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Mobile System for the Prevention, Diagnosis, and Personalized Treatment of Neck Pain Under a Patient's Everyday Life Circumstances

Abstract: This work presents a new system concept for the prevention, diagnosis and interactive treatment of neck pain. It comprises two measurement units worn at the head and the torso, a smartphone/tablet and a medical assistance software. The system aims to provide mobile measurement of full neck movement including rotatory and translatory movements under a patient's everyday life circumstances. Multiple features including biofeedback and therapy exercises are intended to be individually configurable according to the specific medical indications of the patient. In addition to the system concept the current implementation state comprising the two measurement units and a visualization app running on a tablet is presented.

Keywords: Neck pain, interactive therapy, biofeedback, inertial sensors, magnetic field system

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1 Introduction

Chronic or recurring neck pain is a serious and widespread disease: complaints in the neck area are the third most common cause of chronic pain in Europe [2]. The main reasons for neck pain lie in the lack of movement and rigid neck posture in monotonous activities e.g. during work with computers and the prolonged use of smartphone or tablets. However, currently no technical devices exist which provide the acquisition of a person's neck posture and movement under conditions of daily life. Existing approaches for mobile

measurement of neck movement are mainly based on inertial sensors and thus only provide the acquisition of rotatory, but not translatory movement (e.g. [3, 4]). For the determination of translatory movement including protraction and retraction the position of the head in relation to the torso must be available. Especially during work in front of PC or Laptop monitors, the head is often in a forward position compared to the torso. This pose is disadvantageous for the neck muscles when held over a longer period [5] and thus an important indicator in the assessment of neck pain causes. Available systems which provide full motion acquisition including rotatory *and* translatory movements of the head in relation to the torso are based on stationary components, e.g. multiple cameras or ultrasonic sources with fixed distances to each other [6, 7], and thus not suitable for mobile movement acquisition during a patient's everyday life circumstances.

Therefore, in the research project MEDITHENA funded by the German Federal Ministry of Education and Research (BMBF), a new interactive and personalizable system concept for the prevention, diagnosis, and therapy of neck pain is proposed which provides full neck movement acquisition including both rotatory and translatory movements. Section 2 of this paper describes the full system

Figure 1: System design comprising the measurement system, the mobile terminal and the medical assistance software

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concept comprising all targeted features and interactions. In Section 3, the current state of implementation including the two units of the measurement unit and a tablet app for motion visualization are described.

2 System Concept

The overall, final system concept includes two wearable measurement devices, a smartphone/tablet device and a medical assistance software (s. Fig. 1). It interacts with the patient bidirectionally, i.e. it outputs information and signals to the patient and also captures information coming in from the patient.

2.1 System components

The *Measurement system* consists of a device worn at a person's head and a device worn at a person's torso. These two devices, referred to as *head unit* and *torso unit*, provide the posture and movement of the head in relation to the torso based on a novel motion capture method employing inertial and magnetic field sensors and a magnetic field transmitter. Both the head and the torso unit contain a set of 3D-accelerometer, 3D-gyroscope and 3D-magnetometer enabling the determination of 3D-orientation of the head and torso. The determination of the head's 3D-position in relation to the torso is based on the sinusoidal magnetic field generated by the transmitter. The frequency of the coil stimulation signal is used to distinguish the coil generated field from other magnetic fields in the surroundings, e.g. the earth magnetic field or the magnetic fields generated by electrical devices. In contrast to standard positioning methods which require a transmitter comprising three orthogonal coils [7] the transmitter in this system concept consists of a single coil only thus facilitating a portable low power realization of

the transmitter. Despite the use of a single coil transmitter the 3D-position is determinable based on the data of a single 3D-magnetometer whereas existing research methods employing a single coil transmitter rely on multiple sensors having a fixed spatial relationship to each other [8, 9]. This is achieved by performing a coherent demodulation algorithm to obtain the amplitudes of the coil related field components. Based on these amplitudes and the relative 3D-orientation between head and torso unit the 3D position of the head unit in respect to the torso unit can be determined applying a dipole approximation of the magnetic field [8].

Both measurement units are battery driven and contain a radio interface for wireless data transmission. In addition, the torso unit contains a vibration motor which can be employed for biofeedback signal generation (see 2.2).

The movement data acquired by the measurement system are wirelessly transferred to a *mobile terminal* which can either be a smartphone or tablet. The mobile terminal contains a personalizable app and serves as interface between the measurement system and the patient. Furthermore, the mobile terminal transfers the data received by the measurement system to a cloud server. An application software (executed on PC or tablet) can be employed to process the data in order to generate graphs and statistics containing medical parameters which can be useful in the diagnosis of neck pain and the evaluation of neck mobility (see Fig. 2). This software is referred to as *medical assistance software* and can also be applied to realize tele-monitoring and tele-therapy for patients suffering from neck pain.

2.2 System Interactions

Fig. 3 shows an overview of the interactions between the

Figure 2: Diagnosis support through offline processing of the long term data captured on the cloud server

Figure 3: Interaction between the system, the patient and the doctor/therapist

system, the patient and the doctor or therapist. The neck movement acquired by the measurement system can be visualized on the display of the mobile terminal in real-time. This can be helpful especially during set up of the overall system to verify correct operation of the measurement units and e.g. to check a person's currently achievable range of motion. The acquired movement data is processed in real-time by the mobile terminal to determine lack of neck movement or disadvantageous posture over a predefined time period. If one of these cases applies, the patient is either warned by an acoustic signal or vibration produced by the mobile terminal (s. Fig. 4).

Alternatively, the warning can be signalled by activation of the vibration motor contained in the torso unit. This *biofeedback* feature helps to avoid the arising of neck pain due to neck muscle stiffness and also aids in increasing the patients awareness regarding the need for regular movement and posture variation.

The app of the mobile terminal allows the patient to record voice memos in order to document his or her momentary pain level or to mark special activities during the day (e.g. sport, work, driving etc.) which may have relations to the causes of neck pain. The recorded voice memos are saved with time stamp and can later be used to evaluate the neck posture and movement data shortly before the emergence of neck pain to determine possible pain causes. As an alternative to the voice memo the patient can tap with the hand against the torso unit to indicate situations with increased neck pain (*pain tapping*). The tapping event is registered by the torso unit through processing of the acceleration data measured by the integrated 3D-accelerometer. The pain tapping can especially be helpful in situations where the mobile terminal is not reachable, e.g. given in case the use of a smartphone is prohibited in the work environment.

The system also provides personalizable interactive *therapy guidance*. The mobile terminal app contains several

therapy programs which can be activated individually by the doctor or therapist. Each therapy program visualizes a certain therapy exercise, either directly on the display of the mobile terminal or displayed on the display of a larger monitor, e.g. a TV, through streaming functionality of the mobile terminal (see Fig. 5). After each exercise visualization, the patient is encouraged to repeat the movement. The measurement system captures and evaluates the movement of the patient during the exercise and gives appropriate feedback.

All data captured by the system during application, including motion data, therapy results, pain events and biofeedback events, are made available to the doctor or therapist via the medical assistance software. Different statistical evaluations and graphical visualizations support the doctor or therapists in the assessment and treatment of neck pain causes.

3 Prototype Realization

As a first step towards concept realization and validation the head and torso unit of the measurement units were realized in form of hardware prototypes. Both units contain a rechargeable battery, a microcontroller, a Bluetooth radio module and a sensor consisting of a 3D-accelerometer, a 3D-gyroscope and a 3D-magnetometer. The torso unit additionally contains the cylindrical coil used for magnet field generation. In the current state of development the coil is connected to the hardware circuit board via cables. It has a length of 4cm and a diameter of 1cm and can be worn at the torso using an elastic belt (s. Fig. 6). In the next prototyping version the coil will be integrated onto the hardware circuit, and the torso unit will be directly attached to the skin via glue pads.

The head unit has a diameter of 3.5cm and a height of 0.5cm and can be worn at the head also by a belt (s. Fig. 6).

Figure 4: Prevention of neck pain through biofeedback signals in case of rigid posture (e.g. during work with a PC)

Figure 5: Interactive therapy exercises guided by the system and displayed on the monitor of a TV per streaming

Figure 6: Current prototype realization of the measurement system and the mobile terminal

The software embedded on the microcontrollers of the head and torso unit determines the 3D-orientation of each unit by performing a data fusion algorithm [10]. The head unit transmits its 3D-orientation and sensor data to the torso unit via Bluetooth. The torso unit uses its own data and the data received from the head unit to calculate the 3D-orientation and 3D-position of the head unit in relation to the torso unit based on the procedure described in 2.1. The processed data is transmitted to a tablet via Bluetooth. The tablet app is able to visualize the 3D-orientation of the two units as well as the 3D-position of the head unit in relation to the torso unit in real time. The overall latency between real movement variation and the corresponding change in visualization is less than 150ms and can be further decreased by using higher coil and sample rate. The movement visualization indicates good agreement with the proceeded movement. However, for evaluation of the orientation and position accuracy comprehensive verification tests are necessary.

4 Conclusion

A new system concept for mobile acquisition of neck movement enabling the diagnosis, prevention and interactive therapy of neck pain has been proposed. Part of the concept could already be put into praxis: this includes the two units of the measurement subsystem as well as the wireless data exchange between the mobile devices and the mobile terminal. In addition, the real-time 3D visualization of the movement between head and torso was implemented on the mobile terminal. The gathered data indicates reliable and plausible measurements.

In the next steps of concept evaluation, the accuracy of the measurement system is verified using a Vicon system as reference. Next, the measurement units are further miniaturized to enable long term measurements of neck movement of probands. Furthermore, the interaction applications described in 2.1.2. are going to be implemented and evaluated.

Author Statement

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