ABSTRACT
The most prevalent musculoskeletal condition and one of the most disabilities are caused by low back pain.

In the low back pain, a large variety of evaluation tools is presented to assess the results of the treatment; therefore, it is important to measure the trunk angle in order to determine the progress during patient’s treatment.

In this project, we developed a low cost prototype system for flexion-extension movement to measure the angle of the trunk in sagital plane. The system consists of clothing that is stretchable; a Rubbery Ruler sensor (RRs) attached on clothing, data acquisition system. Inertial Magnetic Unit (IMU) sensor installed on spine is used to calibrate the orientation for the output of RRs twenty times. This system was validated by repeated experiments. The curve equation of the RRs output versus the IMU output is presented. Finally, this curve equation can be used to determine the angle of trunk in the clinical applications.

KEY WORDS
Trunk measuring system, Rubbery ruler sensor, flexion, extension

1. Introduction
Musculoskeletal pain is shown to be a prevalent complaint among people of a rural area in Iran in year 2009. The statistics published by Davatchi and et al indicated the pain percentage for questioned population were: shoulder 22.7%, wrist 17.4%, hands and fingers 14.9%, hip 13.9%, knee 39.2%, ankle 19.6%, toes 12.7%, cervical spine 17.9%, and dorsotrunk spine 41.9%. The same investigation was done for urban area which showed increasing pain distribution as well [1, 2]. Other investigators have also reported pain on joints as a widespread issue [3-8], so we can conclude that low back pain is one of the widespread problems. Each part of spine has their range of angle during spine motion, for example maximum average value of lumbar angle in flexion-extension is 19 degree and this value for cervical region is 15 degree [9]. Therefore, measurement of spine angle for various physical activities in healthy and patient people is important for prevention of spine injuries and it will be useful for diagnose of the problems such as athlete injuries in sport activities and treatment progress in patients so having a measuring device is essential to determine the movement domain of trunk for clinical applications.

Analysis of human motion originates far back as the fifth century, when Aristotle developed a measuring system for human movements [10]. Various methods in human movement determination have been published, Weissman 1968; Bullock and Harley 1972; Thometz et al. 2000; Liu et al.2001 used image-base methods. Pearcy et al. 1987; Dawson et al. 1993; Gracovetsky et al. 1995 used optoelectric analysis, also Robinson et al. 1993; Masso and Gorton 2000; Nault et al. 2002; Engsberg et al. 2003 defined human movement using video analysis [10]. The disadvantages of these methods include complicated set up, time consuming and limited volume of sight. In recent years, many advanced and cheap sensors have been design to compensate the problems of video based methods [10-16]. W. Y. Wong et al reviewed five types of electronic positional sensors and systems for tracking human posture and movement [12]. These sensors are accelerometer, gyroscope, flexible angular sensor, electromagnetic tracking system and sensing fabrics. Summary of these sensors applications are: gait analysis, posture and trunk movement analysis, upper limb movement analysis and physical activity analysis. The environment influence and signal extraction difficulties are the two main problems with these sensors.

In this project, a new low cost and low weight device to record trunk flexion/extension is presented. The system consists of stretchable clothing, Rubbery Ruler sensor (RRs) attached on trunk, data acquisition (Advantech-4716 and computer). IMU sensor is attached on trunk is used to calibrate the orientation for RRs. This system was calibrated by repeated experiments for twenty times.
2. Materials

2.1 Rubbery Ruler sensor (RRs)

Sensors are used in this system are Rubbery Ruler sensor and IMU as Xsens. The RRs is a wide range, conformable and capacitive displacement transducer. In its basic form the RRs consists of a bifilar helix of insulated conductive wires embedded in a tube of elastomeric material which is shown in Fig. 1.

The Rubbery Ruler sensor can be easily configured to monitor joint movements. It is insensitive to electromagnetic interference and requires simple electronic conditioning.

Summary of Rubbery Ruler properties are: [17]
- low cost
- flexible
- custom size
- high resolution
- self-aligning
- long life
- very wide range
- vibration-proof
- low power consumption
- non-invasive
- sealed

Types of RRs are shown in Fig. 2.

The setup circuit for RRs is shown in Fig. 3. This circuit is prepared in accordance with datasheet of RRs.

The output specifications of RRs are:
- Humidity: 0 to 100%
- Linearity (10% to 90% elongation): 3%
- Repeatability (10% to 90% elongation): 1%
- Durability (10% to 90% elongation): 1 million cycles
- The frequency range is typically 2kHz to 40kHz [17].

2.2 IMU sensor (Xsens)

The IMU is a small and accurate 3DOF inertial orientation tracker. It provides 3D orientation as well as kinematic data: 3D acceleration, 3D rate of turn (rate gyro) and 3D earth-magnetic field [18].

The orientation as calculated by the IMU is the orientation of the sensor-fixed co-ordinate system (S) with respect to a Cartesian earth-fixed co-ordinate system (G).
The output orientation can be presented in Euler angles: roll, pitch, yaw (XYZ Earth fixed type, also known as Cardan or aerospace sequence).

2.3 Clothing

In this study, to investigate the sensor elongation, we developed a clothing to detect natural trunk motion. Ninety markers are attached in certain location on clothing. As shown in Fig. 5, the distance between markers changes during trunk motion. Therefore, RRs can be useful for studying markers path during flexion-extension movement.

Integrating measurement systems into the clothing has some major advantages over carrying such systems; clothing is personal, comfortable, close to the body, and worn almost anywhere and anytime [16].

3. Assembling

RRs and IMU were mounted on the clothing. The data was simultaneously gathered by two sensors. IMU sensor was used to calibrate the output of RRs versus orientation. Assembling and testing the device is shown in Fig. 6.

The sensors are located on spine accurately. RRs elongates during flexion /extension. We gathered data twenty times for trunk from 0 to about 90 degrees in flexion-extension movement.

The output of the RRs (Voltage Vs Time) during flexion/extension of trunk movement for ten times are shown in Fig. 7. We used Curve fitting toolbox of Matlab software for plotting the output of RRs signal. The Moving Average method is selected for smoothing the signal.

A moving average filter smoothes data by replacing each data point with the average of the neighboring data points defined within the span.

Consequently, the output of the IMU (Yaw angle) is shown in Fig. 8. The Yaw angle demonstrates flexion/extension movement.
4. Results

The output signal of RRs is mapped to the Yaw angle of IMU using Matlab. Consequently flexion of the trunk has been obtained and is shown in Fig. 9.

We used Curve fitting toolbox of Matlab software for mapping the orientation to the output of RRs signal. The Moving Average method is selected for smoothing the signal.

Also, the extension of the trunk has been obtained which is shown in Fig. 10.

The general curve fitted equation of the all results is as equation (1):

\[ F(x) = P_1 x^6 + P_2 x^5 + P_3 x^4 + P_4 x^3 + P_5 x^2 + P_6 x + P_7 \]  

(1)

The parameters of equation (1) are presented in Table. 1.

The hysteresis curves of RRs are shown in Fig. 11. As it is shown, deference between two curves is about 10 degrees.

5. Conclusion

In this study, a low cost; user-friendly and low weight system is introduced to measure the flexion/extension movement of trunk from 0 to 90 degrees. The system consists of a clothing that is stretchable, Rubbery Ruler.
sensors (RRs) that attached on trunk and data acquisition system. This system is useful to diagnose the progress of health in back pain patients. Output voltage of RRs is calibrated versus angle using the output of IMU sensor and transformation equation for each movement is presented.

<table>
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<th>Parameter</th>
<th>Test</th>
<th>P_1</th>
<th>P_2</th>
<th>P_3</th>
<th>P_4</th>
<th>P_5</th>
<th>P_6</th>
<th>P_7</th>
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<td>9.77</td>
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References

[18] www.xsens.com