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Implementation of Wireless Sensor System in Rehabilitation After Back Spine Surgery*

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Abstract: In this paper, we present a method for determining the mobility of the spinal column using a network of sensors. The sensors consist of accelerometers and gyroscopes, and mutual communication is accomplished using a I2C bus. The main sensor node collects data from all the sensors and sends them to a computer using Bluetooth communication. The collected data is then filtered and converted to the values of the angles that are of interest to quantify the movement. The experimental part of this work method is applied to determine the range of motion of patients in the Clinical Center in Kragujevac.

Keywords: Rehabilitation procedure, Back spine, Wireless sensors, Accelerometer.

1 Introduction

It is essential to know the range of motion values for proper rehabilitation procedure after spine surgery. Also, it is helpful during the rehabilitation treatment to observe the progression of the patient's recovery. Various methods and devices are used for motion analysis. Schober technique, radiology researches, video fluoroscopic analysis, goniometry and inclinometer are the most frequently used [1 – 4]. Nowadays the devices which enable three dimensional motion analysis on the skin have been developed due to technological advance. There are a number of devices such as Moire topography, photogrammetry, video raster stereometry, optoelectronic scanner, ultrasound scanner and cineradiography.

Following standard lumbar discectomy, the residual complaints persist to some degree in 28% to 74.6% of patients and they are common diagnostic and therapeutic problems. Studies have focused on the radiological identification of

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possible pain-inducing structures in failed back surgery patients. However, recurrent pain following lumbar surgery is clinically often nonspecific, and imaging techniques frequently fail to demonstrate a structural reason for the pain. As a consequence, no consensus exists on the management of such residual pain, especially if technical investigations are negative. Exercise therapy following surgery has been shown to have a beneficial effect [5], but how rehabilitation programs should be composed remains a controversial issue [6, 7]. Following back surgery, surgical recovery has to be facilitated. During the inflammation phase, the focus in rehabilitation is on the wound healing and on the pain control. The duration of this phase is depending on the surgery performed: the more invasive the surgery, the longer the inflammation phase. Adequate pain relief, with pain killers on schedule, inhibiting break through pain, is essential. Although a lot of surgeons brace their patients postoperatively, there is an obvious lack of consensus regarding indications for immobilization, the most appropriate type of brace and the duration of bracing. In our opinion, the duration of bracing should be kept as short as possible, since it has been shown that lumbosacral orthoses reduce muscle activities in the thoracic and lumbar erector spinae muscles [8]. During patient lower part spine motion the most interesting is the Spinal Motion Segment (SMS) L5-S1 which supports the biggest part of total spine loading. The aim of this study was to determine Range Of Motion ROM values of lumbar spine motions of patients after spine surgery by using wireless three dimensional acceleration measurements.

2 Hardware

Our goal was to use in the experiments the Avatar (multi-sensory) for wirelessly detection of acceleration on the certain spine position. Avatar device [9] is a small, wireless, battery powered experimental platform. Unlike common embedded system device. The hardware platform includes a range of built-in sensors as well as the ability to easily interface to external devices. One basic Avatar device has three layers: the battery layer, the processor and wireless communication layer and the sensor layer. Main part of device is master node shown in (Fig. 1). Master node is connected with internal nodes with I2C bus. The master node control network of internal sensor nodes, processes data and communicates with data capture device. The master node features an ARM7 processor NXP LPC2368 with 58 KB RAM and 512 KB program memory and clock rate of 72 MHz.

Internal sensor node (iSense) contains a 3D accelerometer (Bosch SMB380) and a two axis gyroscope (InvenSense IDG500). iSense features a low power microcontroller MSP430F2274 for signal conditioning, processing and communication [10]. A network of iSense modules communicate with the gateway through the shared I2C bus (Fig. 2).

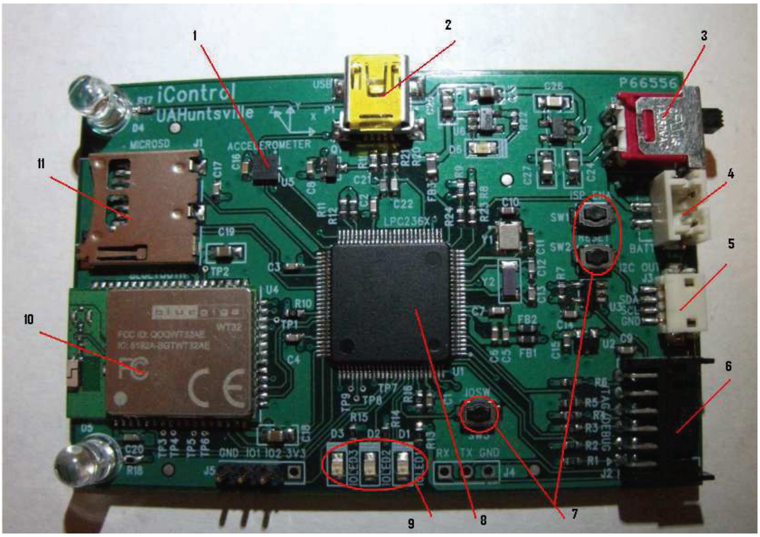

Fig. 1 – *Master sensor node:* (1) *accelerometer* (2) *USB port* (3) *switch* (4) *battery connection* (5) *I2C connection* (6) *JTAG connection* (7) *reset switch* (8) *microcontroller* (9) *diodes* (10) *Bluetooth module* (11) *micro SD card slot.*

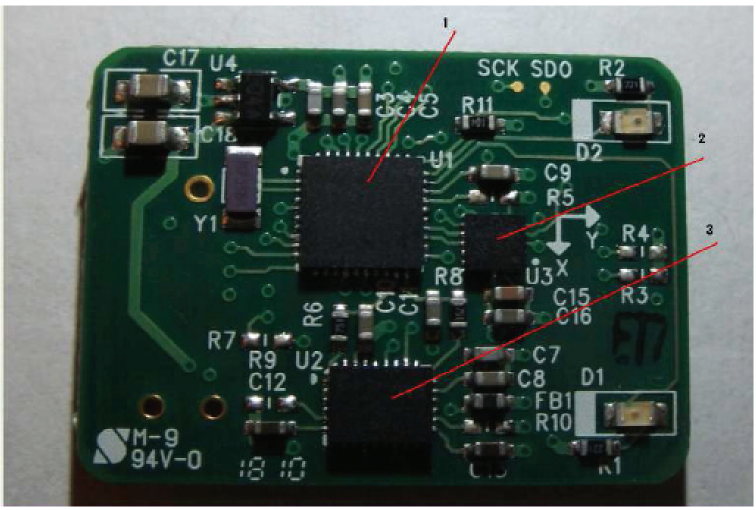

Fig. 2 – *Internal sensor (iSense) node:* (1) *microcontroller;* (2) *accelerometer* (3) *gyroscope.*

Communication takes place over four-wire cable (Vcc, GND, SDA, SCL). The development system must be connected to a PC via the serial port (RS232) or via Bluetooth connection [11]. Master node provides power supply for the all system with lithium-ion polymer battery as shown in (Fig. 3).

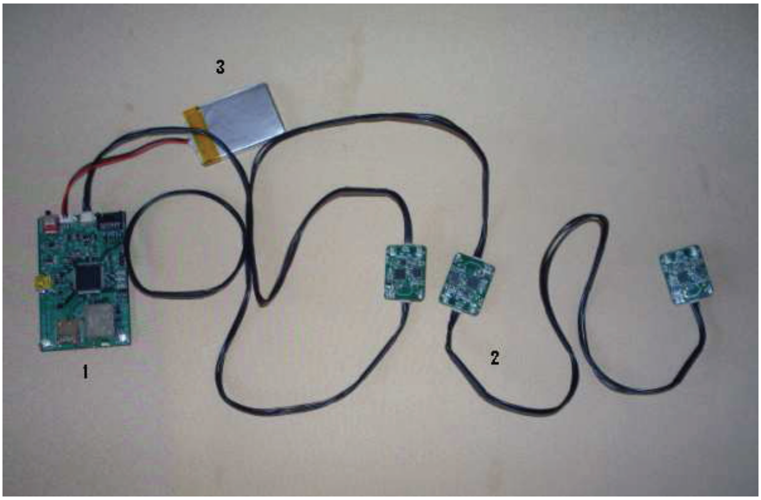

Fig. 3 – *Sensor networks:* (1) *master node* (2) *iSense node;* (3) *lithium-ion polymer battery.*

3 Experimental Results

The Avatar master node processor controls sensors and communicates with the capture device. In our case the Avatar base station was connected to the standard PC over Universal Serial Port. All signals were sampled at 100 Hz. The output was generated every 10 ms. The estimated positions for X, Y and Z signals are represented in (Fig. 4).

Following the acquisition of signals in the next step it is necessary to remove noise from the signal (in our case it was used moving average filter with 15 points), appearance of obtained signal is shown in (Fig. 5).

A first few samples represent value of sensor signal in neutral position, and peak, the value of the signal when it's reached the maximum movement.

Since the signal values are projections of the normal acceleration of gravity on the axis of the sensor, from the received data it is not difficult to determine the angles at the beginning and end of the movement of which is obtained range of motion in degrees (°).

Kinematics measurements were performed with 3D accelerometer placed on Avatar device board. Sensors were positioned near lower lumbar segment (L5/S1). The measurements were performed during the period 10.00–13.00 hours in a Clinical Centre at room temperature. The movement measuring protocol required from the subjects to perform trunk flexion, extension and lateral flexion in a standing position. The measurements started from vertical neutral position and followed with continuous movement how much is possible.

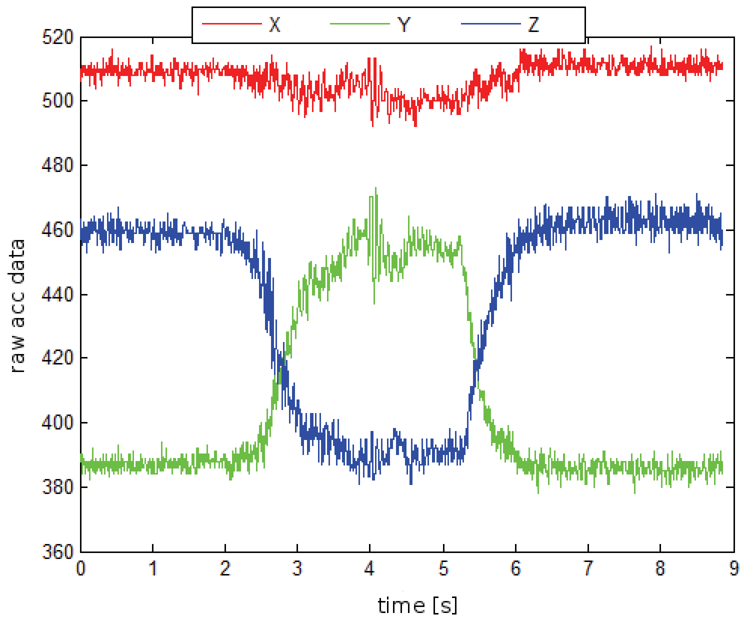

Fig. 4 – *Accelerometer signal for X, Y and Z axis*.

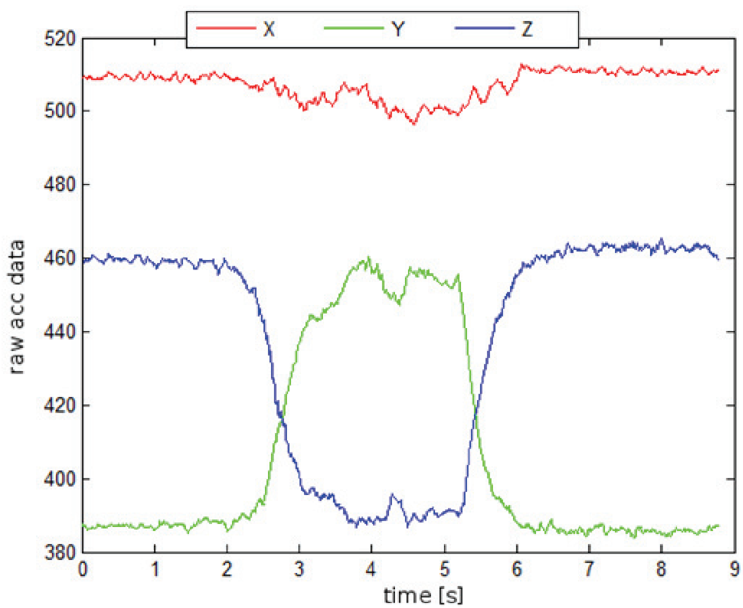

Fig. 5 – *Filtered accelerometer signal with average standard deviation 2.2285.*

The experiment was conducted on a group of four patients of the Clinical Centre in Kragujevac, aged between 37 and 60. Two sensors were used as shown by the one set in the L1 level and the other at the level of L5 vertebra as shown in (Fig. 6).

Fig. 6 – *Placing the sensor in the region of* L1 *and* L5 *vertebrae.*

In **Table 1**, we are present the range of motion for subjects in degrees, whereas only used data obtained from sensors positioned at the L1 vertebra.

Table 1
Range of motion for various type of movement of subject in degrees (°).

Subject			Lateral flexion	
	Flexion	Extension	Right	Left
1	38.8	12.7	1.4	4.2
2	45.2	13.5	2.4	8.2
3	27.3	5.0	2.5	5.8
4	39.1	2.4	2.4	5.1

The logical question that arises is about the error value and measurement uncertainty, which is made in this mode of measurement. In our case, the sources of measurement error are: the final resolution of the measuring sensor and the error that occurs as a result of averaging the signal filtering. Based on characteristics of devices and the mean average deviation for all performed measurements, we find that the total error that is made in the order of 1.5°. This is quite a good result considering that the measurement error in conventional methods go up to 9°.

4 Conclusion

In this paper we present a system of sensors, which can be used to measure range of motion of the spinal column. The system of sensors that communicate using the I2C bus and acquisition data are collected to PC over Bluetooth device. Based on measurements performed on several subjects and characteristics of the sensor, it is estimated that the error rate of this method about 1.5°, which is quite good considering the accuracy of conventional method is significantly lower in some case up to six times.

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