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A 3-space electromagnetic tracking device – a useful method in an *in vitro* study

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A 3-space electromagnetic tracking device is used for determinating the position and orientation of a sensor relative to a source by utilizing the principle of low-frequency magnetic field technology. A general description of the application of this system to biomechanical analysis of a spatial rigid body (cadaver elbow as an example) motion is provided. The analysis based on Eulerian angle description has been performed. The system has been found to be quite accurate and easy to use, and it would be a useful tool in kinesiologic research.

Key words: 3-space electromagnetic tracking device, in vitro study, elbow biomechanics, valgus/varus laxity

1. Introduction

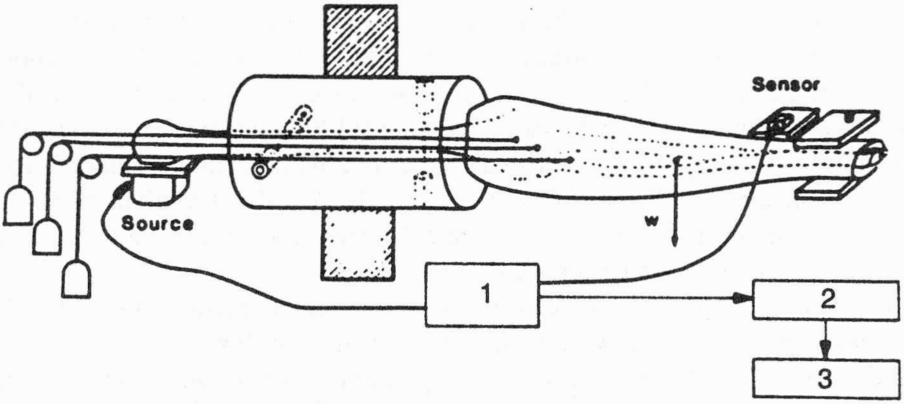
A magnetic position and orientation tracking system has been developed which can determine the three-dimensional position and orientation of a sensor relative to a source. The six-degree of freedom measurements are accomplished by using low-frequency, magnetic field technology to interpret the interaction of magnetic fields between three sets of orthogonal coils contained in both the source and the sensor. Various commands are available to set parameter values of the system and to obtain information and data from the system. With appropriate alignment and attachment of the source and sensor to anatomical structures, the relative location and orientation of anatomical elements can be monitored. The 3-Space Isotrak System is used for both two-dimensional and three-dimensional kinesiologic analyses.

2. Description of 3-Space Isotrak System

The aim of this paper is to introduce the method, which the author used in the *in vitro* study during his two years' fellowship at the Orthopaedic Biomechanics Laboratory Mayo Clinic. As an example to describe more precisely the effectiveness of this system, the measurement of cadaveric elbow motion is introduced. The 3-Space Isotrak System (3-Space Fastrak, Polhemus, Colchester, Vermont) [1] consists of three components: a System Electronics Unit (SEU), a source, and a sensor. Both the source and the sensor are connected to the SEU by cables (the figure). The source which emits low-frequency magnetic field signals is mounted on the testing apparatus. Sensor which detects the signals is attached to the ulna, for continuous positional data collection. The SEU contains all the analog circuitry to generate and sense the magnetic fields as well as the hardware and software to control the analog circuitry, digitize the signals, and perform the calculations to compute the position and orientation of the sensor. The accuracy system is up to 0.5° for angular rotation [2]. The three-dimensional spatial orientation of the ulna relative to the humerus is measured using an electromagnetic tracking device sampling at a rate of 30 Hz. Position and orientation are determined by a process of updating the previous values based on the difference in the magnetic fields detected by the sensor transformed to changes in position and orientation. The intensity of magnetic fields is controlled by the SEU which automatically adjusts for the change in distance between the source and sensor to keep the strength of the field reaching the sensor at a constant level. If movement of the sensor towards the source is too fast, the SEU cannot react fast enough, and the signal reaching the sensor overdrives the system and an error signal is generated until compensation is achieved. Operation of the tracking system is affected by the presence of metallic conductors. Large metallic objects nearby and metallic objects in between the source and sensor cause distortions in the magnetic fields and, consequently, affect signals received by the sensor. Manufacturer's recommendations are to keep large metallic objects 6 feet away from the source and/or sensor and smaller objects at least twice the source and sensor separation distance. Also, the source and sensor cables should not come between the source and sensor [1]. Although the accuracy of the electromagnetic tracking device is affected by certain metals, orthopaedic implants are not ferromagnetic and thus are relatively transparent to this device [3].

Passive flexion of the elbow was effected using a string attached to the distal radius to move the forearm from full flexion to full extension. The string was used to minimize interference with normal joint motion. Elbow flexion was performed in the vertical plane (neutral orientation) as a reference motion pattern, then in the horizontal plane with the elbow subjected to valgus and varus stresses, respectively. The gravity-valgus stressed position placed the humerus horizontally to the floor with the medial epicondyle facing upwards, by turning the apparatus 90 degrees (figure) [2]. The same procedure was undertaken with the forearm in a varus stress position with the lateral epicondyle facing upwards. Tests were performed with medium –2, 2, and 4kg-loads applied to the biceps, brachialis and triceps tendons, respectively (figure) [4], [5]. The valgus/varus laxity of the elbow joint was calculated as a difference between the laxity of valgus and varus stress positions throughout the measured range of elbow flexion, as was previously described by King et al [6]. The elbow flexion with valgus/varus laxity measurements was always repeated three times.

The three-dimensional motion of the ulnohumeral joint was described by sequential rotations about three axes: flexion–extension, abduction–adduction (varus–valgus), and axial ulnar rotation. Description of the sequential rotation about three axes was given as the Eulerian angles of the system. Because the Eulerian angle calculation was dependent on that sequence, the axes of reference for description of the Eulerian angle were established based on the component of dominant motion of flexion–extension [1], [2]. The axis of flexion–extension (*z*) was defined by a line perpendicular to the dominant plane of motion, which was described by a reference point on the moving ulna (as represented by the sensor) and passed through the center of the trochlea. A second line (*y*) was then constructed between the center of the humeral head and the center of the trochlear groove. The cross-product between the *z*- and *y*-axes then defined the *x*-axis and completed the orthogonal system. The sequence-dependent rotations of this model were as follows: first, flexion (rotation about the *z*-axis); second, abduction (rotation about the *y*-axis); and finally, axial rotation (rotation about the *x*-axis). The Eulerian angles, yaw (flexion–extension),



The schematic setup of the electromagnetic tracking device system.
The experimental arrangement demonstrating the gravity valgus position of the cadaveric elbow. The simulated muscle force has been applied. The signal is processed and sent to the computer, which calculates the Eulerian angles that describe flexion, axial rotation, and varus and valgus changes, by Morrey at al. [2]. 1 – system control unit, 2– computer, 3 – Eulerian angles

pitch (abduction–adduction), and roll (axial rotation) were simultaneously generated and recorded.

The electromagnetic tracking device may also be used as a three-dimensional digitizer. After completion of the kinematic study, the elbow joint was disarticulated to digitize the bony landmarks and articular surface geometry using the sensor with a calibrated probe attached [1], [4]. The following anatomic sites were digitized: trochlea, capitellum, greater sigmoid notch, humeral shaft, and distal ulna. Data obtained from the electromagnetic tracking device were used to measure the three-dimensional spatial orientation of the ulna relative to the humerus. By digitizing the contours of the bones and joint surfaces, data points were obtained which allowed the creation of an anatomical coordinate system to describe the motion of the ulna in relation to the distal humerus.

The spatial coordinate system of the tracking device was then transformed to the anatomical coordinate system, centered at the trochlear notch of the humerus. The motion pattern of the intact elbow formed the basis for an optimized kinematic axis, which was calculated using principal component analysis, and the data were transformed from the anatomical coordinate system to this optimized kinematic coordinate system. The position of the ulna in the intact elbow at 90 degrees of flexion was defined in the anatomical coordinate system as zero degrees of roll (forearm rotation) and zero degrees of yaw (valgus/varus). Loading of the biceps, brachialis and triceps allowed maintenance of optimum elbow tracking as dictated by bony and soft tissue constraints.

With the axis of optimal flexion–extension defined, the majority of the kinematics of the elbow joint can be described by this flexion–extension rotation. The coupled motion in other planes, due to the geometric contour of the joint articular surfaces and laxity of the soft tissue constraint, is then represented by the additional components of the Eulerian angles, namely, abduction–adduction and axial rotation. To assess elbow subluxation or maltracking the coupled Eulerian angle rotations of the ulna in each condition were compared to the "optimum positions", as defined by motion of the ulna in the intact elbow [1], [2], [4]. Angular deviations of the ulna from the optimum tracking position were calculated through the arc of the elbow flexion from 130 to 0 degrees in one degree intervals.

Based on this experiment we can assess very precisely valgus/varus laxity of the cadaveric elbow joint during its passive movement from flexion to extension. Using this method we can also evaluate the degree of the internal and external rotation of the ulna against humerus, and also we can collect data regarding ulna translation. Based on this data we can pick up a lot of information regarding elbow stability and kinematics. We can evaluate the intact elbow and also we can mimic different injury such as: radial head resection, coronoid fracture, disruption of the medial or lateral ligaments complex and many other. While this system is relatively accurate for not only elbow, but also many other joint and limb studies, the measured data could be filtered, smoothed and averaged to eliminate the noise and increase the accuracy of subsequent calculations [1].

3. Conclusion

The electromagnetic tracking device is accurate and easy to use, and is a useful tool in kinesiologic research.

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