Determining the Position of Head and Shoulders in Neurological Practice with the use of Cameras

P. Kutílek, J. Hozman

Abstract

The posture of the head and shoulders can be influenced negatively by many diseases of the nervous system, visual and vestibular systems. We have designed a system and a set of procedures for evaluating the inclination (roll), flexion (pitch) and rotation (yaw) of the head and the inclination (roll) and rotation (yaw) of the shoulders. A new computational algorithm allows non-invasive and non-contact head and shoulder position measurement using two cameras mounted opposite each other, and the displacement of the optical axis of the cameras is also corrected.

Keywords: shoulder posture, head posture, neurology, camera calibration.

1 Introduction

The objective of our study was to develop a technique for precise head and shoulder posture measurement or, in other words, for measuring the native position of the head and shoulders in 3D space. The technique set out to determine differences between the anatomical coordinate system of the head and shoulders and the physical coordinate system with accuracy to two degrees for inclination, flexion/extension and rotation. No similar technique has previously been developed that can be widely and easily used in neurological clinical practice. Nevertheless, the technique could have important applications, as there are many neurological disorders that affect the postural alignment position of the head and shoulders. These can be divided into three main groups:

- Cervical blockages and diseases of the cervical spine often cause a wide range of positional abnormalities.
- Dystonic "movement disorders". Abnormal body segment position is typical for dystonia.
- Paralyses of eye muscles also often cause a position that attempts to compensate for the insufficient function.

In many cases, the abnormalities of the head and shoulder position can be small and difficult to observe. In clinical practice, it has until now been possible to quantify only those deviations that are well visible. Although an accurate method for measuring head and shoulder postural alignment could contribute to the diagnosis of vestibular disorders and some other disorders, this issue has not been systematically studied in the past.

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

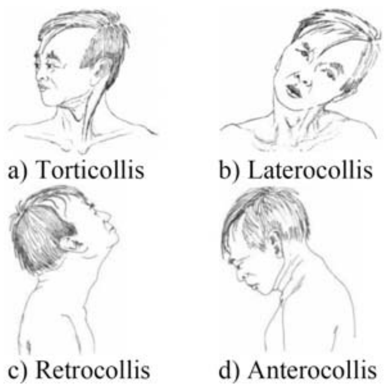

Fig. 1: Examples of head position abnormalities

Ferrario, V. F., et al, 1995 [1] developed a new method based on television technology that was faster than conventional analysis. The subject's body and face were identified by 12 points. On the basis of an image analysis program, the specified angles were calculated after digitizing the recorded films.

Galardi, G., et al, 2003 [2] developed an objective method for measuring posture using Fastrack. Fastrack is an electromagnetic system consisting of a stationary transmitter station and four sensors. The head position in space was reconstructed (based on sensor signals) and was observed from the axial, sagittal and coronal planes.

In this paper, we will describe our contribution and our proposed method for measuring head and shoulder position. The method is designed for use in neurology to discover relationships between some neurological disorders and postural alignment. Pictures of the head marked on the tragus and outer eye canthus, and shoulders marked on the acromion, are taken simultaneously by two digital cameras.

2 Methods

Hozman, J., et al, 2004 [3] proposed a new method based on the application of three digital cameras with stands and appropriate image processing software. This new non-invasive head position measurement method was designed for use in neurology to discover relationships between some neurological disorders and postural alignment. The objective was to develop a technique for precise head posture measurement or, in other words, for measuring the native position of the head in 3D space. The technique aimed to determine differences between the anatomical coordinate system and the physical coordinate system with accuracy from one to two degrees for tilt and rotation. Pictures of the head marked on the tragus and the outer eye canthus are taken simultaneously by three digital cameras aligned by a laser beam. No similar technique has previously been developed that can be widely and easily used in neurological clinical practice. Head position was measured with precision of 0.5° in three planes (rotation-yaw, flexion-pitch and inclination-roll) [3].

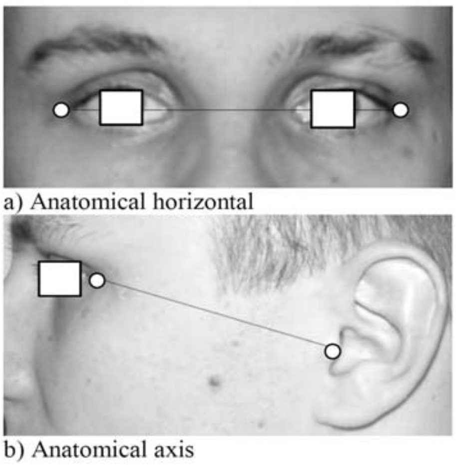

Fig. 2: Anatomical horizontal and axis

In our recent method for studying only head position [5], two cameras are required for determining head positions. The rotation and inclination of the head is evaluated from the difference between the tragus coordinates in the left-profile and right-profile image. The coordinates of the left and right tragus (Figure 2) are evaluated by finding the centre of the rounded mark attached to the tragus. The images are captured simultaneously, using two cameras, which are situated on the same optical axis parallel with the frontal plane of the subject.

It is a mathematically simple problem to determine the tilt in the sagittal plane (flexion/extension) of the head from side shots (profile photographs). The flexion value was measured relatively as the inclination of the connecting line between the tragus and the exterior eye corner. The angle between the anatomical and physical horizontal is determined by the angle between vector v (horizontal vector), given by the camera position, and vector u, which represents the coordinates of the points evaluated in the image. The angle is calculated as follows (1):

$$\theta = \arccos \frac{u \cdot v}{|u| \cdot |v|} \tag{1}$$

where

$$u = (a_{1x}\ [\mathrm{px}] - a_{2x}\ [\mathrm{px}], a_{1y}\ [\mathrm{px}] - a_{2y}\ [\mathrm{px}]),$$
$$v = (1, 0).$$

a_{1x} and b_{1x} are the x-axis coordinates of the tragus in the right-profile and left-profile images, and a_{2x} and b_{2x} are the x-axis coordinates of the outer eye canthus in the right-profile and left-profile images. The coordinates are evaluated by finding the centre of the rounded mark attached to the tragus and outer eye canthus of the patient.

The circumvolution extent (rotation) of the head is evaluated from the difference between the tragus coordinates in the left-profile and right-profile image (Figure 3). These images were captured simultaneously, using two cameras, and the cameras are situated on the same optical axis parallel with the frontal plane subject.

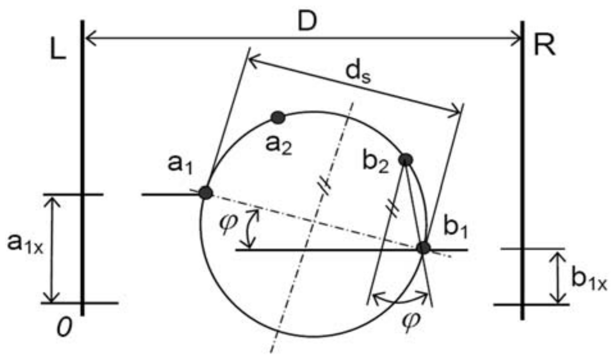

Fig. 3: Geometry used for measuring the head position

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

$$\varphi = \arcsin \frac{(a_{1x}\ [\mathrm{px}] - b_{1x}\ [\mathrm{px}]) \cdot \mathrm{const}}{d_s\ [\mathrm{mm}]}. \tag{2}$$

where

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

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

For evaluating the inclination we applied the same method as was used for evaluating the rotation:

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

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

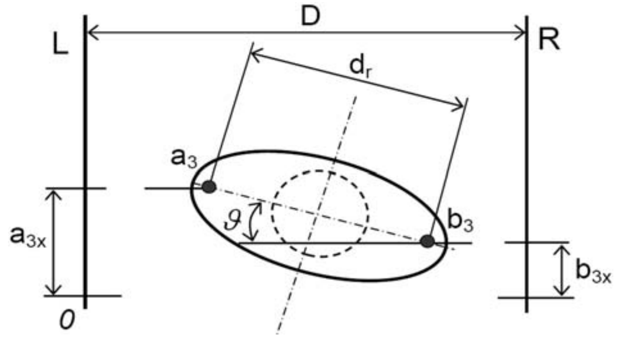

Fig. 4: Geometry used for measuring the shoulder position

For evaluating shoulder position, we use a method similar to the method that we use for evaluating head position. We assume an approximation of the shoulder movement by a circular movement of the markers, so the formula for determining shoulder rotation is:

$$\vartheta = \arcsin \frac{(a_{3x}\ [\text{px}] - b_{3x}\ [\text{px}]) \cdot \text{const}}{d_r\ [\text{mm}]} \qquad (4)$$

where

$$\text{const} = \frac{ccd\ [\text{mm}] \cdot (D\ [\text{mm}] - d_r\ [\text{mm}])}{2 \cdot f\ [\text{mm}] \cdot s\ [\text{px}]}$$

a_{3x} and b_{3x} are the x-axis coordinates of the acromion in the right-profile and left-profile. A medical doctor indicates these anatomical points with a red mark for easy location of the anatomical points in the pictures. If the clinical investigation is carried out by an experienced medical doctor, it is not necessary to apply colored marks to the anatomical parts of the body before making an examination using our camera system.

d_s is the distance between the acromions measured by a medical doctor before a clinical examination using our system. The value *const* is a constant converting the distance between the acromion coordinates from pixels to millimeters. The quantity *ccd* is the width of the CCD sensor given by the camera's manufacturer, D is the distance between the CCD sensors (cameras), f is the focal length of the camera lens, and s is the horizontal x-axis image size.

To evaluate the shoulder inclination we applied the same method as was used for evaluating the shoulder rotation:

$$\zeta = \arcsin \frac{(a_{3y}\ [\text{px}] - b_{3y}\ [\text{px}]) \cdot \text{const}}{d_r\ [\text{mm}]} \qquad (5)$$

a_{3y} and b_{3y} are the vertical y-axis coordinates of the acromion in the right-profile and left-profile. The calculation of *const* has to take into account the modified quantities for the vertical y-axis, i.e. *ccd* is the height of the CCD sensor given by the camera's manufacturer, and s is the vertical y-axis image size.

The software also determines the angular displacement of the head to the shoulders for rotation, using the formula

$$\kappa = \vartheta - \varphi \qquad (6)$$

and the angular displacement of the head to the shoulders for inclination

$$\lambda = \zeta - \phi. \qquad (7)$$

In the way described above, based on identifying anatomical points with the use of cameras, we can avoid influencing patients while we are measuring the inclination (roll), flexion (pitch) and rotation (yaw) of the head and shoulders.

Unfortunately, the measurement accuracy is determined by the accuracy of the calibration of the cameras. Problems of deviations of CCD sensors and deviation of optical axes can be excluded by special hardware or by computationally intensive software. In the earlier version of our system, a laser collimator was tested and used. When the cameras are on the same optical axis, the right position is signaled by the LED diode (the laser beam is detected).

A test version of our system currently uses software correction based on computational algorithms implemented in our software, or we can use, e.g, the Camera Calibration Toolbox in MatLab software for identifying and correcting the position of the cameras.

Problems of deviations of CCD sensors and deviation of optical axes can be excluded by scanning the correction mark on a transparent mask. In this way, we find the differences between the coordinates of this scanned point in the two frames. These differences represent the deviations that will be used for correcting the calculation. An easily adjusted formula for calculating, for example, the rotation is

$$\varphi = \arcsin \frac{(a_{1x}\ [\mathrm{px}] - b_{1x}\ [\mathrm{px}] - k_x\ [\mathrm{px}]) \cdot \mathrm{const}}{d_s\ [\mathrm{mm}]}, \quad (8)$$

other assumptions are identical with the calculation without corrections.

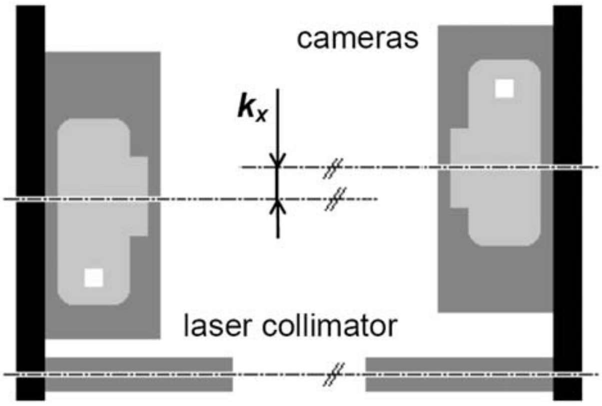

Fig. 5: Displacement of optical axes

Fig. 6: The two-arm stand with fixed cameras and laser collimators

For the angular deviation of optical axes, the correction is more difficult. We have to apply special intensive software, e.g. the MatLab Camera Calibration Toolbox. This software enables accurate detection of the mutual positions of the optical axes by scanning the correction marks on a transparent mask/board. The software provides information on the mutual displacement and the mutual rotation of the optical axes of the cameras.

With our proposed software, we find the values for the relative position of the two axes of the cameras, i.e. the rotation vector $[\omega, \xi, \psi]$ and the translation vector $[k_x, k_y, k_z]$. For calculating the position of the head and shoulders, one of the cameras must be selected as the main camera and we determine the rotation, inclination and flexion of head and shoulders in 3D space to the coordinate system of the main camera. The physician must also take this state into account in the clinical examination. Using components of the rotation and translation vector, the formula for determining head rotation is

$$\varphi = \arcsin \left[\frac{(a_{1x}\ [\mathrm{px}] - b_{1x}\ [\mathrm{px}]) \cdot \mathrm{const}}{d_s\ [\mathrm{mm}]} + \frac{k_x\ [\mathrm{mm}] + \frac{D\ [\mathrm{mm}] - d_s\ [\mathrm{mm}]}{2} \cdot \sin \xi}{d_s\ [\mathrm{mm}]} \right],$$

where ξ is the angle of mutual rotation of the coordinate systems / the axis of the cameras, $D = k_z$ is the total distance between the cameras purposely adjusted to this distance, k_x is the deviation of the optical axis due to the displacement the cameras and the deviation of the centers of the CCD sensors. The formula for calculating the inclination is defined in a similar way

$$\phi = \arcsin \left[\frac{(a_{1y}\ [\mathrm{px}] - b_{1y}\ [\mathrm{px}]) \cdot \mathrm{const}}{d_s\ [\mathrm{mm}]} + \frac{k_y\ [\mathrm{mm}] + \frac{D\ [\mathrm{mm}] - d_s\ [\mathrm{mm}]}{2} \cdot \sin \omega}{d_s\ [\mathrm{mm}]} \right]$$

Flexion/extension is calculated using the formula:

$$\theta = \arccos \frac{u \cdot v}{|u| \cdot |v|} + \psi,$$

where ψ is the angle of mutual rotation of the coordinate system of the cameras. The plus sign, i.e. addition of the mutual rotation and displacement of the cameras, in general, determines the relation of the values, but the values can be positive or negative depending on the direction of the mutual rotation and displacement of the cameras.

Other conditions are identical with the calculations for the position of head and shoulders if the cameras are mounted and adjusted by a laser system which ensures that the position of the optical axes of the cameras is on the same axis. Similarly, the characteristics for calculating the angles of inclination, rotation and flexion are identical.

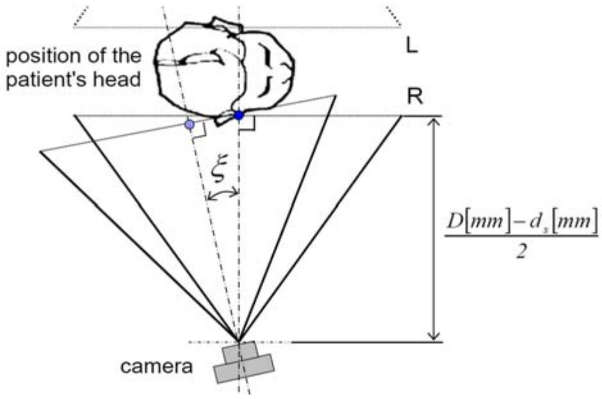

Fig. 7: Angular deviation of the optical axes

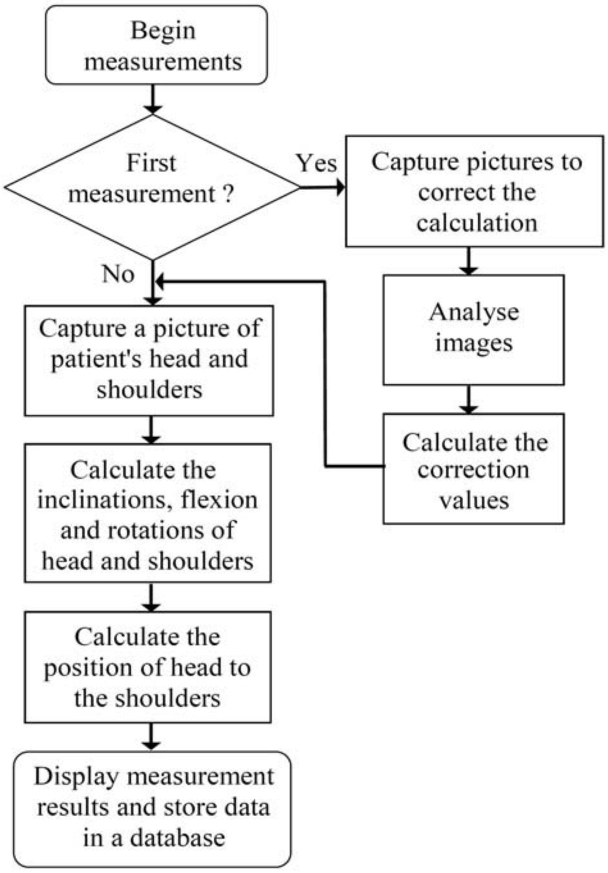

Fig. 8: Flowchart of clinical measurements using our camera system

The cameras are opposite to each other, and we cannot take pictures of one pattern using two cameras. For this reason, we have to use a transparent plate with colored correction marks or a planar checkerboard [9] located at a distance D/2 between the cameras. The correction procedure is such that the measured mark is scanned on a transparent mask which is located at a distance D/2 between the cameras. We can make the correction for rotation and inclination by observing the vertical and horizontal components of the coordinates and their mutual deviations in the two images/photographs. The subsequent image processing is the same as common calibration procedures using a planar checkerboard [9]. The exact values of the displacements and rotations of the optical axes can be added to the calculation for correcting the displacements or to refine the angles, Figure 8. It appears, however, that the angle correction software is time consuming and impractical for medical practice, and for this reason it is used only for correcting the displacement of the optical axes and the CCD sensors.

3 Results

Our method was tested in clinical practice, and preliminary experiments indicate that the method functions effectively. A user interface has been created for easy control of the new system (Figure 9).

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

Our system based on two identical digital cameras is a sufficiently accurate system for determining the inclination, flexion and rotation of head and shoulders in neurological practice. An advantage of the system is that it is easy to determine the angles between the anatomical horizontal and axis and the physical coordinate system defined by the position of the cameras.

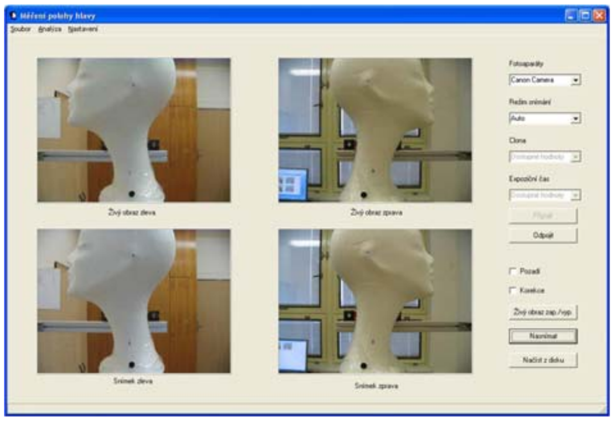

Fig. 9: User interface of the software during accuracy tests on a dummy placed on an accurately slewing stand

The two cameras are placed on both sides (lateral profiles) of the patient. This is a very important advantage for medical doctors, because they can make various examinations which need an open space in front of the face.

A disadvantage of the system with cameras is that there is increasing error of the detected angle with increasing abnormalities of the head position / measured angles. The reason for this is the large deviation of head position from the optimum location in the middle distance between the two cameras, which causes large differences in the distances between the CCD sensors (cameras) and the measured head and shoulders. Our system is therefore designed for accurate identification of small abnormalities during the rehabilitation process and for cases when the abnormality is so slight that it cannot be determined by conventional goniometers.

A second disadvantage of a system of cameras is the increasing error of the detected angle with increasing motion of the measured subject. We cannot measure the position/angles of fast moving patients. However, there is an advantage when measuring the positions of small angles (head and shoulders) with very small error. This means that we can measure very small abnormalities of head and shoulder position.

4 Conclusion

We have designed special calibration equipment and implemented procedures for evaluating measured data. The new analytical methods for the implemented procedures have been described in this paper. The new equipment and measurement method are designed for a very accurate evaluation of head and shoulder position in neurological practice. The system is cheaper than sophisticated systems using accelerometers and magnetometers.

Nevertheless, the greatest advantage of the proposed method is its non-invasive and non-contact way of measurement, without using any sensors and applying only cheap single-use markers. If the clinical investigation is performed by an experienced medical doctor, it is not necessary to apply colored marks to anatomical parts of the body.

An advantage of our system over conventional systems such as Zebris or SonoSens is that it can measure a patient without the influence of mechanical elements on the patient's body segments. The system also allows direct detection of the anatomical axes of the patient's head and shoulders, which cannot be done using current systems.

These ways of measuring head and shoulder posture could also be applied in other areas of engineering, medicine and science. Our system can be used anywhere to study the posture of a person.

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