# EPES: Seizure Propagation Analysis in an Immersive Environment

**Zahra Aminolroaya**
University of Calgary
2500 University Dr NW
Calgary, AB T2N 1N4
zahra.aminolroaya@ucalgary.ca

**Samuel Wiebe**
University of Calgary
2500 University Dr NW
Calgary, AB T2N 1N4
swiebe@ucalgary.ca

**Colin Bruce Josephson**
University of Calgary
2500 University Dr NW
Calgary, AB T2N 1N4
cbjoseph@ucalgary.ca

**Hannah Sloan**
University of Calgary
2500 University Dr NW
Calgary, AB T2N 1N4
caelum.sloan@agilesoftwareengineering.org

**Christian Roatis**
University of Calgary
2500 University Dr NW
Calgary, AB T2N 1N4
christian.roatis@ucalgary.ca

**Patrick Abou Gharib**
University of Calgary
2500 University Dr NW
Calgary, AB T2N 1N4
pgabough@ucalgary.ca

**Frank Maurer**
University of Calgary
2500 University Dr NW
Calgary, AB T2N 1N4
christian.roatis@ucalgary.ca

**Kun Feng**
University of Calgary
2500 University Dr NW
Calgary, AB T2N 1N4
fkun1012@hotmail.com



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## Abstract
Planning for epilepsy surgery requires precise localization of the seizure onset zone. This permits physicians to make accurate estimates about the postoperative chances of seizure freedom and the attendant risk. Patients with complex epilepsies may require intracranial electroencephalography (iEEG) to best lateralize and localize the seizure onset zone. Magnetic resonance imaging (MRI) data of implanted intracranial electrodes in a brain is used to confirm correct placement of the intracranial electrodes and to accurately map seizure onset and spread through the brain. However, the relative lack of tools co-registering iEEG with MRI data renders this a time-consuming investigation since for epilepsy specialists who have to manually map this information in 2-dimensional space. Our immersive analytics tool, EPES (Epilepsy Pre-Evaluation Space), provides an application to analyze iEEG data and its fusion with the corresponding intracranial electrodes' recordings of the brain activity. EPES highlights where a seizure is occurring and how it propagates through the virtual brain generated from the patient MRI data.

## Author Keywords
Epilepsy; MRI; intracranial EEG; surgery pre-evaluation; virtual reality; immersive analytics.

## CSS Concepts

• **Human-centered computing → Virtual reality** • Human-centered computing → Scientific visualization • Applied computing → Life and medical sciences

## Introduction

In this paper, we describe an immersive analytics tool, EPES that supports pre-planning of epilepsy surgery by fusing intracranial EEG data with brain MRI scans to help physicians understand how seizures propagate through a patient's brain. Up to two-thirds of patients with epilepsy continue to have seizures despite optimal management with medications. These patients are all candidates for presurgical evaluations and, in properly selected patients about one-half to two-thirds can become seizure free with surgical resection of the region of the brain. Precise and effective preoperative evaluation is essential to optimizing surgical outcomes. IEEG monitoring in pre-surgical evaluation of patients with epilepsy is one way to localize a seizure onset zone and its spread. To record seizures, electrodes are implanted into a patient's brain (intracranial). Grid electrodes are planted in a thin sheet of plastic and placed on the surface of the brain, and depth electrodes are made of thin wire implanted in the brain to pick up signs of seizures.

This research focuses on analyzing seizure based on depth electrodes. Each electrode consists of 4-12 contacts (sensors) recording brain activity at different depths. Analyzing the patient's rendered MRI data showing implanted electrode positions and mentally correlating it to iEEG signals allows a physician to understand seizure onset and propagation. However, using existing tools, the analysis process is time-consuming. It can also be mentally challenging to attempt to visual 2-dimensional information in 3-and 4-dimensional space. By using software applications for analyzing MRI scans, specialists search for suitable Axial, Sagittal and Coronal planes to be able to observe the depth of electrodes and determine seizure sites from different perspectives.

EPES provides an analysis of iEEG data and seizure propagation through the brain by utilizing the MRI scans in a spatial environment and overlaying iEEG in situ. EPES offers the following features to the physician:

- Seizure evaluation before surgery using MRI scans and iEEG data
- Visualizing seizure onset and propagation through a brain
- Fusing iEEG signals with the corresponding electrode contacts in the virtual brain hologram generated from MRI scans
- Realistically modeling frequency and instantaneous amplitude of iEEG signals using shaders in the brain hologram
- Controlling the speed of visualizing the seizure propagation

We expect that our immersive analytics tool can help physicians to pre-evaluate epilepsy before surgery faster and more effectively.

## Background

Different techniques can be used for epilepsy surgery pre-planning. For example, EEG data provides temporal dynamics of neural activities and interactions, and MRI scans demonstrate the localization of neural activities [3].

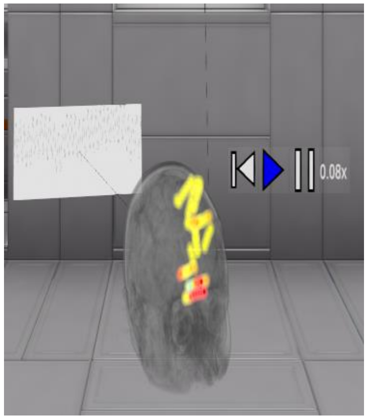


Figure 2: The developed system for epilepsy analysis in an immersive environment. The system provides analysis of the brain produced by MRI scans and iEEG data.

Some software tools are developed to enhance analysis in the field of neurosurgery preplanning. For example, Curry is a tool for multimodal neuroimaging analysis providing solutions for epilepsy investigation such as surgical planning, EEG source estimation, etc. using normal PC screens. This software also provides 3D representations of depth electrodes by marking their precise locations in MRI scans [1]. Curry includes epilepsy propagation analysis using grid electrodes and voltage distribution. EPES focuses on surgery pre-evaluation analysis in an immersive environment based on the intracranial EEG datasets from depth electrodes implanted in the epileptic patient and MRI scans.

Immersive technologies have been used in the field of neurosurgery [5]. Kockro et al. developed a tool for neurosurgical planning using the coregistration of MRI, MRA (Magnetic Resonance Angiography) and CT (computerized tomography) data in a virtual reality environment [2].

BrainX3 [4] focuses on using virtual reality for neurosurgical intervention in epilepsy and specifically iEEG analysis. It identifies the patient brain network using different functional connectivity metrics and fMRI (functional magnetic resonance imaging) data. However, the anatomical structure of the brain and the electrodes' hologram are fixed and independent of individual patient records. Plus, iEEG signals are not shown.

## Approach

The main goal of this research is to develop a system for physicians to enhance epilepsy pre-evaluation before resection using an immersive environment. Immersive environments provide users with 3D visualization and interactions that can facilitate specialists to analyze epilepsy in the brain.

We fuse the following data sets into an immersive analytics visualization (see Figure 1):

- MRI brain scans
- iEEG channels recorded by intracranial electrodes
- location of the electrodes in the brain onset and end of seizures in individual iEEG channels

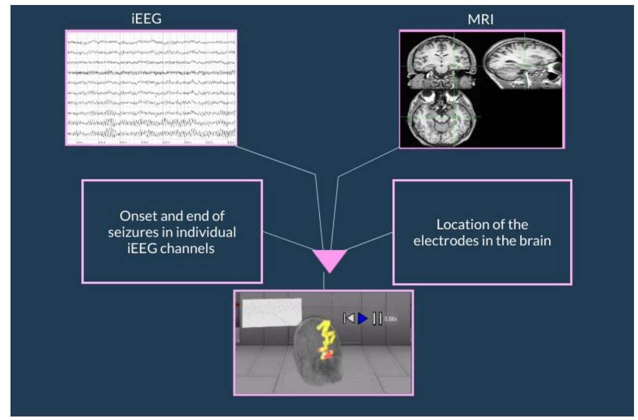


**Figure 1**: The data sets fused into an immersive analytics visualization.

Essentially, by fusing the different data sources, we are creating a 4D spatial-temporal visualization of the electrical activity in the brain – allowing physicians to understand how a seizure propagates through it.

Our immersive application can improve the analysis process by providing an evaluation of patient iEEG signals and a seizure onset and propagation through the virtual brain hologram. The iEEG channels recorded by intracranial electrodes are depicted and the software highlights the electrode contacts involved in seizure onset and propagation. Electrode activity is illustrated by "lights" in a patient brain. When an electrode sensor records seizure, the light hue changes. The hue brightness and light duration correspond to seizure iEEG signal amplitude and frequency. Shaders are used for the visualization seizure propagation.

Each set of iEEG signals is linked to the corresponding sensors of the electrode in the brain hologram, so specialists can correlate the MRI and iEEG modulations providing the spatial brain activity.

Users can control the speed of propagation and also pause the visualization to analyze iEEG channels and seizure location in a specific time step (see Figure 2).

## Data

Our dataset consists of intracranial EEG records, in EDF[1] format, and MRI scans, in DICOM[2] format, related to epileptic patients. As an example, a patient brain with 13 implanted electrodes was chosen. Each electrode for this patient consisted of 4 to 8 contacts. Each contact provides 1 iEEG channel and the data recorded 79 channels. Overall, 31 electrode connections recorded seizures while the remaining showed normal electrical cerebral activity. The MRI scan consists of 176 2D images and is used to generate the brain hologram showing the physical place of electrodes in the patient brain.  The medical co-authors identified iEEG channel segments where seizure started and ended and where depth electrodes' locations are in MRI scans. The patients' datasets were anonymized before being used for application development and visualization.

## Conclusion

We developed an immersive analytics software tool called EPES that helps medical experts more quickly and effectively assess the results of epilepsy pre-surgical intracranial evaluations. The co-registration of the iEEG data with the brain hologram produced by from MRI scans expedites the analytic process. Also, the seizure start zone, propagation, and end location are traced using electrodes in the patient's brain.

## Future Work

We will evaluate EPES using the specialists' feedback to analyze the usability and usefulness of an immersive environment for analyzing epilepsy. If successful, immersive technologies would have many applications in neurology and neurosurgery in the near future. We aim to add automatic seizure detection and an easier way to markup electrode locations to our software to ease physician's work-load.

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