PostureMonitor: Real-Time IMU Wearable Technology to Foster Poise and Health

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Abstract. This paper presents the prototype development and verification of a simple wearable posture monitor system, based on a miniature MEMS Inertial Measurement Unit (IMU). The Inertial Measurement Unit uses accelerometers and gyroscopes to estimate the orientation of the module through sensor fusion algorithms. The system provides a warning to the user wearing it when he/she is departing by an adjustable margin from the posture indicated to the system as correct. Continuous real-time warnings of this type will help the user acquire good posture habits, which has the potential to prevent or assuage health problems caused by chronic bad posture.

Keywords: Posture monitoring · Inertial measurement system · Accelerometer · Gyrosscope · MEMS · Sensor fusion

1 Introduction

Daily activities in the modern world frequently require that individuals spend long hours in a static position. Office workers frequently sit in front of computers for long hours, many times without being able to stand or change their posture. It is well documented that maintaining an improper posture, such as 'slouching' while sitting can lead to improper alignment of the vertebrae in the spine. Improper alignment of the spine can cause damage to the discs that exist between the vertebrae and/or apply inappropriate pressure and stress to the nerves that exit the spine between the vertebrae. This, in turn, can be the cause of very significant afflictions, such as back pain, leg pain, numbness, headaches, etc. [1–6].

Therefore, it is imperative that all individuals develop the habit of maintaining a proper posture. However, many individuals tend to gradually deviate from their intended correct posture, unconsciously. It is in this context that a simple wearable device capable of providing a warning to the user when he/she is drifting away from the correct posture would be very valuable towards helping the user develop sound postural habits that would contribute to the prevention of problems stemming from chronic inappropriate posture.

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2 Related Work

In the past, there have been several attempts to monitor the posture of the human body, pursuing a variety of goals and applications. For example, Tanaka, Yamakoshi and Rolfe [7] developed a portable instrument for long-term ambulatory monitoring of posture change, using miniature electro-magnetic inclinometers. However, the electro-mechanical inclinometers used here are delicate and therefore make this type of system more appropriate for clinical use than for ordinary consumer use.

Dunne et al. [8] developed a wearable plastic optical fiber (POF) sensor for monitoring seated spinal posture, and a garment that integrated their optical fiber sensor. While the technology used in this system is novel, it is unlikely that most individuals (e.g., ordinary office workers) would adopt the use of a special garment for the sole purpose of having their posture monitored during their daily activities. This same consideration applies to the smart garment for trunk posture monitoring developed by Wai Yin Wong and Man Sang Wong [9], which consisted of a T-shirt with three sensors attached, as well as a sizable battery pack and digital data acquisition module.

3 Inertial Measurement Units for Posture Monitoring

A key element in keeping a good posture is to preserve an adequate angle of the upper back, while standing or remaining seated. Ordinarily, most individuals will first make an effort to keep their backs 'straight', i.e., in such a way that the upper back is parallel to a vertical plane and there is no tilting of the spine to the left or to the right. The objective of a posture training system would be, therefore, to alert the user when the upper back is 'bent forward', i.e., when the subject is 'slouching', or when there is an inappropriate tilt to the left or to the right.

Fortunately, new Inertial Measurement Unit (IMU) modules have emerged in the market, which are capable of continuously monitoring, in real-time, the orientation of the module, providing digital values of the angles of rotation about three orthogonal axes. Further, these systems provide the evaluation of those, so called 'Euler Angles' of rotation, known as 'pitch', 'roll' and 'yaw', as differences with respect to initial or 'tared' values. This feature is particularly auspicious for the application at hand, because the user can reset or 'tare' the angles to zero when he/she is in the target posture, such that the reported pitch, roll and yaw will represent the corresponding angular deviations from the target orientation of the anatomical segment (e.g., the upper back), to which the IMU module is attached. Figure 1 shows the definition of the pitch, roll and yaw angles with respect to the orthogonal X, Y and Z axes, according to the convention used in our work (left-handed system).

In particular, for this work we used the 3-Space Embedded module, from YEI Corporation, which is an ultra-miniature, high-precision, high-reliability, low-cost Attitude and Heading Reference System (AHRS) / Inertial Measurement Unit (IMU) which uses triaxial gyroscope, accelerometer, and compass sensors in conjunction with advanced sensor fusion processing and on-board quaternion-based orientation filtering algorithms to determine orientation relative to an absolute reference in

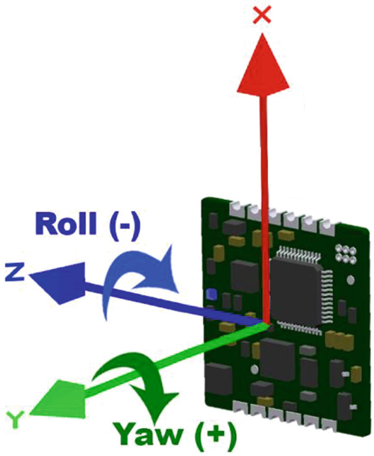

Fig. 1. Coordinate axes used, and definition of the roll and yaw angles, superimposed on the image of the 23 mm × 23 mm 3-Space YEI Embedded IMU module.

real time. This module, with dimensions of 23 mm × 23 mm x 2.2 mm (0.9 × 0.9 × 0.086 in.) is also shown in Fig. 1, with the coordinate frame (orthogonal axes) superimposed on it.

4 The PostureMonitor System

We developed the PostureMonitor system around the 3-Space Embedded module. This module has small physical dimensions and light weight (1.3 g, i.e., 0.0458 oz.), and can, therefore, be attached to the upper back of any ordinary garment worn by the user by means of Velcro glued to the bottom of the module. The specific position in which the module is attached to the upper back is not critical, since the system will be reset (or 'tared') to pitch = 0°, roll = 0° and yaw = 0° when the user adopts the target (correct) posture, initially. Figure 2 illustrates the general area and approximate orientation of attachment for the IMU module to the subject. In this figure, it can be noticed that the critical rotations which would imply an inappropriate departure from a correct posture are:

A. Bending toward the front: will result in a negative roll value (F)
B. Tilting to the right: will result in a positive yaw value (R)
C. Tilting to the left: will result in a negative yaw value (L)

According to the conventions illustrated in Fig. 2, the operation of the PostureMonitor system only requires the 3-Space module (powered by a voltage source), an elementary user-interaction device, such as a normally-open push button which can be pressed to close its circuit, and a mechanism to provide the warning to the user, such as the speaker in an earphone (or alternatively a piezo-vibrator that could provide tactile output to the user). The 3-Space Embedded module can be supplied with 3.3 V to 6.0 V, and has minimal power consumption (45 mA @ 5 v). Therefore, it can be

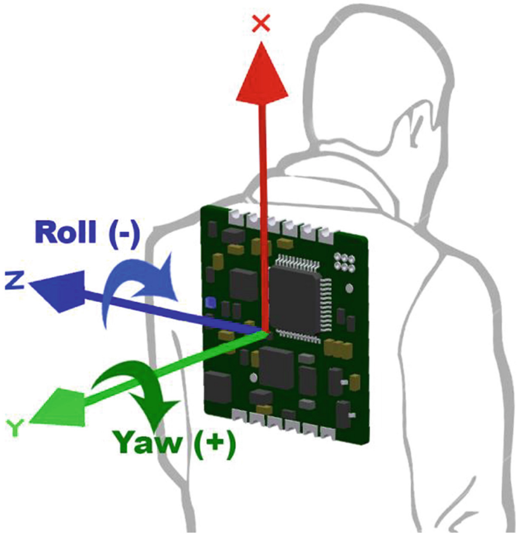

Fig. 2. Approximate position and orientation of attachment for the 3-Space module to the user (Module not to scale).

powered by a 'wrist watch battery'. In our initial prototype, we operated the 3-Space sensor in a tethered configuration in which a USB cable is attached to it, so that the power is supplied to the module from the host PC through the USB cable and commands (e.g., 'tare the sensor', 'read the current angles', etc.) and data (e.g., pitch, roll, and yaw, values estimated in the IMU module using sensor fusion of its accelerometer and gyroscope readings) are exchanged through the USB connection, under control of a C program running in the host PC. This program utilized several library functions provided by YEI Corporation to facilitate the development of applications of their IMU module.

Specifically, the PostureMonitor system operates in one of two modes:

1. INITIALIZE
2. SENSE

Figure 3 depicts the flowchart corresponding to the INITIALIZE mode. On power-up the PostureMonitor starts execution in this mode. In this mode, the system continuously waits for the activation of the push button, which will serve to indicate that the user is currently adopting the target position and the angles should be, therefore, reset ('tared') to zeros. Upon re-setting all the angles, the program branches to the SENSE mode.

In the SENSE mode the system will read the values of pitch, roll and yaw estimated by the IMU module and compare them to pre-defined (programmable) thresholds to determine if any of the 3 critical departures from correct posture exist, according to Table 1.

Then the system will determine if any of the flags (FrontFlag, RightFlag, LeftFlag) has been set and, in that case, it will assert the variable Alarm, which will cause the

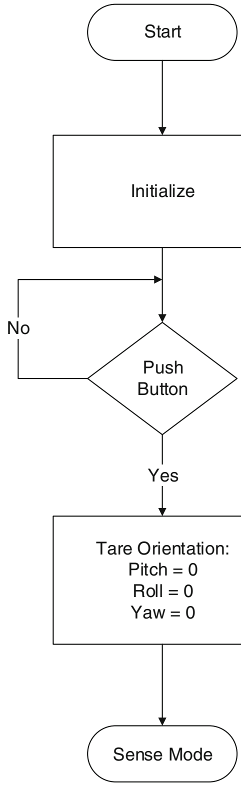

Fig. 3. Flowchart for the INITIALIZE mode

Table 1. (Programmable) Thresholds used to trigger indications of incorrect posture

Departure from correct posture	Set flag	If this condition is met
Bend toward the front (F)	FrontFlag	Roll < -5^{o}
Tilt to the right (R)	RightFlag	Yaw > 10^{o}
Tilt to the left (L)	LeftFlag	Yaw < -10^{o}

warning to the user (speaker or piezo element) to be activated. The user can force the system back to the INITIALIZE mode (to be able to re-tare the angles to zero), by pressing the push button. Figure 4 shows the flowchart for the SENSE mode.

5 Verification of the PostureMonitor System

In our preliminary implementation we have tested the PostureMonitor system while still connecting the 3-Space module to a host PC through a USB cable. This provided power to the 3-Space module and allowed commands and data to be exchanged between the 3-Space module and the host PC. In this preliminary implementation the

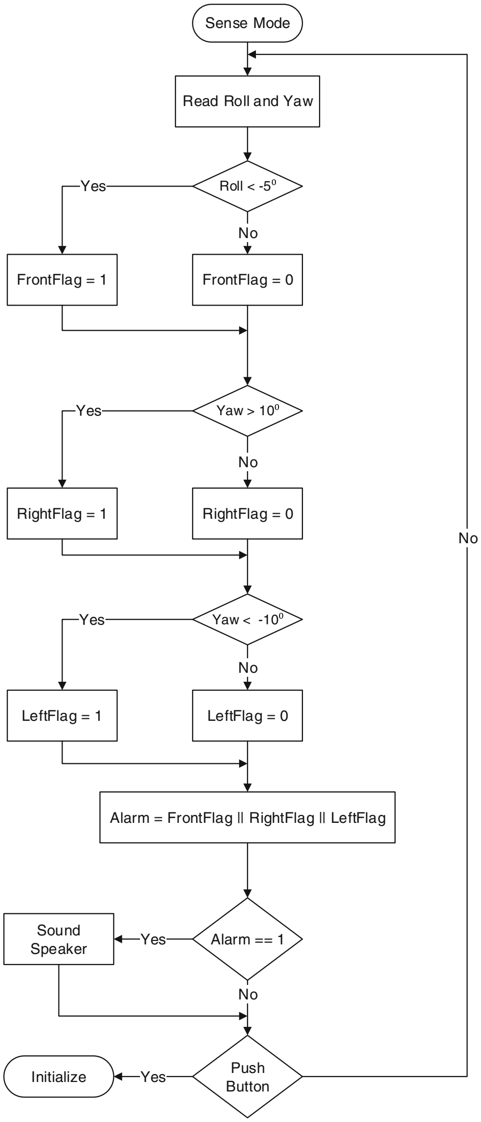

Fig. 4. Flowchart for the SENSE mode

push button was functionally substituted by a key in the keyboard of the host PC, and the actuator (speaker or piezo element) was substituted by the speaker of the host PC. Under these circumstances, we have tested the performance of the PostureMonitor system, on several volunteers, with positive results.

Figures 5 (side view, from the left of the subject) and 6 (back view) illustrate the target position (in which the sensors were 'tared') for one of the evaluations performed.

Fig. 5. Target ('tare') position - Side view

Fig. 6. Target ('tare') position - Back view

After the PostureMonitor system was initialized ('tared') in the position illustrated in Figs. 5 and 6, the system was made to change to the SENSE mode and the subject was asked to shift her position to adopt some of the typical instances of improper posture. The subject was asked to stop her movement as soon as the system activated the speaker, indicating the detection of the incorrect posture. Figure 7 shows the position in which the system reported that the subject was bending forward ('slouching'). Figure 8 displays the position in which the system activated the speaker, to report that the

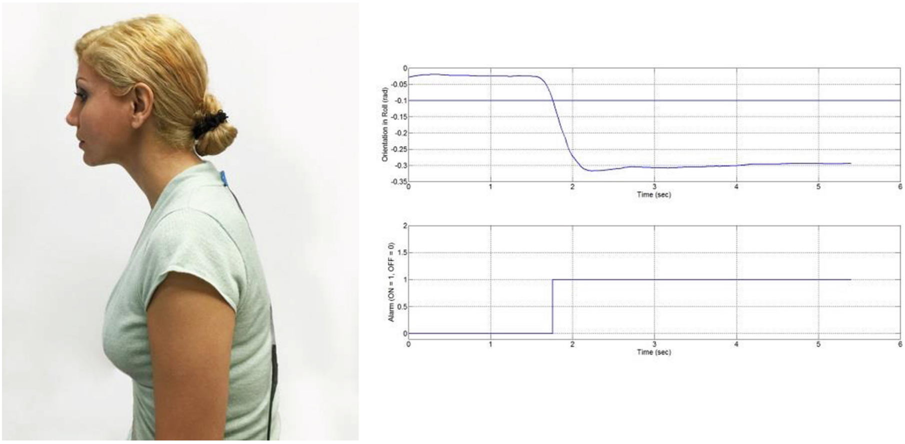

Fig. 7. Detection of subject bending forward ('slouching'), change in roll value and setting of the FrontFlag.

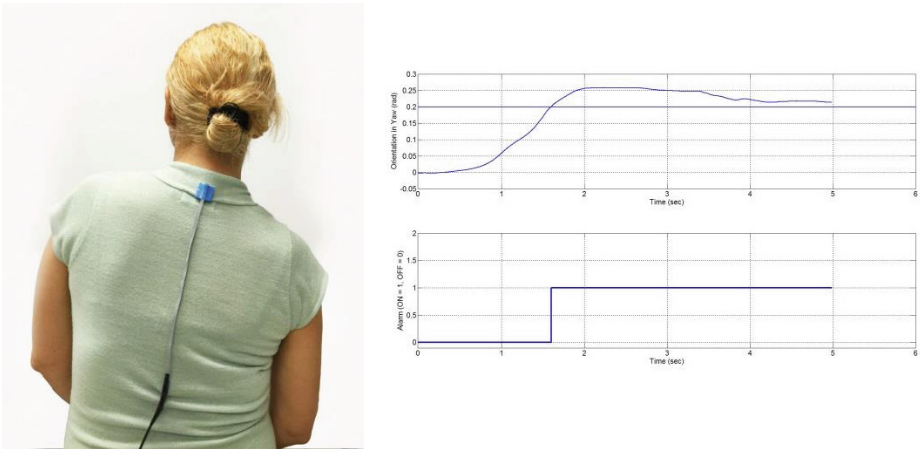

Fig. 8. Detection of subject tilting to the right, change in yaw value and setting of the RightFlag

subject was tilting to the right. Figure 9 shows the position at which the system indicated that the subject was tilting to the left.

The figures above confirm that the PostureMonitor system is sensitive enough to provide useful warnings to the user and, in that way, foster the development of good postural habits.

To visualize the operation of the SENSE mode of the system, Fig. 10 shows the changes in roll and yaw angles when the subject bent forward, then tilted to the left and then tilted to the right, causing the corresponding flags to be set. Then the subject adopted two 'combined' incorrect postures, leaning simultaneously to the front and the left and then to the front and the right.

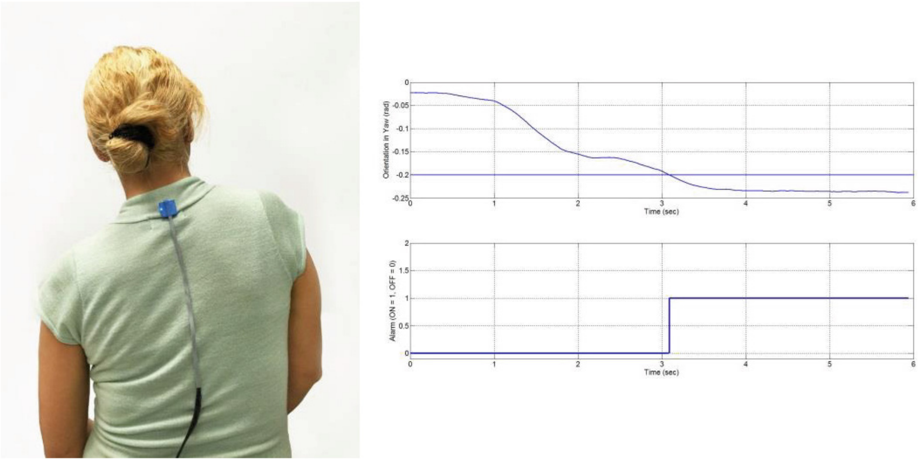

Fig. 9. Detection of subject tilting to the left, change in yaw value and setting of the LeftFlag

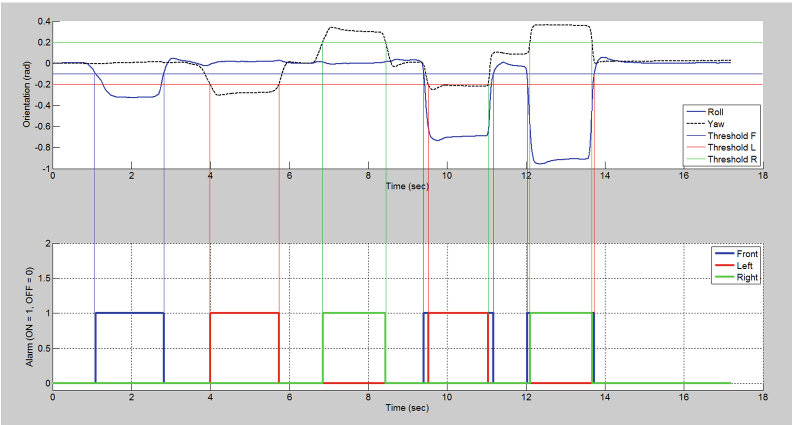

Fig. 10. Roll and yaw changes and flags set when improper postures were adopted

6 Conclusions and Future Work

This paper describes the development of a simple posture monitoring system, requiring a single MEMS IMU module (3-Space Embedded, from YEI Corp.). The verification of the system indicates that the PostureMonitor is capable of providing useful warnings to its user and therefore help him/her to develop good postural habits, which may aid in preventing or assuaging health problems derived from chronic improper posture.

Our future work will include the consolidation of the 3-Space Embedded module with a microcontroller, a miniature switch (push button), and a wrist watch battery in a fully independent wearable unit that can be connected to a headphone to provide its warnings to the user.

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