Inertial Sensor Measurement of Head-Cervical Range of Motion in Transverse Plane

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Abstract: - This paper describes a method for measuring range of motion (RoM) of head in transverse plane. The measurement is performed using single inertial measurement unit MTx XSens sensor (XSens Motion Technologies, Netherlands). Specialized software for sensor data acquisition, with high visualization abilities has been developed in LaBACAS. MTx XSens sensor can provide useful, noninvasive measurement of head motion in three cardinal planes for fast evaluation of disturbances related to head/neck problems and cervical dysfunctions. The aim of this work is to investigate the feasibility of the use of inertial sensors in routine clinical assessments. The advancement of the proposed measurement over standard methods is the ability to measure unilateral RoM of the head. This technique overcomes limits of 'gold standard' measurement devices by estimating the neutral position, which is assumed to be a nontrivial problem in standard RoM measurement. In addition, a proposal for use of sensor for visual feedback RoM assessment is presented.

Key-Words: - **I**nertial measurement sensors**,** Head motion, Range of motion, Neutral position measurement, Clinical assessment

1 Introduction

The measurement of range of motion (RoM) and static posture of the head gives important physical parameters for clinical assessment and diagnosis related to cervical spine functions. In literature, this movement is referred to as a cervical range of motion. The detection of an abnormal RoM or asymmetrical patterns is an essential for preventing cervical dysfunction [1,2]. Active RoM is defined with the number of degrees through which a person can move head in various directions. Range of motion is usually measured in three directions: (1) bending the head forward and backward (i.e. flexion-extension in saggital plane), (2) turning the head left and right (i.e. axial rotation in transverse plane), and (3) bending the head left and right (i.e. lateral bending in frontal plane).

Various techniques have been employed to measure RoM. Video-based analysis have been widely applied to study human movement in general. However, these methods are too complex, expensive and time consuming which makes them inappropriate for routine clinical use. Commercial examples are VICON Motion System [3] and Qualisys System [4]. Electromagnetic tracking systems are available, as well, but these suffer from the same drawbacks like vision-based system. Example in use is a FASTRAK, [5]. Radiographic techniques have long been a standard for clinical studying of RoM and posture [6-8]. Major drawback is health risk due to repeated exposure to X-rays, in addition to inability to measure dynamic motion. The latter is characteristic of other two simple devices used extensively in clinical practice: goniometers and inclinometers. These techniques are impaired with the rater errors, inconsistency among raters, [9] and subjects fluctuations in movement performance. Likewise, electro-inclinometers, such as Cybex Electronic Digital Inclinometer- EDI 320, Cybex, Inc., USA, [10], are also widely employed because they are portable and don't have to be attached to the human subject. However, this handheld device cannot measure unilateral RoM. It records gross movement only, while exact RoM is calculated by subtracting initial position reading from final position reading. E.g. most right position is subtracted from the most left endpoint to obtain angular assessment of heads movement. The issue of identification of asymmetry in RoM measurement can be raised here. In standard RoM measurement it is assumed to be a nontrivial problem to obtain a neutral position,[11].

The literature review shows that there is a need to test and investigate more appropriate method for cervical RoM measurement for medical practice applications. This is supported with the current trend toward evidence based health care practice, where it is essential to have reliable, yet simple techniques for measurement.

In the robotic industries, inertial measurement units (IMUs) are rapidly taking leading role in providing information on position, orientation and motion of rigid bodies. Similarly, same techniques can be applied and developed for measuring clinical parameters of human body. Inertial sensors are lightweight, small size and low power consumption. These characteristics enable the portability of the system which can be easily mounted on the body segment to be measured. In the present work MTx sensor from the XSens is used as IMU. MTx XSens sensor has integrated 3D magnetometers accelerometers and gyro, with the embedded processors capable of calculating roll, pitch and yaw in real time, and it is recommended as an excellent measurement unit for 3D driftless orientation measurement of human body segments, [12]. In this work, the feasibility of using inertial sensor to measure cervical RoM in transverse plane will be examined. Although MTx XSens provides information of position, orientation and motion in all three cardinal planes, we will demonstrate the convenience for measurement of lateral rotation RoM in transverse plane. Moreover, we will measure the ability of subjects to return the head to self defined neutral position and show that inertial sensor measurement can alleviate the problem of neutral position estimation.

2 Methodology

2.1 Subjects

Ten asymptomatic subjects were enrolled, 5 man and 5 woman, the subjects ranged between 25 and 34 years old. Subjects were in good health. None had report any physical condition that might affect the experiment and no recorded history of neck or back pain in last two years.

2.2 Instrumentation

2.2.1 Sensor

A three-dimensional inertial sensor MTx XSens (Xsens Motion Technologies, Netherlands) was used to measure the movement of the head. The size of the MTx sensor module is 38 x 53 x 21 mm (W x L x H) and the weight 30 g. The sample frequency of all sensors was 100 Hz using the internal analog-to-digital converter of the sensor module. Angular resolution of sensor is 0.05°, with static accuracy or roll/pitch 0.5°and 1° for heading. The sensor modules were connected via a portable data bus system (Xbus Master, Xsens Motion Technologies) providing the sensors with power and transmitting the signals by a wireless Bluetooth connection to a PC. In order to measure movements of subject's head, we have mounted the sensor on a cap, as shown in Fig.1.

2.2.2 Software

LaBACS MTx Software was developed by in-house, [13], to control the operation of the IMU, acquire the data and display them in the real time. Program was developed under Microsoft Visual Studio 2005, using MFC (Microsoft Foundation Class). Fig. 2. shows a frame of a running software.

Fig.1. Subject with sensor mounted on a cap

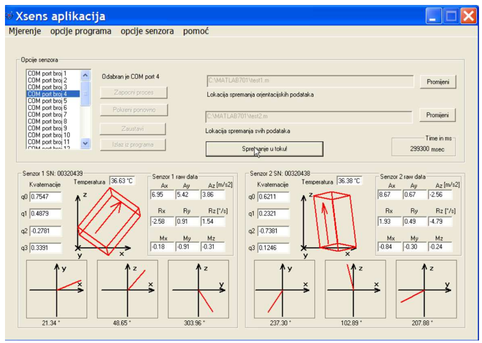

Fig.2 User interface of LaBACS MTx Software

2.3 Measurement procedure

Each subject was seated in a fully supported manner on a chair with the back support, with arms resting on the lap and feet firmly on the ground. The MTx XSens sensor is placed on the upper midline of the forehead. The subject was allowed to practice a few to get the feeling of movement, with the remark to avoid compensatory movements in the thoracic and lumbar region. Three measuring points (α_L, α_N and α_R) are given in Fig 3. Endpoints (α_L and α_R), corresponding to left and right rotation, are reached when the comfortable maximal rotation is achieved or when light discomfort is provoked, while the neutral position (α_N) is defined with the head pointing naturally in the direction normal to the frontal plane.

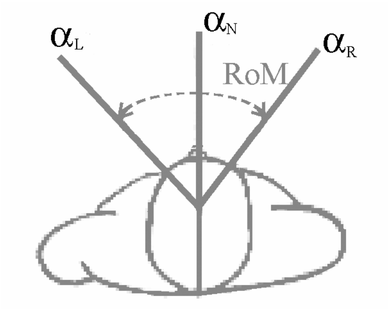

Fig. 3. Three measuring points in transverse plane

The subject is required to perform the rotational movement with the self-selected speed in such a way as to maintain the position of the head for a few seconds in three given points to obtain steady value reading. We have chosen this static state to be approximately 3 sec. Five repetitions of movement are recorded for each participant. Example of the recorded angles of one repetition of cyclic movement is given in Fig. 4.

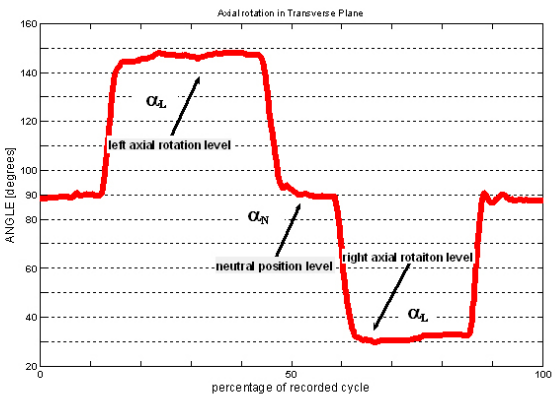

Fig. 4. Recorded angles of cyclic movement

3. Data processing and analysis

3.1 Estimation of neutral position and endpoints

In accordance with standard, total RoM is calculated by subtraction of maximal and minimal angle, or by summation of left and right RoM, assuming that the neutral position angle is known. During the measurement neutral position α_N is identified statistically, over time interval of five repetitions of cyclic RoM movement. Notations for measured and calculated angles are described in the Table 1.

Interested parameters: RRoM, LRoM, both RoMs and ratioR/L are calculated from the values estimated at three measuring points. Although left endpoint α_L, neutral position angle α_N and right endpoint α_R are available by processing signal acquired from the sensor after one cycle is terminate, multiple repetitions enable us to calculate mentioned values reliably. Description of the procedure is as follows. First, the values of interest are selected from the signal by finding local minimums and

Abbreviation	*Description*
α_N	neutral position angle
α_L	left endpoint angle
α_R	right endpoint angle
RRoM	right side RoM, i.e. difference angle α_N -α_R
LRoM	left side RoM, i.e. difference angle α_L -α_N
tRoM	total range of motion, in terms of α_L-α_R and (LRoM+RRoM)
ratioR/L	reciprocal ratio RRoM / LRoM

Table 1. Measured angles in transverse plane

maximums (Fig. 5). This way the transient angles are eliminated. Than, a histogram of selected discrete values is computed. Histogram of local minimums and maximums exhibit three-modal distribution as shown in Fig. 6, where left, middle and right mode correspond to α_L, α_N and α_R, respectively. Since the nature of measurement is such that the values are grouped around distinguishing static positions, thresholding is not an issue. Mean value of each of the three clusters estimates angles α_L, α_N and α_R.

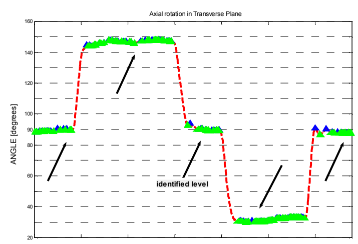

Fig.5. Local minimums and maximums of recorded angles

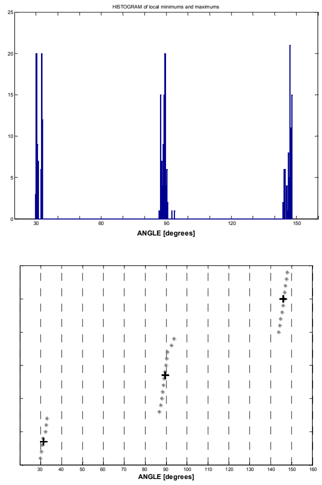

Fig.6. Histogram computation of neutral position and endpoint angles

3.2 Data analysis

It is assumed that tRoM is obtained reliably in most of the measuring techniques by subtracting endpoint angles. Therefore, tRoM=α_L-α_R. Also, total range of motion can be calculated as a sum lateral RoM tRoM=LRoM+RRoM. Both calculated ranges of motion are expected to have high level of agreement in case neutral position angle α_N is estimated correctly. Unilateral measurement implies that ratioR/L=$\frac{RRoM}{LRoM}$ is reliable parameter which can be indicative of some clinical diagnosis related to asymmetric mobility of the cervical spine. When ratioR/L=1, lateral motions are symmetric. When ratioR/L>1, mobility in right side is higher than in the left side, and vice versa, when ratioR/L<1.

4. Results

Five repetitions of movements were analyzed and averaged for each subject in order to eliminate the variability during movement recording. The results of the measurement on subjects are given in Table 2. Resulting angles of each group are described in terms of mean [°] ± standard deviation[°]. The results of the present study demonstrate similar ranges of motion as found in [13], although the existing results are obtained with different instruments. Measurement of individual neutral position has a standard deviation ranging from minimally ±1.12° to maximally ±3.36°. These results imply that the subjects are able to return the head to a self-defined neutral position. Therefore, the measurement of head motion by inertial sensors is valid for current application of RoM in transverse plane and able to measure neutral position, as well.

	LRoM	RRoM	tRoM[1]	tRoM[2]	ratioR/L
Asymptom. group	73.02° ± 7.61°	74.34° ±9.44°	147.28° ±15.51°	147.36° ±15.54°	1.022° ±0.096°

Table 2. RoM results of asymptomatic group; ([1] – α_L -α_R); ([2] – LRoM+RRoM)

5. Discussion

Agreement of tRoM data obtained in different ways verifies that the neutral position angle α_N can be reliably estimated and unilateral measurements performed. With standard measurement techniques, neutral point, α_N, is not trivial to establish. Usually this requires examiners subjective determination of α_N which is prone to human error. The measurement of head motion by inertial sensors enables monitoring of actual neutral position of person repetitively for a certain time interval. Statistical neutral position obtained by head rotation signal analysis and histogram computation can be considered as representative, moreover because the deviation of head positioning in the neutral point obtained from multiple time instances has a low deviation. This implies that the ratioR/L value is also accountable parameter, meaning that it can indicate laterally restricted movement abilities, if significantly discrepant from unity value.

6. Future work with application to visual feedback therapy

Visual feedback therapy manipulates subjects perception of performance and is used to encourage subjects (patients) to move beyond the level of performance. However, to prevent forcing, it is desirable to first establish the comfortable RoM. Angles measured during comfortable rotation are used as a reference of minimal angle which is increased with the therapy progress. Therefore, two sets of measurements are applied to individual subject/patient. In the first measurement procedure described previously in this paper is applied. Subject's motion is performed naturally. Mean values for each angle for self selected course of measurement is indicated in the graph in Fig.7 (blue line). After, a biological visual feedback is applied in the second set of measurements, with the $\Delta\alpha$ increased angle of RoM (red line). Subject is instructed to adjust his/hers motion in such a way as to follow this visually provided angle pattern. This protocol coordinates movements,

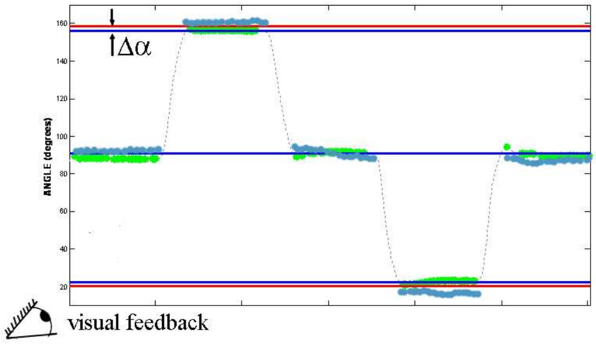

Fig.7. Visual feedback manipulates increase of RoM (*red line*) according to the level of RoM during self-selected motion (*blue line*)

verifies calculated values and estimates the reference value of the subject for the diagnostic purposes, since this provides a less deviated measurements. After the therapy a RoM is recorded again. Effect of the therapy, if successful, is indicated with the increase Δα in graph. This difference can be measured up to 0.5°, which is a smallest detectable angle. A pre-therapy and post-therapy results are visually available and more intuitively presented to the rater (therapist) and the subject (patient). Currently, this application has only sparse pre-experimental, but promising results. Extensive long-term experiments are required to assess the biofeedback effect on the course of rehabilitation and the quality of therapy.

7. Conclusion

In this work RoM in transverse plane was established to investigate the possibility of inertial sensor quantification of head-cervical motion. The measurement of head motion by inertial sensors is valid for measurement of RoM in transverse plane, and the results are in agreement with previous findings. Startpoint estimation is a promising feature of this framework. XSens sensor measure static position of a subject which enables the statistical estimation of neutral position of the head. Clearly, future work is needed to include more extensive measurements within other anatomical planes. The inclusion of more sensors is a matter of future work, as well. A novelty of a sensor measurement is possibility to include a biofeedback therapy, with a visually appealing user-interface, for which we have preliminary results Visual feedback manipulation needs to be explored further and experimentally establish the rigorous measurement protocol to manipulate and track the course of rehabilitation.

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