

VALIDATION OF TRI-AXIAL ACCELEROMETER FOR THE CALCULATION OF ELEVATION ANGLES

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INTRODUCTION

One of the main issues in occupational studies focusing on musculoskeletal disorders of the upper extremity is to quantify workers' exposures to risk factors during a workday. It has been shown that workers are more susceptible to shoulder injuries when they have a high lifetime exposure to arm elevation above 90° (Svendsen et al. 2004). For whole day ambulatory recordings, body-mounted transducers, in combination with data loggers are used. It has been shown that accelerometers with a DC response can measure static acceleration and therefore can detect orientation relative to the line of gravity (Hansson et al. 2001). However, most of these devices are clumsy, complicated to mount, not self-contained and not commercially available. The Virtual Corset™ (Microstrain Inc, Williston, VT) is a battery powered tri-axial accelerometer with an integrated data logger, all contained within a pager casing with no cables, intended to measure 2 planes of trunk motion, flexion and lateral bending. The purpose of the study was to derive an equation to convert accelerometer data to shoulder elevation angles and to validate this equation with data collected with the Virtual Corset™.

METHODS

The first step was to derive an equation to convert accelerometer data to elevation angles. In a Cartesian coordinate system the angle θ between a vector (x y z) and its projection on the XY plane represents the elevation angle of the vector relative to that plane (figure 1).

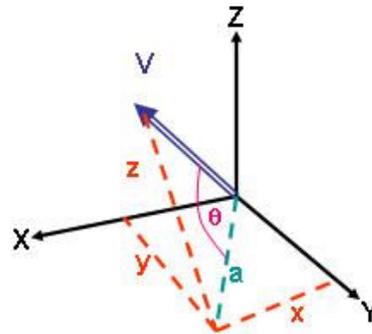


Figure 1: Vector projection on the XY plane.

To find the angle θ we first solve for the length a :

$$a = \sqrt{x^2 + y^2} \quad (1)$$

Next θ , is given as:

$$\theta = \tan^{-1}\left(\frac{z}{a}\right) \quad (2)$$

Combining equations 1 and 2 yields equation 3, which solves for the elevation angle as a function of x , y and z :

$$\theta = \tan^{-1}\left(\frac{z}{\sqrt{x^2 + y^2}}\right) \quad (3)$$

When measuring acceleration with a tri-axial accelerometer (x y z are the component of the acceleration) in static position the resultant vector is the gravitational acceleration, thus, equation 3 can be used to calculate the elevation angle at different orientation of a tri-axial accelerometer relative to gravity.

To validate equation 3, the Virtual Corset™ was mounted on a vise which can be rotated through 360° of elevation and 90° of axial rotation (figure 2), where 0° of axial rotation represents shoulder abduction and 90° of axial rotation is shoulder flexion. A PRO 3600 digital protractor (Macklanburg Duncan, OK), with a reported accuracy of 0.1°, was attached to the vise to identify the elevation angles. The vise was rotated through 360° of elevation in 10° increments. At each elevation angle, the axial rotation was varied from 0° to 90° in 15° increments. Each position was held for 10 seconds and the x y z accelerometer data were recorded and averaged. Elevation angles were calculated using equation 3. This procedure was repeated two different days for the Virtual Corset™.

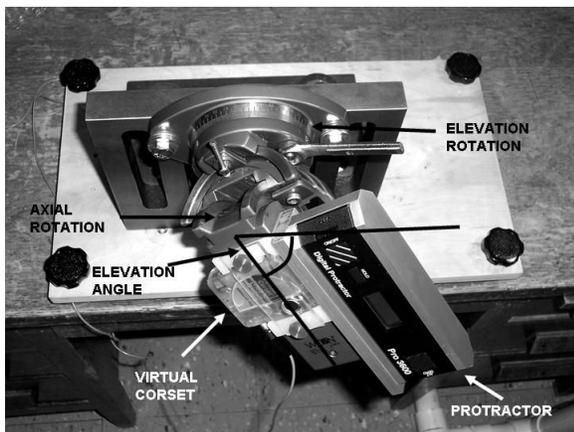


Figure 2: Test setup

The root mean square (RMS) error was calculated for each position between the

known inclination angles and the calculated elevation angles.

RESULTS AND DISCUSSION

The RMS error of the calculated elevation angles, for the whole range, was found to be less than 1° for both trials (figure 3). The maximum difference between the calculated and the actual elevation angles was less than 2°. The Virtual Corset™ manufacture reports a typical accuracy of ± 0.5° of projection angles which are limited to 360° of trunk flexion and ± 70° of trunk lateral bending; not reporting angles accuracy when the movement occurs in different planes. Our results showed that the calculated angles error was similar in the different axial rotation angles that were tested.

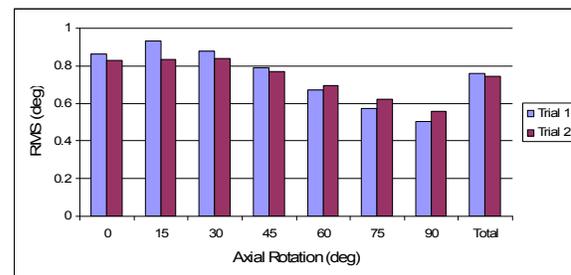


Figure 3: RMS error of elevation angles at different axial rotation in two different trials

SUMMARY/CONCLUSIONS

The tri-axial accelerometer (Virtual Corset™) can be used to accurately reconstruct elevation angles. Future studies will be conducted to measure the elevation angle during dynamic conditions and in-vivo scenarios for the upper extremity.

REFERENCES

- Hansson, G. A., et. al., 2001. *Med Biol Eng Comput* 39, 405-13.
 Svendsen, S. W., et. al., 2004. *Occup Environ Med* 61, 844-53.