Measurement of Head-to-Trunk Orientation Using Handheld 3D Optical Apparatus

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http://dx.doi.org/10.15221/14.225

Abstract

The system for head-to-trunk orientation is presented. It is based on the 3D measuring of the upper trunk and head of the measured person and registration of the partial head and trunk surfaces to the reference position. The rotations of the head and trunk, necessary for the registration, are monitored. By the subtraction of the head rotation with trunk rotation, we get the orientation of the head with the respect to the trunk. It is insensitive to the movement or rotation of the 3D measuring system or measured person as a whole.

The accuracies of the method and proposed measuring system were verified *in-vitro* and *in-vivo*. For the *in-vitro* verification the mannequin with a movable head was used, to which the reference orientation tracker was attached. The shape of the surface of the mannequin with handheld 3D apparatus (HA, accuracy 1.5 mm) and 3D laser scanner (LS, accuracy 0.3 mm), which is inappropriate for in-vivo measuring, were measured simultaneously. To calculate the orientation of the head the proposed method was used in both cases. Analysis of the acquired angles showed that precision in the case of OT and LS is 0.3°, while in the case of HA the precision was 2°. In the case of in-vivo verification, the precision of the system was 3°.

Keywords: 3D measurement, surface digitalization, biometrics, profilometry measurement systems, triangulation, head orientation

1. Introduction

Knowing the orientation of the head is important in many fields, including human–computer interfaces, face recognition systems, biological experiments and medicine [1-3]. Researchers usually use the combination of different gyroscopes, accelerometers and electronic compasses to determine the orientation of the head [4-6]. Those systems achieve high accuracy and fast response, but require the fixation of certain equipment or markers to the measured head. To avoid these non-rigid junctions which affect the result, we propose the method which employs the shape of human body as a marker and the corresponding noncontact optical measuring system which measures the orientation of the head with respect to the trunk. In that manner we can distinguish rotations of the head from rotations which were caused by trunk twisting, rotation or tilting.

2. Methods

2.1. 3D measuring

3D measuring system was developed on the basis of a commercial DSLR camera, to which we added the fringe projection system (PS). The 3D shape of the measured surface is reconstructed using triangulation principle from the single image in combination with the Fourier transform profilometry method [7] (see figure 1). Thus, the measuring time equals the time of the exposure, which is typically 5 msec. Measuring range of the system at the distance of 2 m is 700x520x400 mm and the precision after the calibration is 1.4 mm [8, 9].

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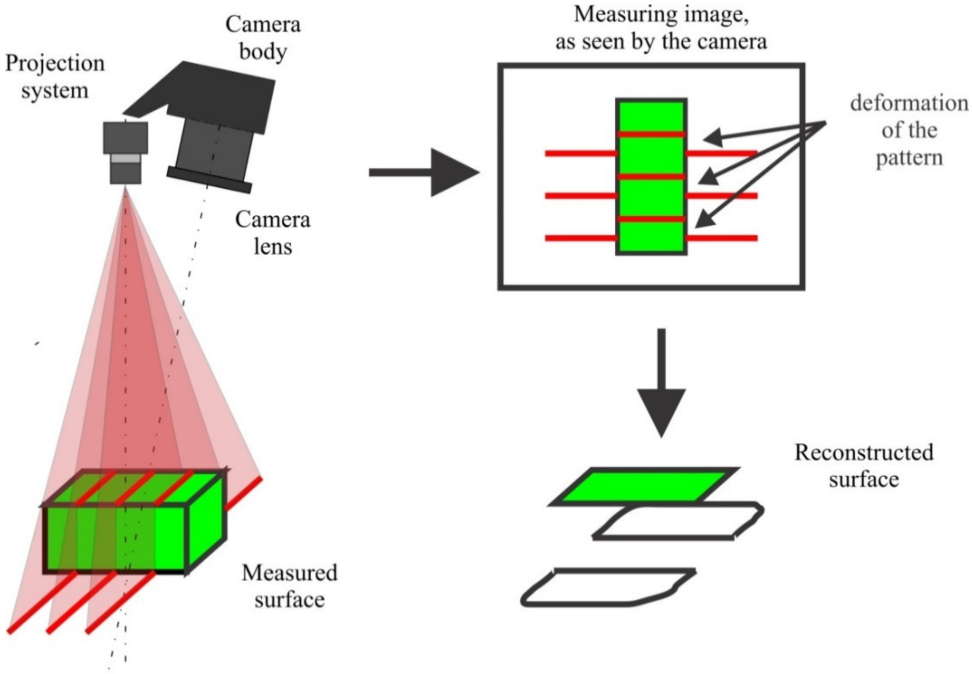


Fig. 1. Sketch of the measuring system.

2.2. Orientation calculation

Orientation in the space can be described as an array of three consequential rotations in all three body planes: sagittal (around X axis), transverse (around Y axis) and coronal (around Z axis) body plane (see figure 2). The coronal plane of the measured subject is parallel to the wall, seen in the measurement. This is ensured by a measuring protocol, where the subject's back must be in contact with the wall during the measurement. In that manner, we also ensure the repeatable positioning and parallelism. The sagittal plane is found by mirroring the body surface around the YZ plane [9].

The orientation calculation procedure is outlined in figure 3. To measure the relative orientation of the head against the trunk, 3D surface of the head and upper trunk are measured. The first measurement is captured in the reference position, where body planes of the head and trunk are parallel (see coordinate systems in figure 4a). Then the measurement of the head and trunk in any position can be measured (measurements in figure 4b and figure 4c). The measured surface is split into the head and trunk region. It is important that parts of the surface, where large degree of deformation during the movement is expected (neck, hand just under the shoulders, etc…) are not included in neither of the regions. These partial surfaces are then aligned to the reference surface using Geomagic Studio [10]. Typical example of aligned surfaces are shown in figure 5.

By that procedure a pair of rotation matrices is obtained. We denote $\mathbf{R}_h$ the rotation matrix (RM) of the head alignment rotation and $\mathbf{R}_t$ the RM of trunk alignment rotation. $\mathbf{R}$ is RM of the head orientation relative to the trunk and is calculated as

$$\mathbf{R} = \mathbf{R}_h \cdot \mathbf{R}_t^{-1}$$

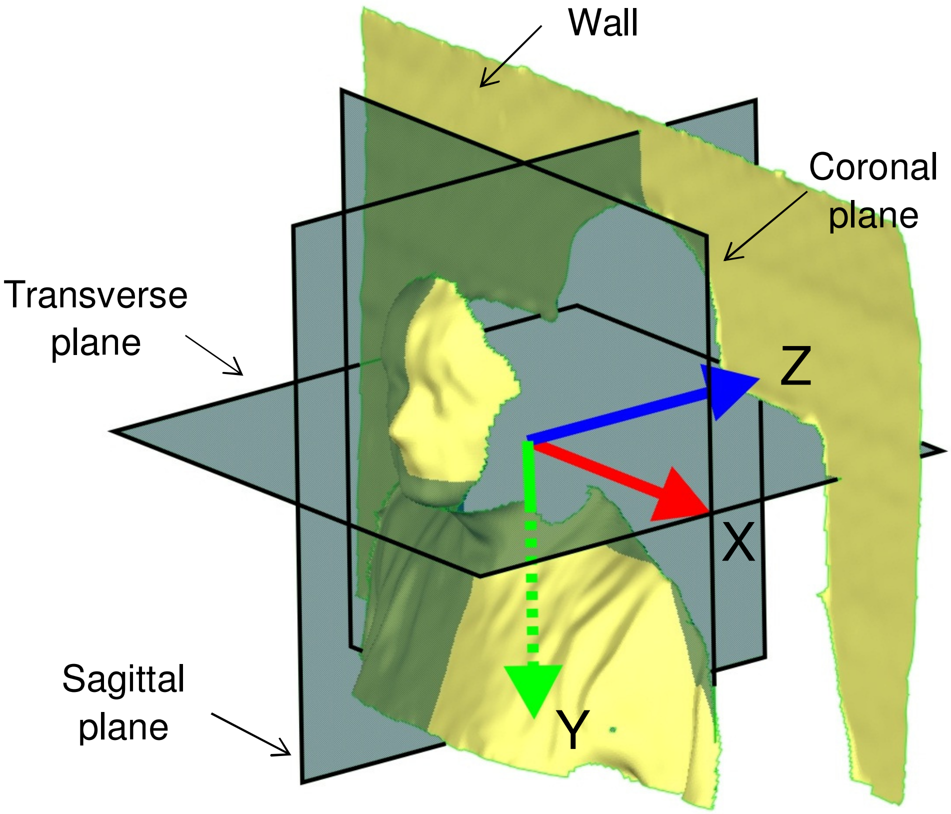


Fig. 2. Measurement aligned to the coordinate system.

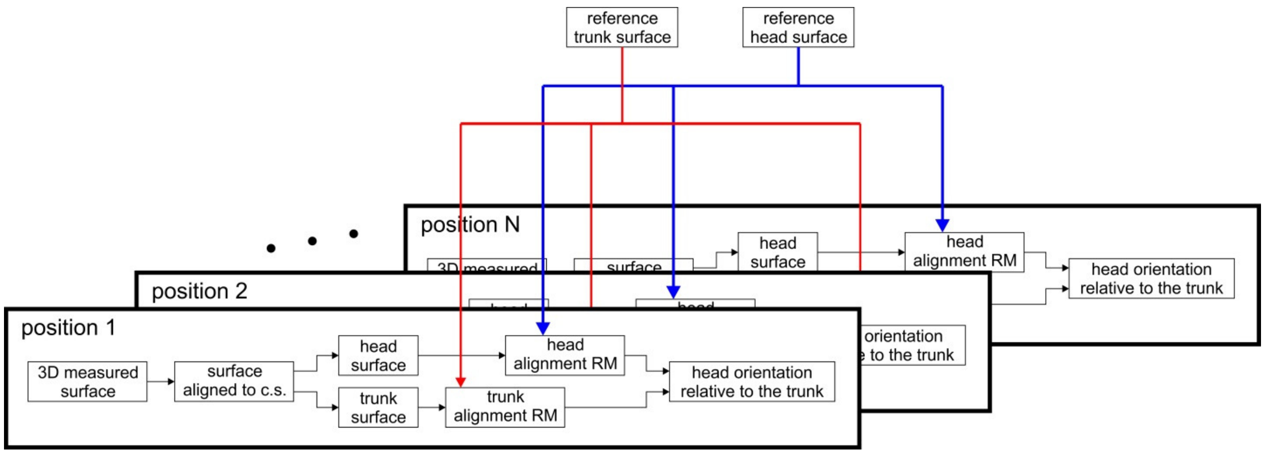


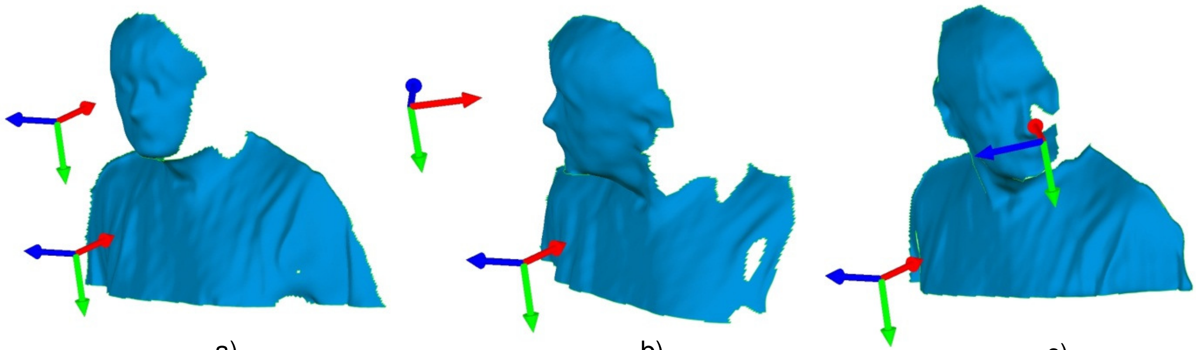
Fig. 3. Flow chart of the orientation measuring.

Once **R** is calculated Euler angles ϕ (rotation in sagittal plane), θ (rotation in transverse plane) and ψ (rotation in coronal plane) of the orientation are calculated by matrix decomposition technique [11] as follows:

$$\phi = \arctan\left(\frac{-R_{2,3}}{R_{3,3}}\right)$$

$$\theta = \arctan\left(\frac{R_{1,3}}{\sqrt{R_{1,2}^2 + R_{1,1}^2}}\right)$$

$$\psi = \arctan\left(\frac{-R_{1,2}}{R_{1,1}}\right)$$



a) b) c)

Fig. 4. Example measurements with corresponding coordinate systems. Red arrow indicates direction of the Z axis, green Y axis and blue X axis. a) Reference measurement. b) Right rotation. c) Left rotation.

3. Verification

Method was verified *in-vitro* and *in-vivo*. For the *in-vitro* verification we used mannequin with movable head, to which the reference orientation tracker [12] (OT) was attached. Simultaneously, the upper part of the trunk and head of the mannequin was measured using presented handheld 3D apparatus (HA) and laser scanner (LS), which has higher measuring accuracy (0.3 mm), but is inappropriate for *in-vivo* measuring due to long data acquisition time (about 7 s). The mannequin's body was fixed during the measuring. The proposed method compensate the movement of the body, but since OT was fixed only to the head, from its data it is impossible to distinguish the rotations, caused by head rotation and rotations, caused by trunk rotation. The analysis showed that the accuracy of measured orientation in combination with LS was 0.3°, while in combination with HA was 2°, which clearly shows the correlation between accuracy of 3D measuring and the accuracy of extracted orientation.

In-vivo verification of the proposed method was performed only in combination with HA measuring system. A patient, diagnosed with cervical dystonia was instructed to rotate head as far left and right as possible with moderate effort for 13 times. Between each pair of rotations, patient stepped away from the wall and relaxed for a minute. Achieved measuring repeatability was 3.0°, which is within the expected limit for clinical diagnostics.

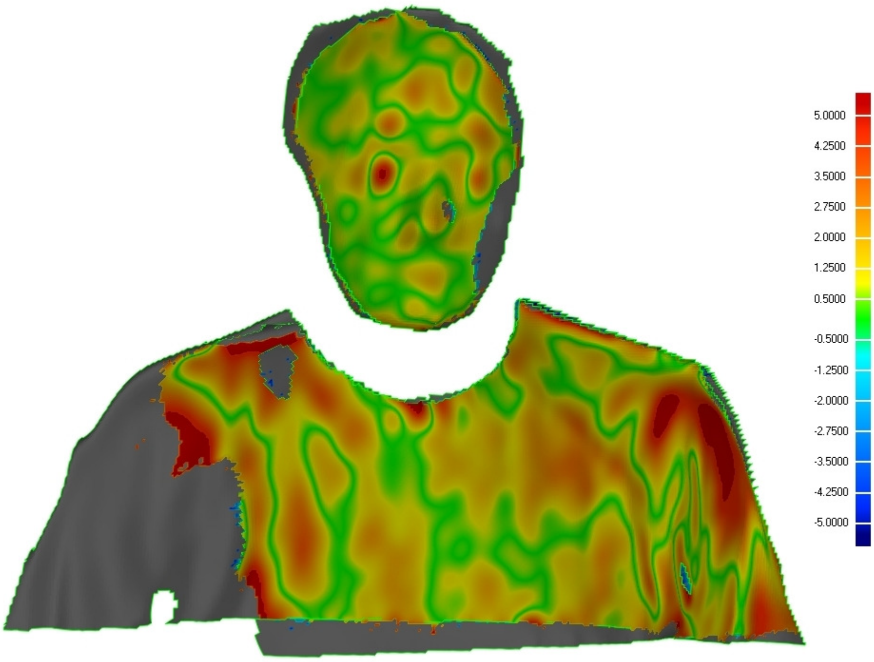


Fig. 5. Map of deviations between reference and surface of analyzed position. The legend on the right is in millimeters.

4. Conclusion

The proposed method enables non-contact head-to-trunk orientation measurement based on 3D surface of head and upper trunk. Since the head and upper trunk are aligned to the reference surface separately, movements and rotations of the measured subject as a whole or measuring system can be compensated. Method is non-invasive, requires little additional equipment and causes little stress for the measured subject and operator. For 3D measuring we used handheld measuring system, which has data acquisition time of 5 ms and accuracy of 1.5 mm. It is highly portable and very user friendly. Measurement repeatability was determined *in-vivo* (3°) and *in-vitro* (2°), which is acceptable for the clinical use of the system. We believe it can represent a good alternative to the contact head orientation measuring systems.

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