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Original article

Detection of spine curvature using wireless sensors

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A R T I C L E I N F O

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A B S T R A C T

Ankylosing spondylitis (AS) is a progressive disease of the spine where the spine slowly stiffens and can eventually become completely inflexible. It can be difficult to diagnose in primary care, and thus there is often a 10-year delay in diagnosis. Within this study an intelligent wearable system is designed and developed to detect the displacement of the spine and provide the subject with a continuous posture monitoring and feedback signals when an incorrect posture is detected using accelerometer and gyroscope sensors. This wearable system can be used both to diagnose AS in early stages and to prevent subjects from lower back and neck pain caused by incorrect posture. We outline here the system which detects the curvature of the spine by using Shimmer sensors placed on the back and provides relevant exercises based on the user's pain records.

1. Introduction

Per the Office for National Statistics (ONS), the number of people with Lower Back Pain (LBP) and neck pain is increasing. There was almost 31 million days of work lost in 2013/2014 due to back and neck pains (O'Flynn et al., 2013b). A common health problem amongst society is Lower back pain (LBP) which is a leading cause of activity limitation and work. This can be an economic burden on individuals, families, governments, industry and society at large. At least 50% of the European population will experience back and neck pain at some time in their lives (Hoy, 2014). Back pain can be caused by many different factors such as diseases, sprains, strains, injuries, or a pinched or irritated nerve which is caused by NHS, 2016 bending uneasily or for long period of time, slouching in chairs, lifting, carrying, pushing or pulling heavy items, twisting uncomfortably, overstretching, driving or sitting in a hunched back position or for long times without taking a break or overusing the muscles during activities such as sport. Many people believe back pain is an ordinary symptom, but in some cases, back pain can be due to more than a strained muscle or other injuries. It can be caused by a chronic condition called Ankylosing Spondylitis (AS).

Ankylosing spondylitis (AS) is a progressive disease of the spine where the spine slowly stiffens and can eventually become completely inflexible. It is arthritis that strikes the spine, but it can move to other joints. (Worldometers.info, 2016). In AS, the stiffness and chronic pain is caused by inflammation, and the degree of pain can vary from one person to another. AS is incurable, but the living condition can be made easier using medications and practicing healthy lifestyle tactics. It can be difficult to diagnose AS in primary care, and thus there is often a 10-year delay in diagnosis. It is not uncommon to see young people between the ages of 17 and 45 presenting to a rheumatologist for the first time having already developed severe and permanent stiffening of the spine due to AS (Pearcy et al., 1987). Back pain is extremely common whereas AS is quite uncommon and many GPs have not been trained in detecting it. There are no symptoms that reliably point to the diagnosis although a questionnaire can help to diagnose it. This questionnaire consists of 6 questions related to 5 major symptoms: fatigue, spinal pain, joint pain/swelling, areas of localized tenderness, morning stiffness. X-rays and MRI scans can fail to detect the condition for several years after it has started. One of the most important clinical tests for early AS is a simple tape measure test: Schober's test[2]

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[2] http://youtu.be/YULeqz1G1HU.

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(Luinge and Veltink, 2004; Tong and Granat, 1999). This test essentially detects a loss of displacement or elongation in the lumbar spine when someone bends forward. Unfortunately, this test is usually not performed in primary care and the diagnosis is missed. Spinal movements in other directions can also be affected in AS: reduced rotation and lateral flexion of the spine, reduced chest expansion. The neck can be affected as well as the lower part of the spine. However, it is uncommon to develop problems in those areas without some reduction in Schober's test. Stiffness in AS is worse in the morning – if patients attend clinic in the afternoon the test may be normal. An ambulatory test may be more sensitive in detecting those with stiffness in the morning (Bouten et al., 1997). Previous approaches to measure spinal deformities (increased bend in the thoracic spine, straightening of the lumbar spine) are limited (Condell et al., 2012). To date, work has not been carried out on measuring dynamic movement in the spine in AS. Ulster University has developed a system coupled with wearable gloves to measurement Rheumatoid Arthritis (RA) in finger joints (O'Flynn et al., 2013a,b; Condell et al., 2012; Connolly et al., 2012). The need to be able to measure stiffness objectively applies to AS even more than in RA, where other outcome measures exist to measure disease activity. Whilst there has been some work with wearable gloves, spinal movement research has not yet been applied to the study of AS. The ISRC team has therefore been developing expertise with conductive wearable fabrics merged with intelligent systems for stiffness measurements (Condell et al., 2012; Connolly et al., 2012).

This research presents a wearable system with piezo-resistive stretchable fabric for the detection of displacement in the lumbar spine (Carlos et al., 2011) using Shimmer sensors. This will facilitate an ambulatory test for people with back pain to achieve early diagnosis of AS; allowing monitoring of stiffness, daily posture and encouraging exercise. Patients with AS are normally given a list of specific spinal exercises to carry out over a 30-minute period each day. This technology will also be used to obtain objective measures of outcome in terms of spinal flexibility. The current clinical process relies heavily on questionnaires which asks the patient to rate the severity of their stiffness and pain. However, by the time the patients visit the clinic, they can forget their symptoms and the severity of their pains. The system therefore has a daily checkup section which allows the user to input their symptoms and the severity of them which is then calculated per the Bath Ankylosing Spondylitis Disease Activity Index (BASDAI) scoring method. Based on their BASDAI score the system promotes individual detailed exercises for the patient. Another important symptom of the AS disease is the kyphosis which is the medical term for "hunchback" appearance. When AS has affected the upper part of the neck, it creates major kyphosis which causes the head to collapse forward (Stewart, 2014). So being able to recognize hunchback appearance at the early stage can help in diagnosing AS.

2. Related work

This section provides an overview of existing works on methods for detecting the curvature of the spine and maintaining a correct posture. In (Campbell-Kyureghyan et al., 2005), an MRI scan was used to to validate a method of predicting the lumbar spine geometry from external (non-invasive electro goniometer) measurements. This allowed for the correct representation of the vertebral position and orientation relative to the sacrum using scaled anthropometric data and individual goniometric measurements. The results achieved by the research had a high degree of accuracy but the main problem is the degree of practicality as it is not practical and easy to have radiograph images taken anywhere. Another study (Bartalesi et al., 2010) described the design and the development of a wearable smart T-shirt system which can estimate the lumbar arch length. This is estimated by processing the raw sensor data through a hybrid model developed to describe the peculiar characteristics of the e-textile sensors. This system used both e-textile and accelerometer sensors. The system has been tested in comparison with a stereo photogrammetric system showing a 2% error in length estimation. This study has no information on how the user's postures in different positions were handled. In (Mattiman et al., 2007), the study presented the use of novel textile strain sensor to detect a bend on the subjects back. The sensors used had a linear resistance vs. strain characteristics and a negligible hysteresis. The resulting measurement error was ±3.5% over a strain range of up to 100%. A garment prototype was developed by connecting the strain sensors with a silicone film on the back area of a tight-fitting stretchy garment. Even though this system showed a good result, they do not calculate the force of gravity against the subject. This can result in system failure if the subject is standing or sitting on an uneven surface.

2.1. Intertial sensors

Inertial sensors are primarily accelerometers and gyroscope sensors and are based on inertia. An accelerometer measures specific force and acceleration, and a gyroscope measures the rate of change of angles. An inertial measurement unit combines multiple accelerometer and gyros (usually three of each) to generate a 3-dimentiaonal (3-D) measurements of accelerations and the rate of angle change, this produces data from x, y and z axis of both accelerometer and gyroscope sensors. These sensors are popular amongst health monitoring systems as they are usually very small, have long battery life and are easily attached to human body. DorsaVi ViMove sensor are inertial sensors, popular with many health clinics. DorsaVi's hardware contains two movement sensors, two EMG (muscle activity) sensors, a recording and feedback device, and a charging dock. The movement sensors consist of a 3-D accelerometer, a gyroscope, and magnetometer which collects movement data in three dimensions as well as measuring the force and the impact. The collected data are transferred wirelessly to the recording device. The data can be collected remotely for up to 24 hours or live data can be received by connecting directly to the PC (DorsaVi, 2016).

2.2. E-Textile sensors

E-textiles are fabrics that can be stretched and allow electronics and interconnections to be embedded into them, offering physical flexibility that cannot be accomplished as easily with other electronic manufacturing techniques. There are two different categories of smart textiles: one is aesthetic and second is performance enhancing. Aesthetic instances are fabrics that can change their color. Many of these smart textile fabrics receive energy from the environment by harnessing harnessing vibrations, sound or heat, reacting to this input. There are also performance enhancing textiles sensors, which are very useful within the sport and military industries. These smart textiles assist in controlling and adjusting the body temperature, its can control the vibration within muscles, and reduce the resistance of the wind. These can all have a huge impact on an athletic performance. There are other smart textile fabrics that can protect the wearer from dangerous environmental threats such as space travel effects and radiation. Bend can also be sensed by textile sensors by detecting the fabric being shortened or stretched which is calculated by evaluating the percentage of change in electrical resistance. Many studies have used textile sensors to detect the curvature of the back (Lorussi et al., 2004; Mattiman et al., 2007; Rajdi et al., 2012; Sardini et al., 2015).