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NeuroKinect 3.0: Multi-Bed 3Dvideo-EEG System for Epilepsy Clinical Motion Monitoring

Hugo Miguel Pereira Choupina[a] Ana Patrícia Rocha[b] José Maria Fernandes[b]
Christian Vollmar[c] Soheyl Noachtar[c] João Paulo Silva Cunha[a,1]
[a]*Institute for Systems Engineering and Computers – Technology and Science (INESC TEC), and Faculty of Engineering (FEUP), University of Porto, Porto, Portugal*
[b]*Institute of Electronics and Informatics Engineering of Aveiro (IEETA), and Department of Electronics, Telecommunications and Informatics, University of Aveiro, Aveiro, Portugal*
[c]*Epilepsy Center, Department of Neurology, University of Munich, Munich, Germany*

Abstract. Epilepsy diagnosis is typically performed through 2Dvideo-EEG monitoring, relying on the viewer's subjective interpretation of the patient's movements of interest. Several attempts at quantifying seizure movements have been performed in the past using 2D marker-based approaches, which have several drawbacks for the clinical routine (e.g. occlusions, lack of precision, and discomfort for the patient). These drawbacks are overcome with a 3D markerless approach. Recently, we published the development of a single-bed 3Dvideo-EEG system using a single RGB-D camera (Kinect v1). In this contribution, we describe how we expanded the previous single-bed system to a multi-bed departmental one that has been managing 6.61 Terabytes per day since March 2016. Our unique dataset collected so far includes 2.13 Terabytes of multimedia data, corresponding to 278 3Dvideo-EEG seizures from 111 patients. To the best of the authors' knowledge, this system is unique and has the potential of being spread to multiple EMUs around the world for the benefit of a greater number of patients.

Keywords. Epilepsy, 3Dvideo-EEG, Kinect v2, Big Data, Epilepsy Monitoring Unit, RGB-D Camera.

1. Introduction

Epilepsy is a neurological disorder that affects 0.5-1% of the world population [1]. Seizure semiology and electroencephalogram (EEG) are considered the cornerstone of epilepsy diagnosis. Despite the establishment of quantitative methods for EEG analysis, most epilepsy monitoring units (EMUs) still rely on visual inspection of 2Dvideo-EEG data of epileptic seizures. This can be a rather subjective method, since it is based on the viewer's interpretation of the patient's movements of interest (MOIs).

Our group has been conducting multiple studies to quantify seizure movements [2; 3]. We started with 2D marker-based approaches, which were latter used to demonstrate the clinical relevance of motion analysis in epileptic seizures [4]. Nonetheless, the

[1] Corresponding author: João Paulo Silva Cunha. Rua Dr. Roberto Frias, 4200 Porto, Portugal. E-mail: jcunha@ieee.org.

limitations of a 2D approach were multiple (i.e. marker occlusions, patient discomfort, lack of precision), which motivated us to develop a 3Dvideo-EEG system.

Recently, we published in *PLoS One* the development of a 3Dvideo-EEG system using a single RGB-D camera, namely a Kinect v1, installed over one bed of an EMU [5]. This study showed that RGB-D cameras mounted on the ceiling of the patient's room provide a comfortable, non-intrusive way (for both physicians, technicians and patients) of acquiring reliable 3D patient motion information.

Following the success of the above-mentioned 3D approach, we report in this contribution a Kinect v2-based three-bed 3Dvideo-EEG system, which is an evolution of our previous single-bed system.

2. Methods

2.1. System Architecture

The architecture of the multi-bed 3Dvideo-EEG system is depicted in Figure 1. Each Kinect v2 is connected to an acquisition PC running *KinecTracker* (*KiT*), a custom software that handles all the 3D information acquired from the sensor [6]. Time synchronization is obtained for all beds using the network time protocol (NTP). Each acquisition PC is connected to a 10-terabyte storage system through a high-speed gigabit Ethernet cable, allowing to continuously acquire data 24/7 during one full week (168-hour buffer).

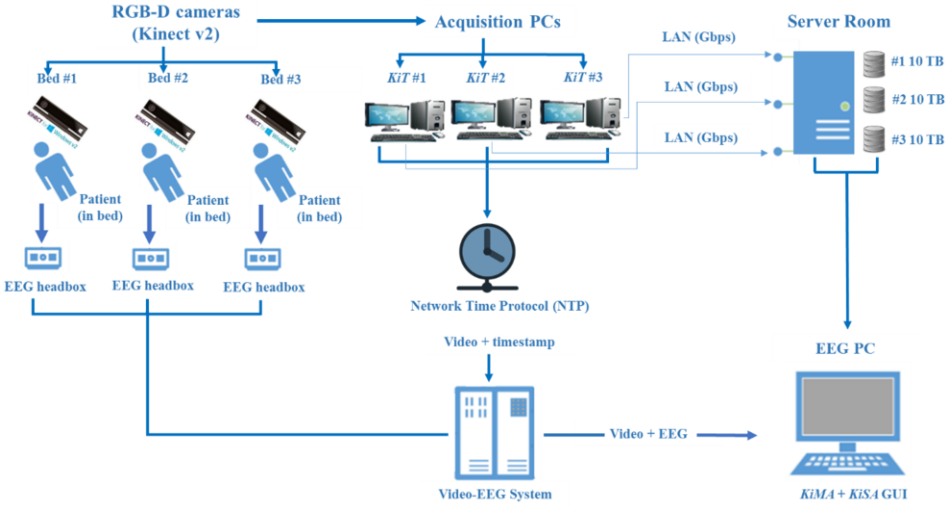

Figure 1. Architecture of the NeuroKinect multi-bed system deployed at the University of Munich's EMU.

2.2. System workflow

Figure 2 presents a footprint scheme of the three-bed system deployed in the EMU unit.

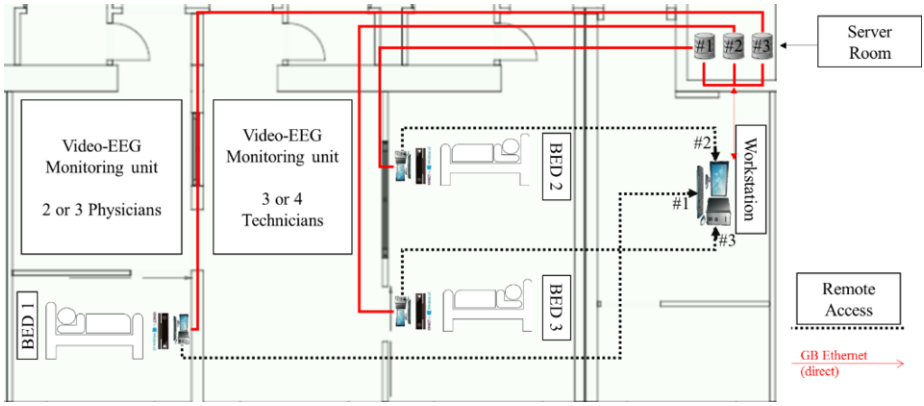

Figure 2. Footprint scheme of the three-bed system deployed in the EMU unit.

Custom-made pipelines were developed to automatically transfer the Kinect data from the acquisition PCs to the server every minute during the data acquisition, as well as manage the buffer storage. Furthermore, whenever a seizure occurs, an e-mail with the seizure information (i.e. seizure date and the clinical beginning and end timestamps) is sent to the research team (physicians and engineers) so that the seizure data is latter correctly exported.

The exportation of the motion information corresponding to a seizure consists in transferring the associated data from the server to the workstation (Figure 2), and storing it in a database. The data can then be edited and analyzed using two custom-made software applications: *KiMA* (*Kinect Motion Analyzer*) and *KiSA* (*Kinect Seizure Analyzer*).

Kinect v2 provides multiple streams of information including high-resolution 1920×1080 color images, 525×424 depth and infrared streams, and 3D body joint information, at a 30 frames per second. This generates a throughout of ~12 GB/min. Therefore, we only acquire depth, infrared and body information, which results in a throughput of ~1.6 GB/min.

As in the single-bed first generation system [5], the *KiT* application enables the management of acquisition sessions. A specific workflow for each new patient being monitored is performed (i.e. calibration). *KiMA* is used as a first step of seizure analysis, allowing to review the information acquired with *KiT*, mark and label specific seizure events, and then export the selected information for further analysis using other tools. Patient monitoring using KiT and KiMA was authorized by the hospital's Ethics Committee and all patients have given written informed consent to participate in the study. With the three-bed system, we integrated a new custom-made seizure analysis software (*KiSA)*, which was developed using Matlab. *KiSA* allows performing 3D MOI analysis using our second generation semi-automatic motion tracking algorithm which

was adapted to handle the new information (infrared and depth) now being acquired. Additionally, *KiSA* generates a 3D view of the tracked MOI, as well an automatic report (i.e. MOI quantification statistics and tracings) for each analyzed seizure.

3. Results

Thus far, a total of 2.13 Terabytes from 278 seizures were acquired from 111 patients using our three-bed system. Table 1 shows detailed information on the dataset characteristics, including the number of patients and seizures per syndrome. The syndrome classification (used for diagnosis and personalised treatment plan) was obtained by the agreement of two experienced epileptologists after carefully reviewing the seizure motion videos together with the EEG patterns. Patients are continuously monitored in the EMU (typically for 48-72 hours) until a diagnosis is reached.

Table 1. Characteristics of our unique 3Dvideo-EEG database with respect to the different seizure classification. GTKA stands for generalized tonic-clonic seizures.

Syndrome	# of Patients	# of Seizures
Aura	3	5
Automotor	18	45
Bilateral tonic-clonic	3	3
Clonic	17	27
Complex Motor	8	59
Diapletic	3	3
Dystonia	1	28
GTKA	15	31
Hypermotor	7	18
Hypnopompe	6	7
Tonic	12	18
Psychogenic	1	1
Versive	16	31
Syncope	1	2
Total	**111**	**278**

4. Conclusion and Future Work

In this contribution, we present the evolution of our 3Dvideo-EEG system from a single-bed using a Kinect v1 into a multi-bed system based on the Kinect v2. The new system allows 24/7 monitoring of three different patients simultaneously in an EMU setting, using a low-cost, non-intrusive, markerless, and low-maintenance approach that is suitable for the clinical practice. The use of the Kinect v2 instead of Kinect v1 brings benefits to the system, since it provides better image quality and the new infrared stream enables the analysis of seizures occurring during the night period.

Together with a comfortable acquisition process of seizure information, we have been focusing our efforts in developing tools that allow seizure analysis automation, avoiding the typical manual evaluation, which requires reviewing the seizure video several times. The three-bed system has been in operation since March 2016 and a large 3D seizure dataset was already acquired.

Currently, to the best of the authors' knowledge, this is the only 3Dvideo-EEG database deployed within the routine of a clinical epileptology department. This dataset has great potential for prospect studies in this research field, such as the development of a system for automatic seizure classification (using convolutional neural networks and features derived from 3D seizure motion data), and/or automated detection of seizures. This system could be useful in hospitals, at home or in residential homes to alert for the nurses or relatives of the occurrence of epileptic seizures, potentially helping to reduce the risk of injuries or SUDEP (sudden unexpected death in epilepsy). It would also be important to support the diagnosis of epilepsy, especially in less well trained epilepsy centers and/or centers with limited financial capacity and EMU beds. An H2020 funded research and innovation action (RIA) is being prepared to explore the above-mentioned R&D potential and the authors welcome manifestations of interest from fellow EU researchers.

We believe that the designed approach has the potential of becoming a solution that can be easily spread and deployed in multiple epilepsy units around the world. We are open to discuss details with other EMUs so that these developments are used towards the benefit of the largest number of patients possible.

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