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Movement quantification in epileptic seizures: A feasibility study for a new 3D approach

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ABSTRACT

Movement quantification of the human body is presently used for analyzing deficits resulting from Central Nervous System (CNS) pathologies or exploring the insights of the human motor system behaviour. Following our previous work on 2D movement quantification of epileptic seizures, we now present a feasibility study for a newly developed 3D technique. In order to validate this new 3D approach we made a comparison with the previous method. Both techniques were tested in two different datasets: a simple motor execution performed by a volunteer and a complex motor motion induced by a real epileptic seizure. The results obtained showed, as expected, the superior robustness and precision of the 3D approach but also confirmed the validity of the 2D method, given certain constraints. We conclude that the newly developed 3D system will highly improve our capacity of pursuing the clinical research on quantitative characterization of seizure semiology to support epilepsy diagnosis.

1. Introduction

Movement quantification of the human body has been used for analyzing deficits resulting from Central Nervous System (CNS) pathologies [1,2] or exploring the insights of the human motor system behaviour [3,4]. This topic acquires an enhanced impact in the study of epileptic seizures semiology. Presently the differential diagnosis of epilepsy is based on the analysis of the EEG and video [5,6]. The extraction and quantification of the EEG features has been successfully optimized due to the growing evolution of the algorithms applied. Although movement is very important in the diagnosis of epilepsy [5,7], its clinical use relies on qualitative analysis that is reported to have poor inter-ratter reliability [8]. Furthermore, quantification of video in epilepsy is still rare due to, in the one hand, the enormous demand from computers in capturing, storing and processing video data and, on the other hand, the fact that many traditional video monitoring units still rely on analogue video recording devices which are an obstacle in terms of image analysis. Nevertheless, this quantification can be of enormous impact to support epilepsy diagnosis. Our research group proposed two different 2D approaches to movement quantification of epileptic seizures. In our first proposal to use motion capture in epilepsy we developed the QMovES framework that allowed the extraction of quantified information of a seizure motion through video processing techniques over data acquired by a commercial video–EEG system using an infra-red video camera. In this 2D approach we used infra-red reflective “blobs” attached to 22 landmark position on the patient’s body [9]. A modified version was later introduced for a different geometric model that allowed patients to be either sited or lying down on the monitoring bed, with or without markers [10,11]. This approach enabled us to perform several clinical studies [11–13]. For example, we proved this technique reliability and clinical use by studying quantitatively the lateralizing significance of ictal head movements of patients suffering from temporal lobe epilepsy (TLE) [12,14]. In that study, a markerless approach was performed so that videos from three different Epilepsy Monitoring Units (EMU) from two countries (and continents) could be used. Other clinical studies have been performed with this technique [13,15–17] that is inserted in the routine of the EMU of the Grosshadern University Hospital, in Munich.

Nevertheless, we have identified some noteworthy pitfalls in our 2D methods, caring for improvement, namely:

(1) Using a single camera means we can only have high precision in measuring translational motion (parallel to the image plane) and depth information is not accurate.
(2) Self-occlusion is also a problem since patients move quite erratically during seizures and can hide markers from camera view resulting in incomplete data for the motion quantification task.

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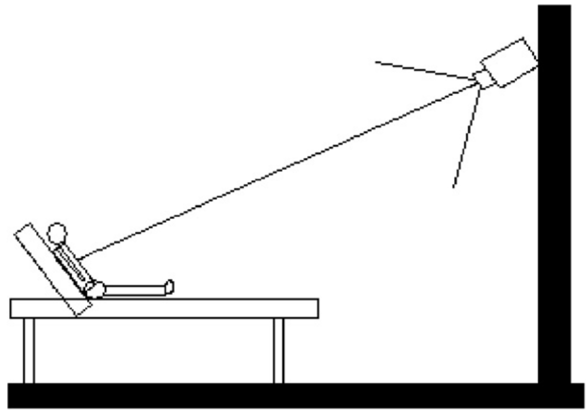

Fig. 1. 2D video setup geometric model.
Adapted from Re. [9].

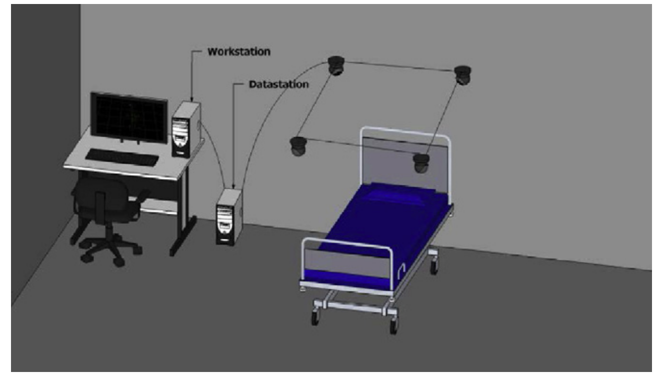

Fig. 2. System setup with the 4 high-speed SVCams to achieve a 3D motion tracking system for seizure movements. A datastation processes the massive information coming from the cameras and feeds pre-processed data to the workstation where the MOIs are analyzed.

(3) Patients need immediate medical attention when having a seizure. A typical scenario is that the technician or nurse, when treating the patient, crosses his body in front of the camera occluding the patient's motion of interest (MOI).

In response to these problems we have developed and implemented a novel system integrating high resolution EEG with a 3D motion capture system (that we called MovEpil3D), allowing a multi-angle, high frame rate and high precision analysis of the patient's movements during epileptic seizures.

In this paper we compare and present clear advantages of this new 3D approach over the previous 2D we have been using for some years. We will address only the movement quantification aspects, leaving the multimedia synchronization with EEG aspects for another paper.

2. Methods

2.1. The framework and experimental setup

The video–EEG system used in the 2D quantification method is based on the most common one found in many EMUs around the world, and follows our previous 2D system as depicted in Fig. 1. For a detailed description please refer to [9,10]. The 2D experimental setup is composed by a video camera (¼″, color/infra-red sensitive VC Videocomponent GmbH, Neumünster, Germany), with 640×480 pixels resolution acquired at 25 fps rate, with its direction and zoom adjusted to ensure that the patient, while in the bed volume, remained always in the field of view.

The 3D optical motion capture system is composed by 4 high-speed (200 Hz) infrared motion-tracking SVCams (Vicon plc., Oxford, UK), disposed as shown in Fig. 2. These cameras are connected to a datastation unit that pre-processes the camera outputs and feeds the user workstation for further analysis. The calibration of the cameras is performed automatically using a delta shape object with three infrared reflective markers placed in the center of the bed and a calibration "wanding" procedure as specified by the system vendor. If correctly calibrated the system has a spatial resolution of approximately 0.5 mm^3 [18]. The movement information was synchronized with the video–EEG data through a custom hardware, firmware and software system that is out of scope of the present paper.

In order to quantify the movement of the subject, a set of spherical infrared reflective markers was attached to anatomic points of the patient following the setup shown in Fig. 3. This setup was designed to have symmetry combinations so that it gets easier to recognize the body positions once the tracking is performed, as this task is done over high reflection image pixels segmentation.

With the positioning of these markers, we are able to correctly quantify the motion of the upper and lower arms, thorax, head and the upper and lower legs. These positions will correspond to the different body segments, allowing us to obtain the 3D movement trajectories used in the quantification of the seizure.

Each marker trajectory can be projected in each of the three orthogonal planes of the scene (x–y, x–z and y–z). To analyze motion as a global variable, we generated movement quantification data of the different body segments through the Euclidean distance between a marker position in each frame and the position of the same marker in the first frame, in the 2D and 3D situation. Eqs. (1) and (2) reflect the calculations performed for 2D and 3D, respectively.

$$Distance\ 2D_i = \sqrt{(x_i - x_0)^2 + (y_i - y_0)^2} \tag{1}$$

$$Distance\ 3D_i = \sqrt{(x_i - x_0)^2 + (y_i - y_0)^2 + (z_i - z_0)^2} \tag{2}$$

where $i = 1, 2, \ldots, N$; $N = Number\ of\ frames$.

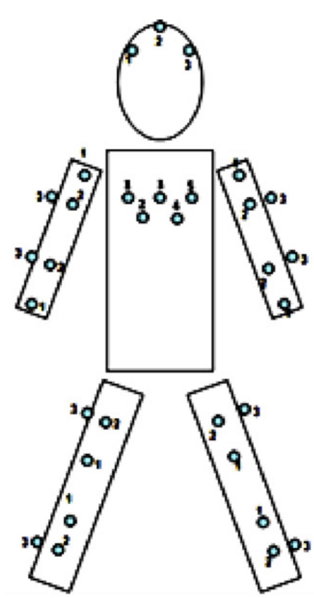

Fig. 3. Setup of the infrared reflective markers placed on the patient/subject.