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DETERMINATION AND REPRESENTATION OF THE HELICAL AXIS TO INVESTIGATE ARBITRARY ARM MOVEMENTS

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Abstract. *This paper suggests a simple method to determine helical axis surfaces in the global coordinate system of measurement. There are many ways for the biomechanical investigation of a human motion. The method mentioned here is theoretically absolutely correct and can be well used as an additional method in clinical applications. The applied graphical representation of helical axis surfaces can assist doctors in diagnosis.*

Key words: *kinematics, global coordinate system, helical axis surface*

1. INTRODUCTION

Spastic hemiparesis mostly arises as a consequence of stroke, brain injury, multiple sclerosis, brain tumor, or perinatal damage. In these cases not only does the muscular strength become weaker, but the muscular tone also increases, causing further problems. The REHAROB project (IST-1999-13109 REHAROB = Supporting Rehabilitation of Disabled Using Industrial Robots for Upper Limb Motion Therapy) is a robotic rehabilitation system for upper limb motion therapy for the disabled. Industrial robots utilizing intelligent identification of the required physiotherapy motion drive the therapy. The REHAROB project provides personalized three-dimensional motion therapy for patients with neuro-motor impairments. REHAROB was designed to provide an on-line physiotherapy monitoring and documentation system with 3D motion therapy measuring, visualizing and logging tools. Exercises were collected by physiotherapists working for the REHAROB project (http://reharob.manuf.bme.hu) and then described in a catalogue. The robot can be required to execute selected exercises from this catalogue. The aim of

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these exercises is to improve the patient's upper limb movements (strengthen the muscles, decrease spasticity, improve coordination and proprioception, increase the range of movement of the joints).

The method described was developed to characterize these exercises, but the formulae can be widely used in general motion analysis. There are many ways for the biomechanical investigation of a human motion. The usual measuring methods determine the spatial position of markers attached to the investigated body segment. This is the root of the problems. Other kinematical parameters such as velocity, acceleration, etc. can be determined by derivation from these coordinates. Unfortunately, these data are not correct. Derivation will highly increase the errors. This is the reason why measuring methods used in engineering practice for vibration analysis determine the field of acceleration. From these data the velocities and positions can be determined by integration, which will smooth the values and decrease the level of errors. In biomechanical motion analysis, only that method became common which is able to determine directly the coordinates of the investigated points. Different techniques are developed for smoothing and correcting the measured data. If the investigated motion is smooth, the mentioned methods can be used successfully. In case of the motion of injured or ill people in other words in clinical applications, scientists have doubts as regards using these methods, because nobody can correctly determine the smoothing parameters that ignore the errors, but keep the original affected motion of the patient.

Application of more precise measuring systems will reduce the risk and after well-managed data postprocessing the results can be safely used in clinical applications. The ultrasound based measuring system developed by Zebris GmbH is a really precise system with an error of less than 1 mm of the measured spatial coordinates. These precise coordinates combined with smoothing, data correction, and derivation techniques ensure smooth data series, which can be successfully used for determining helical axis surfaces.

2. METHOD

"In accordance with the Chasles theorem (see "Euler's and Chasles' Theorems" in Zatsiorsky,1998), any three-dimensional, rigid-body motion can be viewed as a rotation around and translation along an axis, called a screw or helical axis. The values of the helical rotation and translation are invariant to coordinate transformation, that is, they are independent of the chosen reference frame. During a joint motion the helical axis, which is the instantaneous axis about and along which a human body segment is thought to be moving, can itself move (it can translate [change place] and rotate [change orientation]). The path of the instantaneous screw axis is called the axode and a surface produced by the migration of the instantaneous axis during motion is called the helical axis surface. The axodes are generalization for spatial motion of the centrodes associated with the planar motion.

Similar to the planar case and depending on the method of measurement, the helical axes can be either finite or instantaneous. A finite axis describes a motion step; an instantaneous axis describes a motion at infinitesimal time. The finite axis only approximates the position of the instantaneous helical axis. The state of velocity of a rigid body is known if the velocity of any point and the angular velocity of the body are given. Let's suppose the point is point A, and we know that its velocity is $\underline{v}_A$, and the angular velocity is $\underline{\omega}$. To be able to solve this problem, the correct values of angular velocity must be known. Unfortunately, most of the professional packages determine the angular velocity of the segments by differentiation of the component angles received from the projections of the segment on the coordinate-planes. This method is not correct. This is well-known for engineers and physicians as Budo already mentioned in his book in 1953 (Budó, 1953), but does not seem to be widely known in biomechanical applications. Many researchers use the change in position of the projection of a body segment onto a plane of interest (usually the film plane) to determine the component of angular velocity in the plane. Ramey, & Nicodemus (1977) wrote a note to illustrate that the determination of angular velocity components in this manner leads to erroneous values except in some special cases, but the mentioned simplification is still in use.

There are systems e.g. Gaitlab (Vaughan et al., 1992) where three markers are in use at each segment, and the Euler angles are used for determining angular velocity and angular acceleration. This is a very complicated calculation and the values are determined in the local coordinate systems connecting to the segments and the whole model must be used. Alexander, & Colbourne (1980) developed a method to calculate the angular velocity of a body segment. Their formula is really simple, and it works well in case of quick movements (they developed it for calculation of a high-speed throwing motion); however, near to zero value of angular velocity the formula cannot be used correctly because the value in the denominator becomes zero. Verstraete, & Soutas-Little (1990) developed another correct method. Their method is based on the Method of Least Squares, and minimum 4 markers must be applied on a segment. In case of active marker systems, this will widely reduce the range of measurement, and for video-based systems the manual digitalization time will be increased. Investigating the state of velocity, let's suppose we know $\underline{v}_A, \underline{v}_B$ and $\underline{v}_C$, which are the velocities of points *A*, *B*, *C* (Kocsis, & Béda, 2001), which points are non-collinear (Figure 1). From these data the angular velocity of the body can be determined by the expression:

$$\underline{\omega} = \frac{1}{c^2}\left\{\underline{r}_{AC} \times (\underline{v}_C - \underline{v}_A) + \left[\frac{\underline{r}_{AB} \times \underline{r}_{AC}}{b \sin^2 \alpha} \cdot \left(\frac{\underline{v}_C - \underline{v}_A}{c}\cos\alpha - \frac{\underline{v}_B - \underline{v}_A}{b}\right)\right]\underline{r}_{AC}\right\}.$$

where $\overline{AB} \equiv b$ and $\overline{AC} \equiv c$ are the distances between *A* and *B* and *A* and *C*, respectively. α is the angle between the line segments *AB* and *AC*. Knowing $\underline{\omega}$ and $\underline{v}_A$, a special point of the helical axis can be determined by the formula:

$$\underline{r}_D = \frac{\underline{\omega}_1 \times \underline{v}_A}{\omega^2} + \underline{r}_A$$

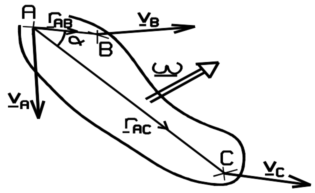

Fig. 1. Positions and velocities of non-collinear points

The direction of the helical axis is determined by $\underline{\omega}$. The length of this axis can be chosen proportionally to the absolute value of $\underline{\omega}$, if we determine:

$$\underline{r}_E = \underline{r}_D + \underline{\omega}\lambda \text{ as the position vector to EO.}$$

The line segment DE is the helical axis, and its length is proportional to $\underline{\omega}$. If $\underline{\omega} \cdot \underline{v}_A \neq 0$, then an elementary translation motion also occurred along the helical axis. This instantaneous velocity can be calculated by the formula:

$$v_{\parallel} = (\underline{\omega} \cdot \underline{v}_A)/|\omega|$$

Figure 2 shows the notations used for determining the helical axis: One triple marker set was fixed on the upper arm, and another one was fixed on the forearm as in Figure 3.

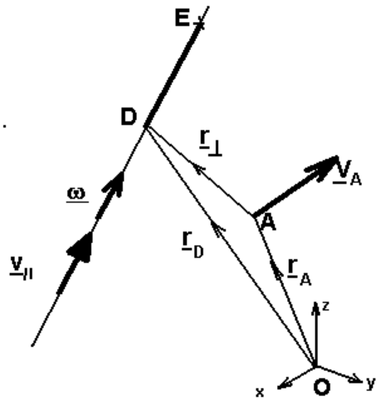

Fig. 2. Notations used for determining the helical axis

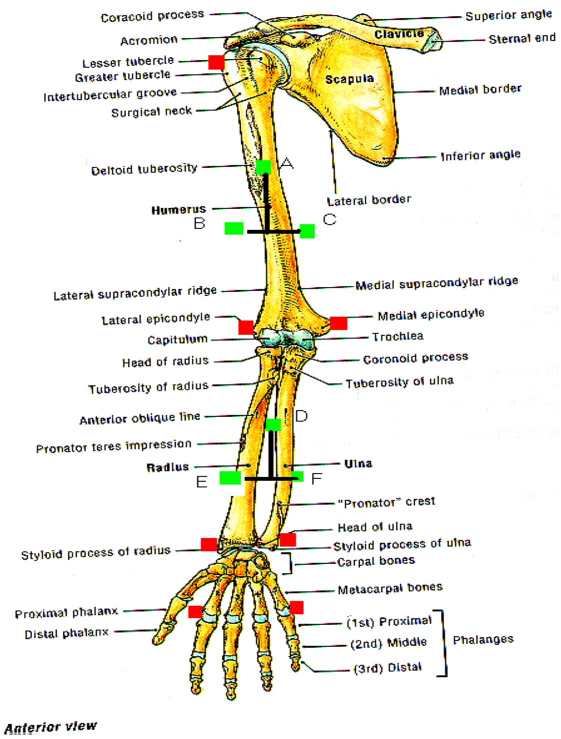

Fig. 3. Markers and anatomical key points of the upper limb

Determination of the helical axis of the forearm according to the upper arm (relative helical axis)

Knowing the coordinates of the markers (A,B,C), fixed at the upper arm, and of the markers (D,E,F), fixed at the forearm (see Figure 4), angular velocities $\underline{\omega}_1$ and $\underline{\omega}_2$ can be determined by the method described above. The relative angular velocity of the forearm will be expressed by:

$$\underline{\omega}_{12} = \underline{\omega}_2 - \underline{\omega}_1$$

The relative velocity of point D according to the upper arm can be calculated by:

$$\underline{v_r}^D = \underline{v_D} - \underline{v_A} + (\underline{r_D} - \underline{r_A}) \times \underline{\omega_1} \ ,$$

The relative helical axis, similarly to the previous equations, will be as follows:

$$\underline{r}_{P_2} = \frac{\underline{\omega}_{21} \times \underline{v}_D}{\omega_{21}^{\ 2}} + \underline{r}_D \qquad \underline{r}_{P_2 O} = \underline{r}_{21} + \underline{\omega}_{21} \lambda$$

3. Results

Let us choose from the exercises collected by physiotherapists a simple one as an example (Figure 4).

start position end position

Fig. 4.

Starting position:	The patient lies on his back. Upper arm lies on the bed next to the body, elbow is in a 90-degree flexion, palm is turned towards the body (0- degree position.)
Line of movement:	Continuous upper arm abduction between the starting and the end position.
End position:	90- degree position of upper arm.
Execution of Movement:	Slow, continuous movement.

Figure 5 shows the helical axis surface of the upper arm during the mentioned arm movement presented in Figure 4. Figure 6 shows the absolute helical axis surface for the forearm at the same arm movement: Figure 7 represents the relative helical axis surface of the forearm and the absolute one for the upper arm.

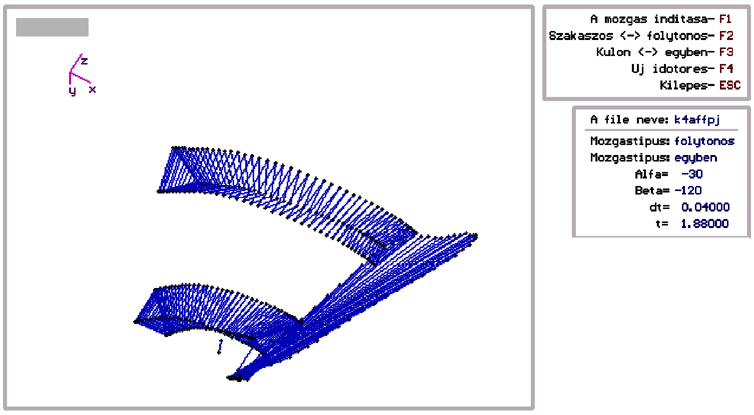

Fig. 5. Helical axis surface of the upper arm during the described arm movement

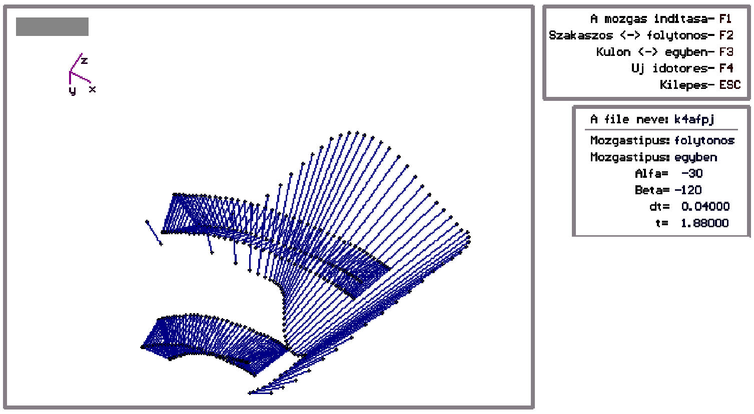

Fig. 6. Absolute helical axis surfaces for the forearm

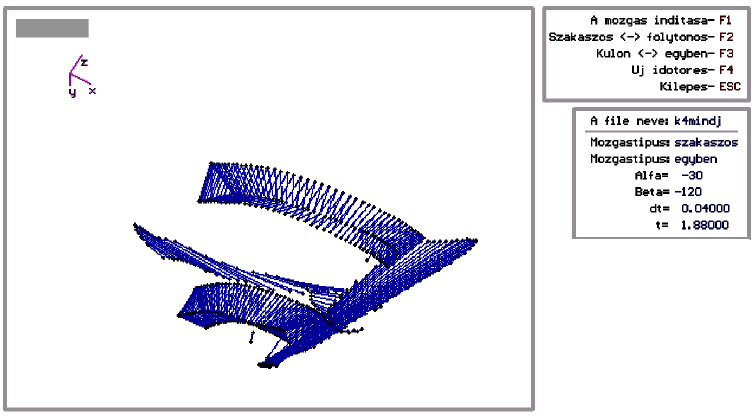

Fig. 7. Relative helical axis surface of the forearm and the absolute one for the upper arm

4.CONCLUSION

This method is useful for diagnostic purposes. The location of the instantaneous center of rotation is also important for determining the muscle moment of the arm, i.e. the shortest perpendicular distance from the line of muscle action to the axis of rotation. Even a small displacement of the instant axis of rotation can dramatically change the estimated magnitude of the moment of the arm. If the rotation is small, the estimation of the position of the instantaneous axis of rotation is highly susceptible to measurement errors. As a center of rotation is not defined for pure translation, when the rotation is small, the center of rotation approaches infinity and even the smallest measurement errors can generate large inaccuracies in the calculated coordinates. The DataManager software package, developed at the Biomechanical laboratory of BUTE in the framework of the REHAROB project, automatically calculates all the previously mentioned procedures and allows a visible representation of the helical axis surfaces.

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REFERENCES

1. Alexander, M.J.L., & Colbourne, J. (1980). A method of determination of the angular velocity vector of a limb segment. JAB
2. Budó, A. (1953). Mechanika (Mechanics). Budapest: Tankönyvkiadó.
3. Kocsis, L., & Beda, G. (2001). Closed formulae to determing angular velocity of a body segments based on 3D measurements. Acta Physiologica Hungarica. 88 (1), 1-13.
4. Ramey, M., & Nicodemus, C. (1977). A note on the determination of angular velocities in human motion studies. Medicine and Science in Sports, 9 (2), 134-136.
5. Vaughan, Ch. L., Davis, B.L., & O'Connor, J.C. (1992). Dynamics of Human Gait. Human Kinetics.
6. Verstraete, M.C., & Soutas-Little, R.W. (1990). A method for computing the three-dimensional angular velocity and acceleration of a body segment from three-dimensional position data. Journal of Biomechanical Engineering, 112, 114-118.
7. Zatsiorsky, V.M. (1998). Kinematics of Human Motion. Human Kinetics.

ISTRAŽIVANJE SPIRALNE OSOVINE PROIZVOLJNOG POKRETA RUKE

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Ovaj rad sugeriše jednostavne metode da bi se utvrdila površina spiralne osovine u globalnom koordinatnom sistemu merenja. Postoje mnogi načini za biomehaničko istraživanje ljudskog pokreta. Metod koji je u radu pomenut je apsolutno tačan i može se, takođe, koristiti kao dodatni metod u kliničkoj aplikaciji. Primenjeni grafički reprezent spiralne osovine može da bude od pomoći doktorima u dijagnostici.

Ključne reči: *kinematički, globalni koordinatni sistem, površina spiralne osovine*