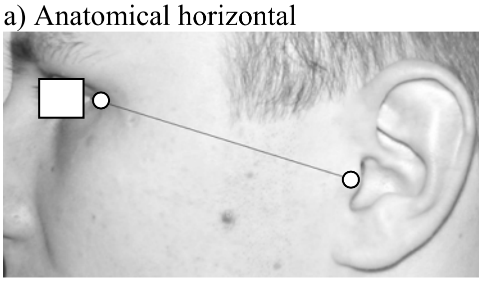
3 Problem Solution

3.1 Applied method

The frontal photograph is used to evaluate the coronal head tilt (inclination). A digital camera is situated on a (tripod) special stand so that its position corresponds to the physical horizontal. The anatomical horizontal can be defined by the following ways: If the measured subject does not suffer from an eye disorder that affects position of eyes, the connecting line between eye pupils can then be considered as anatomical horizontal. Otherwise, the anatomical horizontal is defined by exterior corners of eye lids. These points are designated by white rounded marks. See Fig. 2.



a) Anatomical horizontal



b) Anatomical axis

Fig. 2: Anatomical horizontal and axis

The position of eye pupils or attached marks is then evaluated in the digital image by using Hough transform. The angle between anatomical and physical horizontal is determined by angle between vector (1,0) (which is given by camera position) and vector that represents coordinates of points evaluated in the image. The angle is calculated as follows (1):

$$\varphi = \arccos \frac{u \cdot v}{|u| \cdot |v|}, 0 \le \varphi \le \pi, [\text{rad}], \qquad (1)$$

where u is the vector representing the physical horizontal and v is the vector representing the anatomical horizontal.

The same method is used for evaluating the tilt in sagittal plane (flexion) using a profile photograph. The flexion value is 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. These images are captured at the same time using two cameras and the cameras are situated on the same optical axis which is parallel with the frontal plane of subject. This is achieved by attaching specially designed devices on stand. These devices allow the cameras to be set on the same axis using laser beam. See Fig. 3.

a) Tripod with camera and laser collimator

b) Stand (advanced version of tripods) with cameras and collimators

Fig. 3: Experimental setup with device for setting cameras on the same optical axis.

The laser beam emitter and the leaser beam detector are equipped with collimators. When the cameras are on the same optical axis, the right position is signaled by LED diode (the laser beam is detected).

The whole configuration is placed on an axis designated on the floor (Fig. 8), or on the special mat (advanced and mobile version). In the middle, there are marks for subject's feet. In order to be photographed, the subjects are instructed to stand on the marks comfortably, in their "normal, loose or habitual" posture, with their weight evenly on both feet and looking straight ahead. When the subject is relaxed photographs are taken from both sides at the same time using remotely computer-controlled cameras to eliminate an error that would be generated by involuntary movement of the subject.

The following figures show how coordinates of the left and right tragus are automatically evaluated by finding centre of the white rounded mark attached on the tragus in the image (Fig. 4), using Hough transform. The tragus coordinates correspond to the coordinates of the maximum in an accumulator from the Hough transform (Fig. 5).

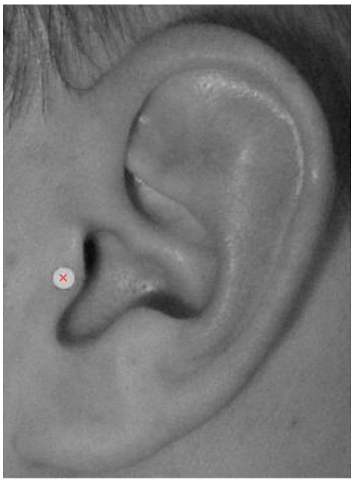


Fig. 4: White rounded mark on the tragus

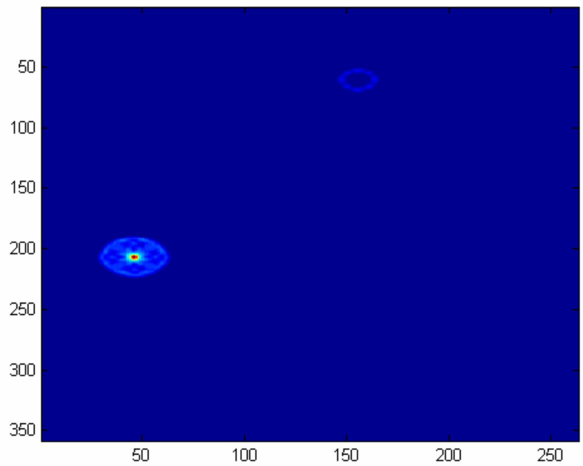


Fig. 5: Maximum in the accumulator after performing the Hough transform corresponds to the coordinates of the tragus (the cross in the Fig. 4).

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

$$\varphi_c = \arcsin\frac{(a-(s-b))\cdot c}{d}, -\frac{\pi}{2} \leq \varphi_c \leq \frac{\pi}{2}, [\text{rad}], \qquad (2)$$

where a[pixel] is x-axis coordinate of the tragus in the left-profile image, b[pixel] is x-axis coordinate of the tragus in the right-profile image, s[pixel] is x-axis size of the image, d[mm] is diameter of the head and c[mm/pixel] is a constant converting the distance between tragus coordinates from pixels to millimetres calculated as follows (3):

$$c = \frac{ccd \cdot z}{f \cdot s}[\text{mm/pixel}] \qquad (3)$$

where *ccd* [mm] is width of the CCD sensor given by the camera's manufacturer, z[mm] is distance between the subject and the CCD sensor (camera), f[mm] is the focal length of the camera lens and s[pixel] is the x-axis size of the image.

This method is based on circle movement approximation – see Fig. 6, which shows the geometry used for measuring the head rotation (d[mm] is diameter of the head, x[mm] is distance between left and right tragus and φ[deg] is the result angle).

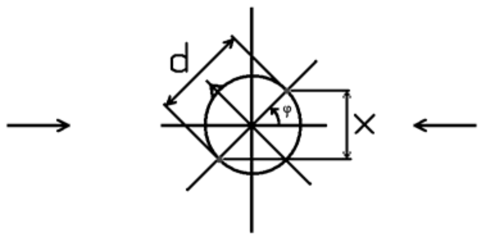


Fig. 6: Geometry used for measuring the head rotation

From the description of above mentioned method follows that the important requirements implied the successful measurement are following:

1. Setting of the whole systems to the plane (flat ground) using spirit level,
2. Identification of the digital cameras optical axes by means of the laser transmitter and receiver including collimator (Fig. 7),
3. Application of the special mat (including highlighted footprint) or pattern on the ground related to the main stand or tripod (Fig. 8).

The last requirement is related to the important idea that all patient´s measurements have to be comparable. It means that the point of departure has to be the same for all measurements independently of the time.

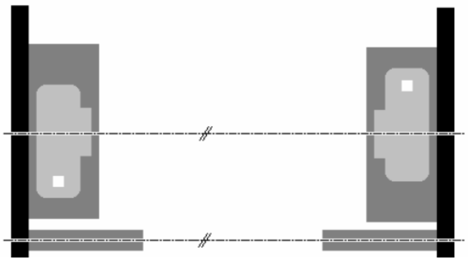


Fig. 7: Identification of the digital cameras optical axes by means of laser transmitter and receiver including collimator and special preparation with digital cameras (top view)

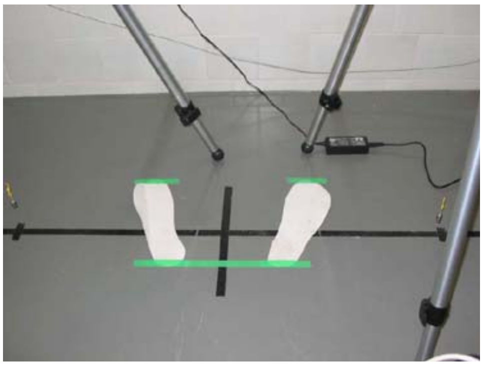


Fig. 8: Measurement axis on the ground related to the tripods and footprints for patient´s position

3.2 Calibration and verification procedure

The main aim was to experimentally check the method accuracy by using a model of a human head and experimental measuring devices and tools. The measurement was divided into three separate experiments (Fig. 9).

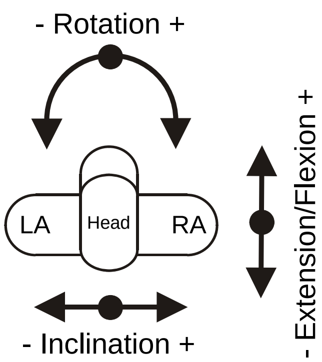


Fig. 9: Schematic view of the possible head positions with assigned signs (LA - left arm, RA - right arm)

Rotation - this measurement was based on using the SW for comparison of reference points against the physical points. Two digital cameras Canon PowerShot S1IS were used and placed on the same optical axis with 90 cm distance. An identification of the optical axes was performed via source and laser radiation detector equipped by collimators. The whole system was attached to the special stand. We used artificial styrofoam head and the Berger-Lahr IcIA IFS stepper motor including planet gearbox with minimum possible single increment equal to 0,00225° (see Fig. 10.). The stepper motor was controlled by special SW IcIA Easy. The head and motor were placed symmetrically between the digital cameras. As reference points we used the above described anatomical points (see section 3.1). The first measured value was used as initial, i.e. zero and was used as correction for all subsequent values (see Table 1 below).

Fig. 10: Model of the head and stepper motor including planet gearbox (verification of rotation measurement)

Table 1: Measured and corrected values for rotation

Initial value (motor pos.) [°]	Measured value without correction [°]	Measured value with correction [°]
5,0	6,9	5,4
10,0	12,5	11,0
20,0	23,3	21,8
-5,0	-3,6	-5,1
-10,0	-9,6	-11,1
-20,0	-20,1	-21,6

Initial value (motor position) "0°" was determined with measuring error 1,5° (see correction above).

Inclination - this measurement was based on using the SW for comparison of reference points against the physical points. We used one digital camera Canon PowerShot S1IS placed on the same optical axis as special protractor 45 cm far from the camera (Fig. 11). This protractor with diameter 45 cm was produced by laser beam into the perspex and has 1° increments within the ±30° and 5° increments within the remainder angles (see Fig. 12 and 13). The protractor was produced with error equals to tenths of mm onto the diameter equals to 50 cm. The horizontal axis has angle 0° and vertical axis has angle 90°. The whole stand is equipped by spirit with level and with adjustable joint. The first measured value was used as initial, i.e. zero and was used as correction for all subsequent values. After this we placed (by the evaluation SW) reference points onto the protractor lines signposted by angle value. It was performed for all four quadrants (see Table 2 and meaning of the superscript ^{*Xqdr}). Values with a minus sign correspond to the left inclination.

Fig. 11: Experimetal setup for inclination measurement verification

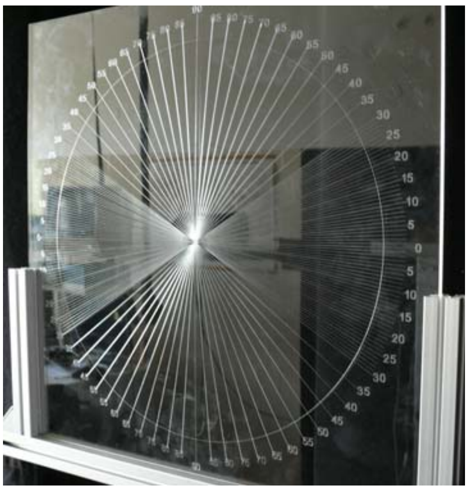


Fig. 12: Detail view of the real protractor

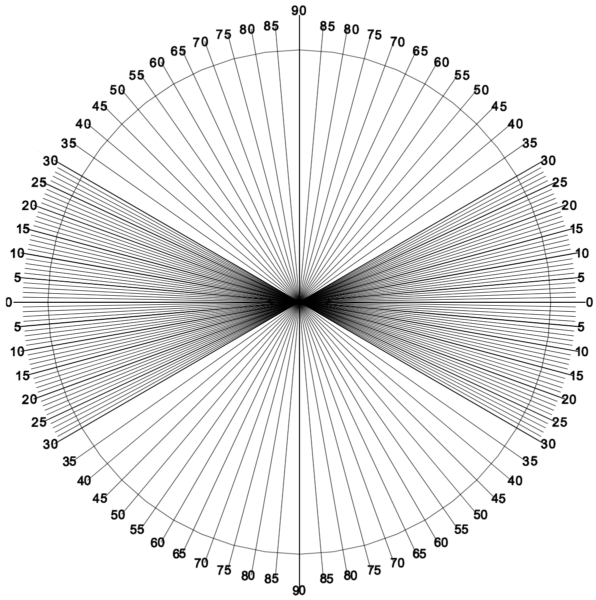


Fig. 13: Detail schematic of the protractor

Table 2: Measured and corrected values for inclination

Initial value (protractor) [°] ^{*Xqdr}	Measured value without correction [°]	Measured value with correction [°]
5,0 ^{1qdr}	6,0	5,0
-5,0 ^{2qdr}	-3,9	-4,9
5,0 ^{3qdr}	6,2	5,2
-5,0 ^{4qdr}	-4,0	-5,0
10,0 ^{1qdr}	11,1	10,1
-10,0 ^{2qdr}	-9,3	-10,3
10,0 ^{3qdr}	11,4	10,4
-10,0 ^{4qdr}	-8,9	-9,9
20,0 ^{1qdr}	20,5	19,6
-20,0 ^{2qdr}	-19,0	-20,0
20,0 ^{3qdr}	21,0	20,0
-20,0 ^{4qdr}	-18,9	-19,9

^{*Xqdr} - measured value in the selected quadrant

Initial value (protractor setting by spirit level) "0°" was determined with measuring error 1,0° (see correction above). Mean is equal to 0,14° and standard deviation is equal to 0,15°.

Flexion/extension - this measurement was based on using the SW for comparison of reference points against the physical points. Two digital cameras Canon PowerShot S1IS were used and placed on the same optical axis as special protractor 45 cm far from every camera (Fig.14). The first measured value was used as initial, i.e. zero and was used as correction for all subsequent values. After this there were placed (by the evaluation SW) reference points onto the protractor lines signposted by angle value. It was performed for all four quadrants. Values signed by mines correspond to the flexion (Table 3).

Fig. 14: Experimetal setup for flexion/extension measurement verification

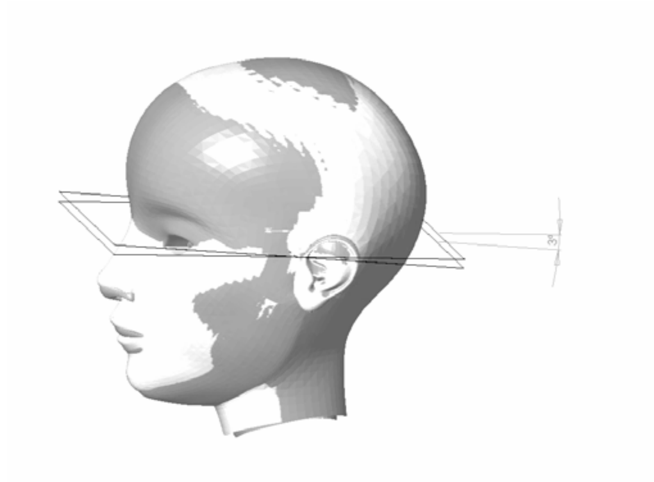
Table 3: Measured and corrected values for flexion/extension

Initial value (protractor) fl. [°]/ext. [°]	Measured value without correction fl. [°]/ext. [°]	Measured value with correction fl. [°]/ext. [°]
5,0/-5,0	4,2/-5,0	4,6/-4,6
10,0/-10,0	9,6/-10,1	10,0/-9,7
15,0/-15,0	14,5/-15,0	14,9/-14,6
20,0/-20,0	19,6/-20,2	20,0/-19,8
25,0/-25,0	24,4/-25,1	24,8/-24,7
30,0/-30,0	29,5/-29,9	29,9/-29,5
35,0/-35,0	34,4/-34,9	34,8/-34,5
40,0/-40,0	39,5/-40,2	39,9/-39,8
45,0/-45,0	44,6/-45,2	45,0/-44,8
50,0/-50,0	49,3/-49,9	49,7/-49,5

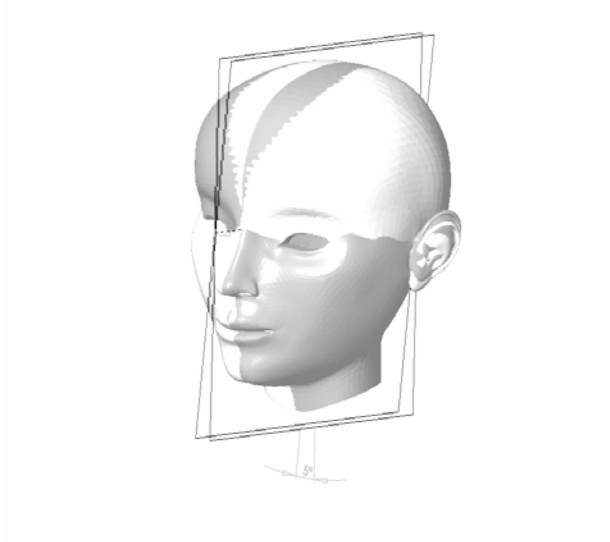
Initial value (protractor setting by spirit level) "0°" was determined with measuring error 0,4° (see correction above). Mean is equal to 0,14°/0,14° (flexion/extension) and standard deviation is equal to 0,15°/0,15° (flexion/extension).

As a result, it was experimentally checked that the accuracy of this method is tenths of degrees. It is in correspondence with the required initial method accuracy, i.e. one to two degrees in case of tilt and rotation. But there is some limitation. All results have the accuracy tenths of degrees, but within the head rotation ±20° only. Over this angle there is increasing error. Because of the standard range of the patient´s head position, the angle range ±20° is sufficient.

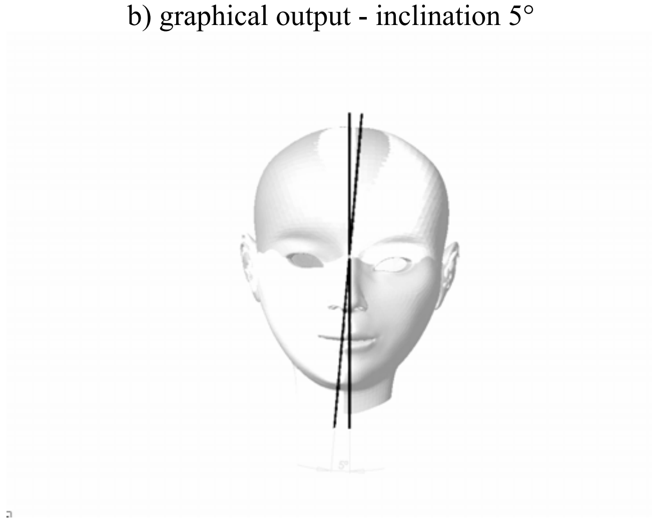
For the graphical output of the measured results we used macro in SolidWorks® (made by Ms. Vera Fiserova from SolidVision, Ltd., Prague, Czech Republic), see Fig. 15.



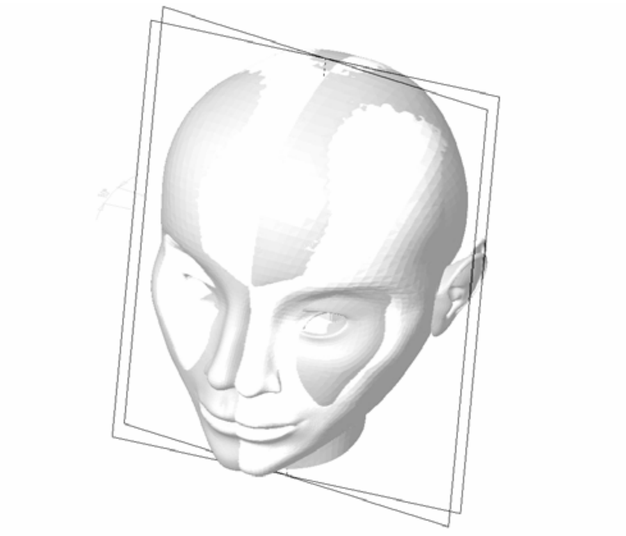
a) graphical output - extension 3°



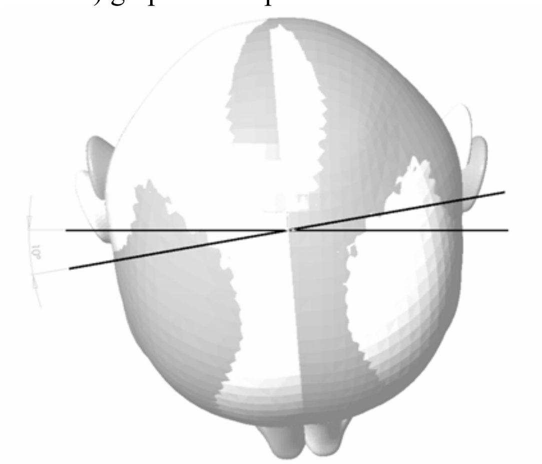
b) graphical output - inclination 5°



c) graphical output - inclination 5°



d) graphical output - rotation 10°



e) graphical output - rotation 10° (top view)

Fig. 15: Graphical outputs of the different head position based on the textures in comparison with physical perfect positioned head

3.3 Results

The first set of data was measured on 31 volunteers recruited from students of the Czech Technical University and Charles University in Prague. The measurement of the head position was completed with measurement of subjective perception of vertical (SPV). The subject tried to align a needle to vertical position when peering into white sphere. Final angle of the needle was measured. The measurement was separately done for left and right eye and then for both eyes. This was done because there can be potential relation between subjective perception of vertical and head position, especially inclination. Measured data show that healthy subject holds his head aligned with physical coordinate system in the range of ±5 degrees. The results also predict that there is a correlation between values of inclination and SPV. Statistical analyses of this sample show that all values (inclination, flexion, rotation and SPV) are from normal distribution. Values of inclination and SPV are from the same distribution at the significance level of $P<0.05$. However, these results can not be considered as final because of small data sample. The detailed results were published in [10].

The second set of data was measured using the second advanced generation of the system described in [11]. Head position was measured with precision of 0,5º in three planes (rotation -yaw, flexion-pitch and inclination-roll). Mean values of the head position (100 healthy controls): retro flexion 21,7º; inclination to the right 0,2º; head rotation to the left 1,7º.

The third set of data was measured using the second advanced generation of the system as well and the results are summarized here. The main result is that the accuracy of the method alone is in tenths of degree. From this follows that the main impact on the accuracy have patients´ artifacts and the fulfilment quality of the measurement requirements. The rotation measurement has greater error in comparison with the inclination and flexion/extension measurement and this follows mainly from the method of evaluation of the length of the anatomical axis projections from the left and right side (see Fig. 6).

4 Conclusion

We designed the special calibration equipment and tools and implemented SW procedures for evaluation of the measured data.

The main result of this study shows that the accuracy of the method alone is in tenths of degree. This result was validated by previous experiments [10] and [11]. From this study follows that the main impact on the accuracy have patients´ artifacts and the fulfilment quality of the measurement requirements.

A result of this study is a recommendation to use three identical digital cameras (instead of two digital cameras) so that the error caused by the patients´ position during the examination (turn to the left) could be reduced. The whole accuracy of the method could be this way markedly increased.

From the point of view of the contemporary technology there is possibility to use miniature 3D inertial measurement unit/motion sensors (IMU) with accelerometer, magnetometer and gyroscope (Xsens Motion Technologies) and custom made Head Mounted Display (HMD). Initial experiments in cooperation with Laboratory for Biomechanics and Control Systems, Department of Automatic Control and Systems, Faculty for Electrical Engineering, Mechanical Engineering and Naval Architecture, University of Split headed by V. Zanchi were performed as well.

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