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MOTION ANALYSIS TOOL FOR DIAGNOSIS OF ORTHOPEDIC DISORDERS

NÁSTROJ PRO ANALÝZU POHYBU PRO DIAGNOSTIKU ORTOPEDICKÝCH PORUCH

Abstract

Rehabilitation after invasive surgeries of large joints is a necessary part of a convalescence process. In clinical practise, the rehabilitation results and its course are assessed by the subjective view of the attending physician and the evaluation depends on the amount of his experience. The modern trend is to supplement this view with measured data and metrics, which objectively assess the course of the convalescence process. This approach is usually implemented by measuring the patient's motion data and creating a computer model, which is then examined. The patient's motion is usually recorded in form of measuring the acceleration of the limb segments, measuring the muscle potential (electromyography) or recording a video with subsequent image analysis. The goal of this work is to create a comprehensive system of objective assessment of the rehabilitation using patient's motion data recording with subsequent analysis of the measured data by classification application. The motion is represented by data from accelerometers placed on flexible bands on the assessed joints supplemented by electromyography signals of the active muscles. The paper contains a brief research of commercially available solutions and a description of the proposed device that will be tested in clinical conditions. The device is in the development phase.

Abstrakt

Rehabilitace pacientů po invazivních operacích velkých kloubů je nezbytnou součástí rekonvalescenčního procesu. V klinické praxi jsou její výsledky a průběh posuzovány subjektivním pohledem ošetřujícího lékaře a vyhodnocení je závislé na jeho předchozích zkušenostech. Moderním trendem je doplnění tohoto pohledu o naměřená data a metriky, popisující objektivně vývoj rekonvalescence. Tento přístup bývá realizován měřením pohybových dat pacienta a vytvořením počítačového modelu, který se poté zkoumá. Pohyb pacienta je běžně zaznamenáván formou měření zrychlení segmentů končetin, měření svalového potenciálu (elektromyografie), nebo snímáním a následnou analýzou obrazových dat. Cílem práce je vytvoření komplexního systému objektivního posouzení průběhu rehabilitace s využitím snímání pohybových aktivit pacienta a následným posouzením naměřených hodnot klasifikační aplikací. Pohybová data představují záznamy z akcelerometrů umístěných na flexibilních páscích na zkoumaných kloubech a záznamy z elektromyografie. Příspěvek obsahuje stručnou rešerši komerčně dostupných řešení a popis navrhovaného zařízení, které bude testováno v klinických podmínkách. Zařízení je fázi vývoje.

Keywords

Gait analysis, orthopedic rehabilitation, motion tracking, electromyography, inertial data measurement

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1 INTRODUCTION

Limb movement disorders associated with neuromechanical abnormalities are common symptoms of various diseases, such as cerebral palsy, scoliosis, or stroke. They also commonly occur after traumatic injuries and after invasive musculoskeletal surgeries, such as total knee arthroplasty [1]. Over time, these disorders can cause more serious health complications, such as hypertension (increased muscle tension) and muscle tremors. Furthermore, they can cause considerable pain and discomfort and can reduce the patient's quality of life [2].

The analysis of these disorders is an important part of postoperative convalescence and its objective assessment can have a major impact on the course of rehabilitation and the possibility of the patient's return to a normal life. In today's practice, this assessment is performed mainly by subjective clinical examination and its accuracy depends mainly on the amount of experience of the performing physician [3]. An incorrect diagnosis and improperly chosen rehabilitation course can significantly reduce the effectiveness of the treatment, in extreme cases can even cause a worsening of the patient's condition and prolonging of the recovery phase.

The goal of this work is to design a comprehensive system for the diagnosis of limb movement disorders enabling objective and systematic assessment of rehabilitating patients after orthopedic procedures, especially after large joints surgeries (total knee/hip endoprothesis, etc.).

2 CURRENT STATE OF KNOWLEDGE

A number of authors are currently studying motion activities for the purpose of diagnosis and movement diseases research. An example of the use of motion activity sensing for diagnostic purposes is the system for early detection of incipient dementia from gait analysis and measurement [4] using, among other things, the commercial device Optogait, which uses non-invasive optical sensing to measure various gait parameters – gait speed, stride length, stride widths, etc.. Another example is the system for accurate detection of Parkinson's disease using 1-D convolutional neural network [5]. The system uses the measurement of the so-called vertical ground reaction force (VGFR), i.e. the forces exerted by the ground plane acting on the body in the vertical direction upwards. It uses 18 force sensors and processes their outputs with a convolutional neural network. An example of the improvement and increase of objectivity of diagnostic procedures used in medicine can be the iTUG system [6], which introduces accurate measurement and separation of components of the TUG diagnostic test (timed up and go) – a simple test of patient mobility and stability. The iTUG system uses data from inertial sensors (accelerometers and gyroscopes) to accurately distinguish the phase of the TUG test being performed. The analysis of data from inertial sensors is also dealt with in the paper [7], in which the authors assess the risk of falls and injuries in geriatric patients. The authors of the paper [8] propose a solution for a system for the assessment of the course of rehabilitation. Their proposed system uses data from accelerometers and analyses them using convolutional neural network.

Some authors use existing and commonly used technologies, such as the authors of the system for evaluating the mobility of the patients with Alzheimer's disease using a smartphone with the Android operating system [9]. The system uses data from the smartphone accelerometer attached to a patient's belt. Other authors, for example, use the popular motion tracking sensor Kinect used in gaming consoles [10]. They use it perform rehabilitation exercises. It is especially useful for pediatric patients because it keeps their attention thanks to the funny and interesting pictures. Others use the Kinect for a so-called telerehabilitation system [11] for rehabilitation from the comfort of the patient's home. The physician examines the patient using a webcam and the data from the system transmitted over the internet.

Currently, there is a number of devices on the commercial market used to measure and analyze the motion data. A brief overview of the available solutions in summarized in the following table.

Tab. 1 Overview of commercial solutions – taken from [12].

System	Motion tracking technique	Details
3-D Gait	Optical tracking, uses point markers on the patient's body (20 to 30 markers). Patient walks on the treadmill.	The markers placement is time consuming and it must be performed accurately for the sake of repeatability. Relatively high price.
PediGait	Optical tracking using 4 cameras and a laptop. Patients walks on the treadmill.	The movement is tracked from 4 sides. The recording can be examined later. The physician can slow it down and zoom in for the detail. The system does not provide any motion data is form of measured or computed features. Low price.
Xsens Out-Walk	Inertial sensors. Wireless data transmission. Uses 17 sensors.	The whole-body motion analysis. The sensor placement on the body is critical – offsets and errors occur in the computed 3D model if placed incorrectly. Limited battery life.
iSen	Inertial sensors. Wireless data transmission. Uses up to 14 sensors.	The sensor placement on the body is critical – offsets and errors occur in the computed 3D model if placed incorrectly. Limited battery life.
GAITRite	Pressure measurement on the walking pad. Uses a matrix of 18432 pressure sensors on a 61x488 cm mat.	Measurement of spatial and kinematic data of the patient's gait.
Optogait	Optical tracking	Measurements of stride length, speed and acceleration can be obtained in real time. Does not track the joint trajectories. Not suitable for the whole-body analysis.

The table shows that none of these systems use data from multiple independent sources. Thus, they are not hybrid systems (data from multiple sources, such as electromyography + optical tracking) and it is not possible to perform a comprehensive analysis of the musculoskeletal system during the performed movement.

3 LIMB MOVEMENT ANALYSIS

To assess the functionality of the patient's musculoskeletal system and the correctness of his movement during the postoperative recovery, it is necessary to create a 3D computer model of his movement in real time and then examine it. The recorded model must be sufficiently accurate, because even small variations of the model's position from the patient's actual position can, for example, inaccurately signal a movement defect or, conversely, erroneously signal that the patient's movement is improving.

3.1 HW part of the system

To record sufficient data on the patient's movement for subsequent evaluation and analysis by a physician, it is necessary to develop a comprehensive system that records and captures all important parameters of movement non-invasively, accurately and reproducibly. When using contact sensors (sensors in contact with the patient's body) for measuring the movement activities, i.e. accelerometers or electromyography (EMG) signal sensors, it is of great importance that the system is designed in such a way that does not restrict the patient's movement as it will be fully attached to his body. The overall electrical safety of the system must be also taken into account in the design phase and the system must comply with the regulations of the design of medical devices [13].

At the same time, these devices must always be designed and configured to fit a specific disease, preferably after consultation with physician with expertise in the field, as the device must focus on specific deficiencies in which specific muscles are used.

The following picture illustrated the block diagram of the proposed system with the arrangement of individual elements.

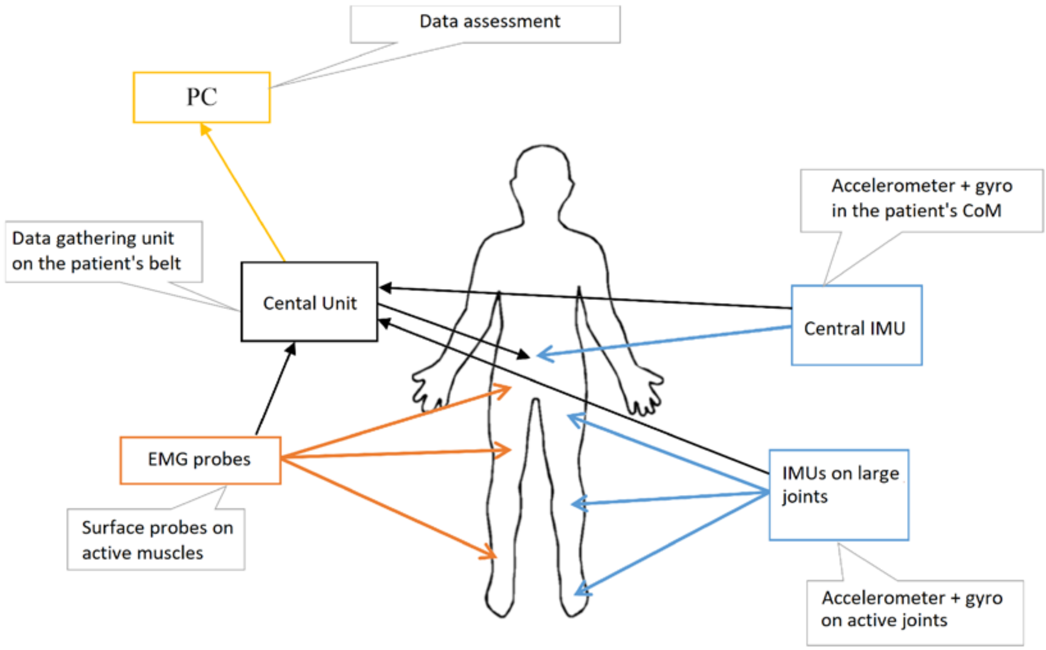

Fig. 1 Proposed system of movement analysis

In the first version, the proposed system will contain a central control unit, controlled by a microcontroller with an ARM core, which will provide the function of data collection from inertial sensors and from the analog front end of the EMG system. The unit will also provide storage of the measured data for the later transmission and representation of data in a computer. Data transfer to the PC will be handled by cable or removable SD card after the measurement is finished.

Measurements of kinematic data of patient's movement will be provided by inertial units (IMU), which will be placed on flexible straps on the joints of the examined limbs. Communication of the IMU with the central unit will be handled using some form of serial link (SPI or I^2C) and to ensure the comfort of the patient when moving, it will be necessary to design a compact cable connection system of the IMUs to the central unit. Proposal of solution of the problem with poor reproducibility of the measurement caused by ambiguous placement of the sensors will be part of the final work. The following picture depicts the test station for accelerometric measurements.

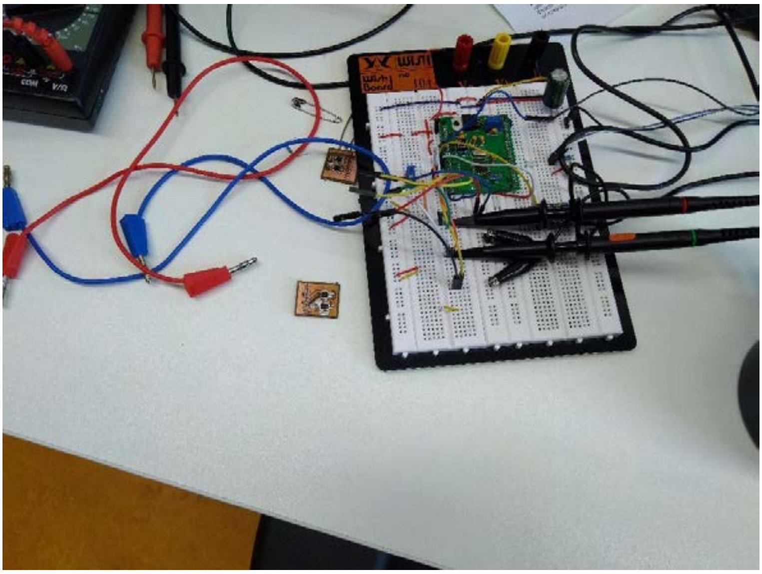

Fig. 2 Test station for accelerometric measurements.

The measurement and digitization of the EMG signals will be provided by an analog front end system consisting of self-adhesive surface mount EMG probes, differential amplifiers, filters and AD converters. The amplifiers will include a circuit for the common mode noise signal filtering – the so-called right leg drive circuit [14]. Great demands will be placed on this system in terms of signal acquisition and processing accuracy and resistance to external interference. The result from the system for the EMG signal measurements will be verified and compared with the results from the commercially available device Go Direct ECG, which in addition to ECG measurement and heart rate computation can also be used to record EMG signals. These signal can be processed in the included Graphical Analysis 4 computer application. The Go Direct ECG set is illustrated in the following picture.

Fig. 3 Go Direct ECG – biopotential measurement unit

After the evaluation of the functionality of the first version, a second version will be implemented, which will decentralize inertial measurements and which will use a wireless data transmission. In the second version, the central unit form the first version will only provide the measurement and digitization of EMG signals. Inertial units will be equipped with their own microcontroller – some of the available wireless MCU solutions will be used (Bluetooth/OpenThread). In this way, it will be possible to reduce the amount of cabling attached to the patient's body only to the terminals of the EMG probes. In this version, the central unit will also be equipped with circuits for wireless communication. Wireless data transmission will allow the reconfigurability of the entire system according to the specific needs of the disorder under study, as it will be possible to select the number of inertial sensors used. This will ensure the applicability of the system for the diagnosis and assessments of a broad range of musculoskeletal disorders.

The concept of the final version of the hardware part of the system is designed to be fully modular, with the possibility of adding a part for the analysis of the upper half of the body in the future. The wireless central unit (in the final version serving only as an EMG signal processor) will be designed for a larger number of connectable EMG probes, or two or more units will be connected to the system. The system will only need to be supplemented with additional inertial units.

The power delivery of both versions of the system will be handled by batteries. In the first version of the system, one accumulator will be located in the central unit, from where the other subsystems will be powered. In the second version, each independent subsystem will be equipped with its own battery. This will result in a great demands for low power consumption of individual parts of the system and the subsystem themselves (IMUs and EMG sensors).

3.2 SW part of the system

Simultaneously with the development of the hardware part of the system, the development of a computer application for the reception, processing and representation of the measured data will take place. The application will have a clean and easy to use user interface and it should be easily used by clinical staff without much experience with working with a PC. The application will provide means of establishing and management of the communication with the hardware part of the system. In the first version, the application will communicate with the central unit using a USB cable or SD card. In the second version, the computer application will provide a function of central element in the star topology wireless network. In this role, in addition to receiving measured data, it will also manage the transmission of time synchronization packets to individual parts of the system (EMG units, IMUs).

From the data from the inertial sensors, a 3D model of the patient's movement will be created, on which it will be possible to examine the course of his gait in time and it will also be possible to measure various gait parameters, such as speed, stride length, etc. It will also be possible to determine individual phases of the gait and to recognize movement abnormalities from this model.

Data from EMG signal measurements will be used to record muscle activity during the gait and they will be displayed synchronized with the inertial data of the 3D model. In this way, it will be possible to link the EMG signal with the currently performed gait phase. The EMG signals will be displayed similarly as in the Graphical Analysis 4 application [15]. Furthermore, it will be possible to determine and calculate individual EMG features from the measure data, such as in the paper [16]. Based on these features, it is, for example, possible to determine the degree of muscle activation and compare it between the rehabilitation sessions. The output of the Graphical Analysis 4 application is depicted in the following figure.

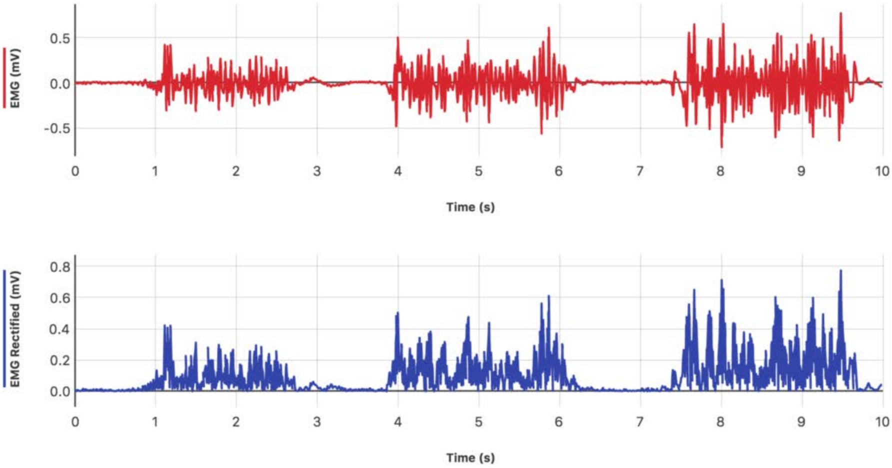

Fig. 4 Graphical Analysis 4 output – EMG measurement

The computer application will also contain a database system to record individual measurements among patients from all of the rehabilitation sessions. This will enable comparison of results between individual phases of the recovery process. Based on this comparison, the physician will be able to determine whether the chose method of rehabilitation is beneficial and it will be possible to determine whether the patient's physical condition improves or worsens.

Data from EMG signal measurements will be used to record muscle activity during the gait and they will be displayed synchronized with the inertial data of the 3D model. In this way, it will be possible to link the EMG signal with the currently performed gait phase. The EMG signals will be displayed similarly as in the Graphical Analysis 4 application [15]. Furthermore, it will be possible to determine and calculate individual EMG features from the measure data, such as in the paper [16]. Based on these features, it is, for example, possible to determine the degree of muscle activation and compare it between the rehabilitation sessions. The output of the Graphical Analysis 4 application is depicted in the following figure.

4 CONCLUSION

The aim of the paper was to compile a comprehensive research of the topic of sensing kinematic motion data and EMG signals for use in diagnosis and rehabilitation. A research of clinically used commercial equipment dealing with similar topics and their comparison is part of this paper.

Furthermore, the aim was to present the proposed concept of a comprehensive solution which is being created in cooperation with the Orthopedic and Traumatology Clinic of the Královské Vinohrady University Hospital, Prague, which focuses on rehabilitation of patients after large joint surgeries (total endoprosthesis, pelvic fracture, meniscus surgery, etc.) The proposed system aims to provide and objective assessment of the patient's condition after surgery and during recovery.

In the following period, the first prototype of the device will be completed (cable design of the communication) and testing and verification will take place in the laboratory and in the clinical environment of the Královské Vinohrady University Hospital.

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