A Novel Electronic Cervical Range of Motion Measurement System

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Abstract— **In this article we describe the design of a novel, portable, head-mounting, electronic system to measure the ranges of motion of the cervical spine (CROM). The device used monolithic integrated circuits such as: accelerometers, gyroscopes and a single-chip 12-bit data acquisition system. This Electronic Cervical Range of Motion measurement system is connected to a personal computer interface that allows for efficient and reliable data transfer, thereby limiting the potential for human calculation and transcription errors. Overall, the system is accurate, reliable, portable, low-cost, and user-friendly. Furthermore, the system displays specific instructions to the user, in order to insure proper measurement technique and to limit inter-user error.**

Keywords— **Cervical Range of Motion, Accelerometer, Gyroscope, Single-chip Data Acquisition System.**

I. INTRODUCTION

Neck pain is a common musculoskeletal disorder, for which large numbers of patients receive medical treatment every year. The diagnosis and the evaluation of treatment success in patients with neck pain often require a continuous physical assessment of the range of motion of the cervical spine (CROM). Therefore it is significant to have a portable device that patient could use themselves to follow up how the treatment evolves.

Measuring CROM consisted of determining the maximum angles that a subject can perform using his/her head alone without pain in 3 plans: frontal (tilt left/right), sagittal (flexion/extension) and transverse (rotation left/right).

There are many methods and devices for measuring cervical range of motion that are currently in use such as: dual inclinometers, bubble goniometers, radiographs, compass technology, visual estimation, ultrasound, geometric methods, the Fastrack, digital optoelectronic instruments, computerized kinematic analysis using passive markers and infrared TV cameras, MRI, and CROM device [1-5].

All of these methods have some success in accurately determining cervical range of motion. The ideal cervical range of motion measurement system would be: accurate, precise, portable, low-cost, electronic, intuitive, and user-friendly. The system would have a personal computer interface that allows for efficient and reliable data transfer, thereby limiting the potential for human calculation and transcription errors. Furthermore, the system would be able to print specific instructions to the user, in order to insure proper measurement technique and to limit inter-user error. A survey of the background literature has revealed that no existing method of measuring cervical range of motion meets all of the aforementioned criteria.

SYSTEM	Axial Rotation Capable	Electronic	Portable	Performance	Low-Cost	Ease of Use
CROM	X		X	X	X	
Digital Optoelectronic		X		X		
Fastrack						
Dual Inclinometers			X	X	X	
Bubble Goniometer			X		X	X
Radiographs				X		
Ultrasound						
Geometric Methods	X		X		X	

Table 1 Range of Motion System Performance Comparison

The matrix in Table 1 indicates that very few current cervical range of motion measurement systems provide axial rotation measurement capability. This paper describes a novel Electronic Cervical Range of Motion Measurement System (ECROM). This electronic system provides accurate measurements, increases quality of documentation, and enhances measurement simplicity.

II. MATERIALS AND METHODS

The ECROM was built using a three-axis accelerometer, ADXL330, used as tilt sensor to measure both the Frontal and Sagittal CROM, a resonator gyroscope, ADXRS150, used as a rotation sensor to measure the Transverse CROM and a MicroConverter® ADuC841, a single-chip 12-bit data acquisition system that includes precision A/D and D/A converters, an 8052 Flash microcontroller, multiplexers, buffers, a temperature sensor, a voltage reference, a watchdog timer, a time-interval counter, serial interface ports, and a post-microprocessor that processed data that can be fit into the monitoring screen, typically a computer terminal for data display and further calculations (Fig.1). These are the monolithic IC from Analog Devices Inc. (Massachusetts, USA) [6].

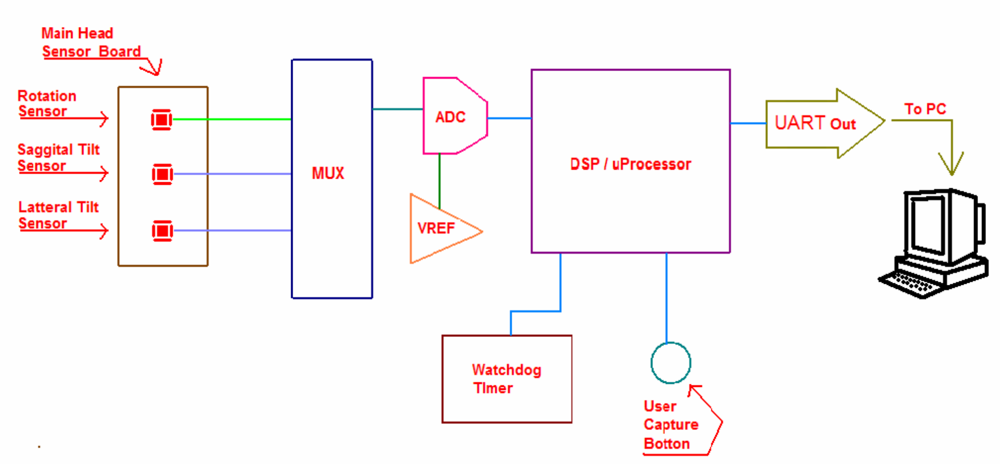


Fig. 1a: Portable ECROM Device Block Diagram

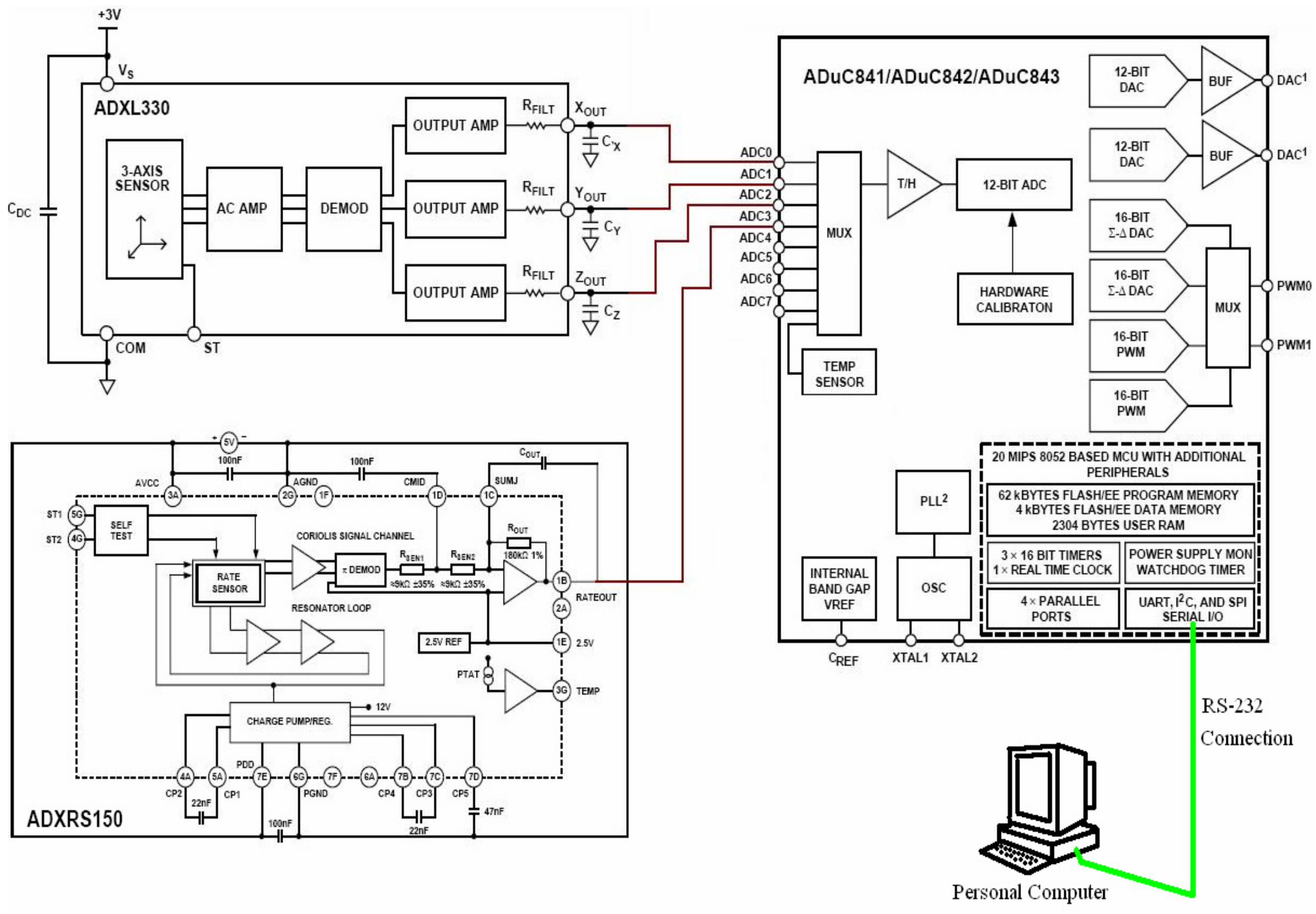


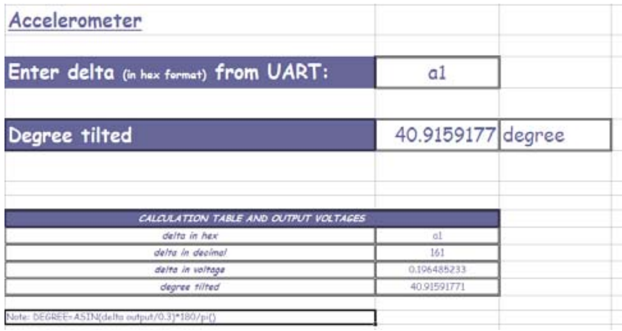
Fig. 1b: ECROM System Integration

The ADXL330 outputs X, Y, Z analog voltages depending on the tilting in respective X, Y, X directions. We will exclusively examine the X-output; the Y-output and the Z-output follow the same underline principle. The analog output voltage from the ADXL330 is fed into AIN1 of the ADuC841. After the analog voltage passes through a MUX, it is propagated into the ADuC841's integrated 12-bit ADC. The output of the ADC is in digital format, which is processed after going into 8052 MCU. The output of the MicroConverter propagates through a RS-232 connecting cable to the personal computer, where it is displayed in the Hyperterminal in Hex format. An algorithm for calculating tilting, or flexion and extension, of the head with the ADXL330 tilt-sensor is listed below:

1. ADXL330 acquires the initial position of the head. After MUX and ADC, the digital form of this voltage is stored as the 1st voltage in ADuC841 memory location for calibration purposes.
2. The INT0 button on ADuC841 evaluation board is pressed to send the 1st voltage to the PC UART screen for system validation purposes.
3. After subject's head is finished turning, the INT0 button is pressed again to record the 2nd voltage- the voltage associated with the final head position. Similarly, this voltage is stored in the ADuC841 memory location and then output onto the PC UART screen.
4. After the absolute difference of these two voltages is calculated by the MicroConverter, it is displayed in the PC's UART window in Hex format. This Hex output is manually entered into the appropriate Microsoft Excel worksheet.
5. The Hex output is converted into decimal format by using an Excel formula. The following equation is used to translate the decimal output into a voltage reading.

$$Voltage = \frac{Output\_decimal \times System\_reference\_voltage}{1 + 2^{Bit\_ADC}}$$

6. The degree of axial rotation of the head is then calculated in Excel with the following formula:
$$Degree\_turned = \frac{\arcsin(delta\_output)}{AccelerometerSensitivity \times 1g}$$
7. A screen shot of Accelerometer Excel worksheet is shown below.



Accelerometer		
Enter delta (in hex format) from UART:	a1	
Degree tilted	40.9159177	degree
CALCULATION TABLE AND OUTPUT VOLTAGES		
delta in hex	a1	
delta in decimal	161	
delta in voltage	0.196485233	
degree tilted	40.91591771	
Note: DEGREE=ASIN(delta output/0.3)*180/pi()		

Fig. 2 illustrates how the tilt sensor's outputs behave as the tilting angle changes. At 0° tilting, the accelerometer is at its default position, which correlating to analog voltage of around 1.5V, half way between 3V power supply and ground. At 75° tilting, the analog voltage decreases linearly to about 1.2V. Approaches 90° tilt, the nonlinearity of the device starts to show. After resetting the device to the initial 0° tilt position, analog voltage of around 1.5V is reestablished. For both clockwise and counter clock tilting, the accelerometer behaves similarly. To measure cervical strength of motion, 75° of linearity is sufficient because the human neck can rarely turn more than 75°. Accelerometer can be safely used in this application.

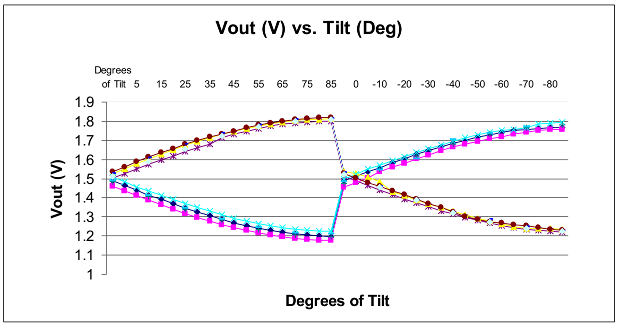


Fig. 2: ADXL330 Accelerometer Characterization Data Plot (see text)

Similarly, the output of the resonator gyroscope ADXRS150 can be converted into the neck rotation angle according to the following formula:

$$Neck\_rotation\_in\_degree = \frac{Initial\_voltage - Ave\_voltage}{12.5mV/degree/second} \times total\_time\_in\_second$$

The whole circuit (5x5cm) was attached on the top of a hard hat that can fit securely on the subject's head and provide a stable platform (Fig. 3). The hat was light and comfortable enough to allow unencumbered and unrestricted movement of the neck. A software program was written to treat the signals and display in an appropriate form in a user-friendly way.

Fig. 3: ECROM system mounted on a hard hat

III. Results and discussions

The accuracy and precision of the measurement system were assessed by mounting the device sensors upon a testing apparatus capable of titling and rotating to pre-set angles.

The test apparatus was designed to reliably simulate the frontal, sagittal and transverse motions. The performance capabilities of the measurement system were determined by comparing the measured angles of flexion, extension, and rotation, to the pre-set angles of the testing apparatus.

System accuracy was characterized by recording the system output for angles varying from -90^o to +90^o of tilt, in 5^o increment. The precision of the tilt sensing system was characterized by setting the test apparatus to various angles of tilt, and performing multiple measurements at each angle setting.

Tilt Sensor repeatability was studied for 38^o tilt angles in both the clockwise and counter-clockwise directions. The maximum measurement error in this case was less than 2.0^o, with a mean error of 0.73^o. The mean measurement system result after ten trials was 37.27^o, with a standard deviation of 0.63^o. This implies that 90% of measured tilt for an actual tilt of 38^o is in the range of 37.27+3x0.63 and 37.27-3x0.63 which is from 35.38 to 39.16^o.

Gyroscope repeatability was studied for 55^o rotation angles in both the clockwise and counter-clockwise directions. The maximum measurement error in this case was less than 4.0^o, with a mean error of 3^o. The mean measurement system result after ten trials was 51.9^o, with a standard deviation of 0.52^o. This implies that 90% of measured tilt for an actual tilt of 38^o is in the range of 51.9+3x0.52 and 51.9-3x0.52 which is from 50.36 to 53.45^o.

IV. Conclusions

We developed an Electronic Cervical Range of Motion measurement system that is accurate, reliable, portable, low-cost, and user-friendly. The system connected to a personal computer interface that allows for efficient and reliable data transfer, thereby limiting the potential for human calculation and transcription errors. Furthermore, the system is able to display specific instructions to the user, in order to insure proper measurement technique and to limit inter-user error.

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References

1. Carpaneto J., Micera S., Galardi G., Micheli A., Carboncini M.C., Rossi B., Dario P. (2004) A protocol for the assessment of 3D movements of the head in persons with cervical dystonia. *Clin Biomech* (Bristol, Avon). 19 (7):659-63.
2. Tousignant M., Smeesters C., Breton A.M., Breton E., Corriveau H. (2006) Criterion validity study of the cervical range of motion (CROM) device for rotational range of motion on healthy adults. *Journal of Orthopedic Sports Phys Ther*. 36 (4):242-8.
3. Strimpakos N., Sakellari V., Gioftsos G., Papathanasiou M., Brountzos E., Kelekis D., Kapreli E., Oldham J. (2005) Cervical spine ROM measurements: optimizing the testing protocol by using a 3D ultrasound-based motion analysis system. *Cephalalgia*. 25(12):1133-45.
4. Jordan K., Haywood K.L., Dziedzic K., Garratt A.M., Jones P.W., Ong B.N., Dawes P.T. (2004) Assessment of the 3-dimensional Fastrak measurement system in measuring range of motion in ankylosing spondylitis. *Journal Rheumatol*. 31(11):2207-15.
5. Chiarello C.M., Savidge R. (1993) Interrater reliability of the Cybex EDI-320 and fluid goniometer in normals and patients with low back pain. *Arch Phys Med Rehabl*. 74(1):32-7.
6. Analog Devices Technical Reference Books: Practical Design Techniques for Sensor Signal conditioning. *Prentice Hall 1994.*

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