A cardiac electrical activity model based on a cellular automata system in comparison with neural network model

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Abstract: Cardiac Electrical Activity is commonly distributed into three dimensions of Cardiac Tissue (Myocardium) and evolves with duration of time. The indicator of heart diseases can occur randomly at any time of a day. Heart rate, conduction and each electrical activity during cardiac cycle should be monitor non-invasively for the assessment of “Action Potential” (regular) and “Arrhythmia” (irregular) rhythms. Many heart diseases can easily be examined through Automata model like Cellular Automata concepts. This paper deals with the different states of cardiac rhythms using cellular automata with the comparison of neural network also provides fast and highly effective stimulation for the contraction of cardiac muscles on the Atria in the result of genesis of electrical spark or wave. The specific formulated model named as “States of automaton Proposed Model for CEA (Cardiac Electrical Activity)” by using Cellular Automata Methodology is commonly shows the three states of cardiac tissues conduction phenomena (i) Resting (Relax and Excitable state), (ii) ARP (Excited but Absolutely refractory Phase i.e. Excited but not able to excite neighboring cells) (iii) RRP (Excited but Relatively Refractory Phase i.e. Excited and able to excite neighboring cells). The result indicates most efficient modeling with few burden of computation and it is Action Potential during the pumping of blood in cardiac cycle.

Keywords: Arrhythmia, myocardium, electrophysiology, action potential.

INTRODUCTION

Modeling of Cardiac Electrical Activity through Cellular Automata concepts provides an efficient and fast stimulation in comparison of other reaction diffusion models which require huge burden of computational steps with complexity and CA (Cellular Automata) also give face paced time duration with moderate number of neighboring cells alike with CA Neural Network Model also solve the big issues in Cardiac diagrams i.e. ELECTROGRAMS pattern recognition and classification.

Cellular Automata implies on propagation of electrical wave AP (Action Potential) by computation of its prototypical property which gives Virtual Bi-polar and Mono-polar cardiac diagrams. It can simulate through this model at any instance in space with efficient manner.

The main purpose of this research was to plot a model for the implementation of Cardiac Electrical Activity which is capable to compute any complex phenomenon without any large calculations.

Heart has its own existing pacemaker that controls the rhythmic physiological and electrical activity. Heart muscles are myogenic because their contraction rhythmically originating in muscles tissues without any external stimulation. The Contractions of heart chambers initiates by S-A Node thus the S-A node is knows as Pacemaker. This Pacemaker lies in the upper segment of right Atrium. It is made up from combination of specialized cells which are electrical stimulus for every wave of excitation for the contraction of Atria. The S-A node is a stimulus for contraction of heart in the form of signals which are generated when Vena cave pumps the blood and fill the right Atrium from other parts of body. Those signals are cause of contraction of Atria and circulate blood through valves into both of the ventricles (Anonymous, 2011).

Cardiac electrical system of heart

The “Electrical System” of Heart also called the “Cardiac-Conduction System”. This cardiac electrical system manages all the activity that happens during the blood circulation. The Electrical Activity System mainly consists upon three major portions:

- Sinus or S-A Node (Located in specific region of right Atrium close to the point of entry of Superior vane cava)
- Atrio-Ventricular or A-V Node (Present on Inter-ventricular Septum close to Tricuspid Valve)
- His-Purkinje System (lies in along the walls of Ventricles)

The Electrical Conduction System is examined by ECG or EKG i.e. Electrocardiogram which gives a graphical image of heart’s conduction activity (Anonymous 2011).

The Heart pumps blood into the whole body and the Heart muscles contraction in Atria is triggered by an instantaneous swift electrical spark this propagated fast rhythm is called as Action Potential (AP). An

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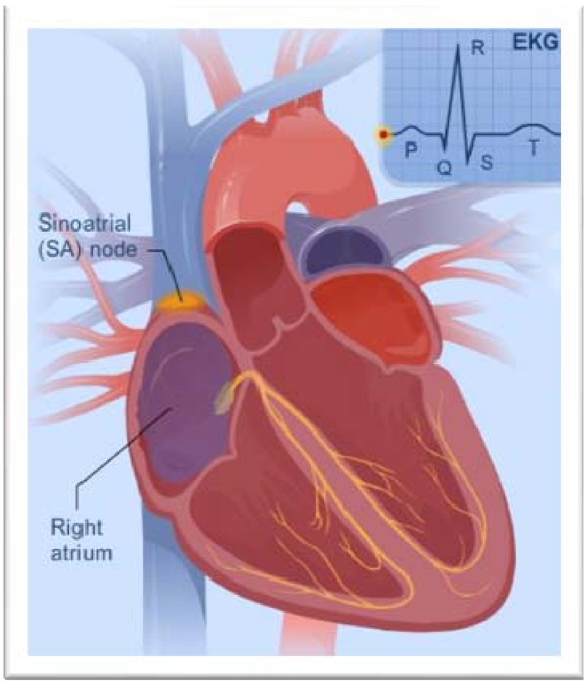
"Arrhythmia" is an abnormal rhythm or fast and irregular rate (speed) of rhythm of the Heartbeat which is basically the contraction of heart muscles.

Cardiac Electrical Activity can also be monitor by artificial pacemaker consists upon a compact electronic device and a source of power which is connected to heart through an electrical wire. It maintains the heartbeat at a regular rate. It is inserted below the skin of chest when Sinus node of a Human do not function properly or when there is some irregular and weak passage of a normal Electrical cardiac rhythm (Gharpure, 1995).



Fig, 1: A Heart Electrical Conduction System showing different parts 1) S-A Node, 2) A-V Node, 3) Bundle of His, 5) Septum, 6) Super Vane-Cava (Anonymous 2011).

Heart muscle (Myocardium) is the medium for excited impulses for the contraction of Atria generated by SA node.

There are several types of Computer simulation models which are used in field of Electrophysiology elucidate and develop a brief understanding of many aspects of Cardiac Electrical Activation. The model which is widely used in cardiology for the Myocardial Electrical Activation is "Cellular Automata".

Advantages of using ca as model for CEA

The core reason to apply Cellular Automata concepts in CEA (Cardiac Electrical Activation) is that it is highly implicated on many aspects like Arrhythmia, Sinus node or Sino atrial node (S-A node) Pacemaker activity, AP (Action Potential) Propagation, Complex Phenomena as Fibrillatory activity also investigated by CA (Clayton, 2001).

In comparison of other methods and models which based on Differential Equations Cellular Automata technique allow fast and high scale stimulations with average risks and very rare load of computation. It is also easy to develop and program.

In cellular Automata Model each of Heart tissue considers as a set of connected discontinuous element. Because Heart muscles are Myogenic; they contract rhythmically within themselves as natural process when bloods pumps into the Heart so each element or tissue works automatically are also known as "Automaton". These Automatons have finite or limited numbers of moderate states i.e. Active and Non-Active States. These allowable states works according to some predefined set of rules and changes as preceding state's function and state of the connected closest nodes or elements (Markus and Hess 1990).

Other Models which are based on Reaction-Diffusions; consist upon Electrical Circuits which floe the ionic current trough the associated dynamic membrane potential and transmission of impulses calculated by solving mathematical equations. These types of models are much more accurate but require high level computation and multiprocessing time to stimulate a minute electrical activity approximately 1 or 2 seconds impulse rate.

The objective to design the stimulation model for Cardiac Electrical Activity based on Cellular Automata concept is that stimulates and elucidates complex phenomena of electrophysiological cardiac activities mainly involved in the irregular or abnormal rhythm of Heartbeat i.e. "Arrhythmias". This model also does not require high load of computation as compared to other models (Defontaine *et al.*, 2005).

Methodology

Cellular Automata is a kind of a discontinuous technique. In this model each cardiac tissue represented as a discrete unit or cell connected with each other and varies their states according to simple predefined set of rules as function of preceding state as well as state of neighboring cells. Cellular Automata properties are based upon finite transmission between each cell i.e. cardiac tissue.

These Cardiac tissues designed in modular form of CA as a grid in which group of cells or elements represented with several distinct or discrete states interconnected with neighboring cells and followed the probabilistic predefined rules of propagation of electrical sparks or impulses. This probabilistic process of activation through the CA (Cellular Automata) model further adjusted using restitution curves.

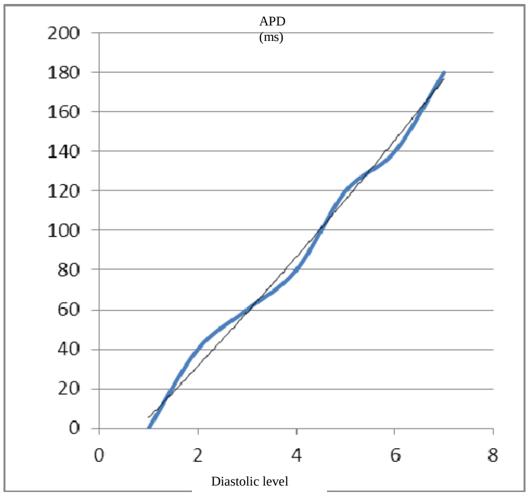


Fig. 2: Graph showing restitution curves for the Action Potential based on Diastolic Interval.

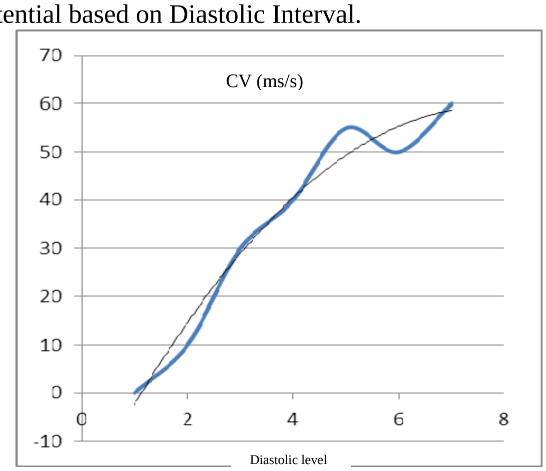


Fig. 3: Graph showing cardiac Conduction velocity based on Diastolic Interval. CV; Conduction Velocity

The properties of each unit is resembles to each cardiac tissue which are cellular automaton so this Automaton have three (3) different states for determining the Electrical Conduction Phenomena. These 3 states are finite. During the AP (Action Potential) the some Automaton approximately 10% of fraction remain in RRP State (Excited but Relatively Refractory Phase) this phase is maintained about little portion of space (Network of Cells) and remaining space cells remains in ARP (Excited but Absolutely Refractory Phase) of the AP (Action Potential) and in Diastolic period or interval these cells changes into the Resting or Relaxed (Excitable) phase (Weimar *et al*., 1992).

The transformation from one state to another governed by some probabilistic rules which are as follows:

1. There must be Incomplete or Partial Repolarization: when transition occur form the RRP to ARP.
2. Complete Repolarization: Transition from ARP to Resting State.
3. Depolarization: Transition from Resting State to RRP.

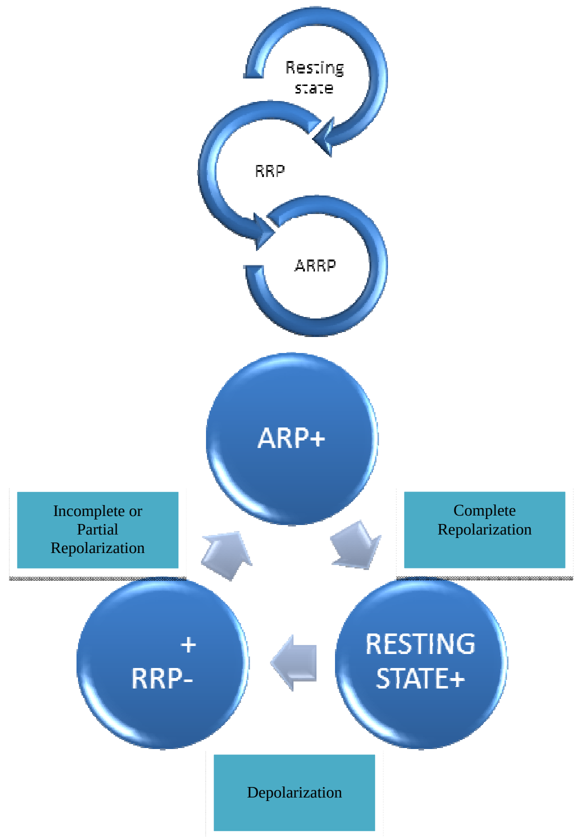


Fig. 4: 3 Finite Automata States (ARP, RRP, and Resting State) of proposed model.

When duration's instant of AP and Depolarization is known then both of Partial and Complete Repolarization take place in manner of standard determination (Gerhardt *et al*., 1563-1566).

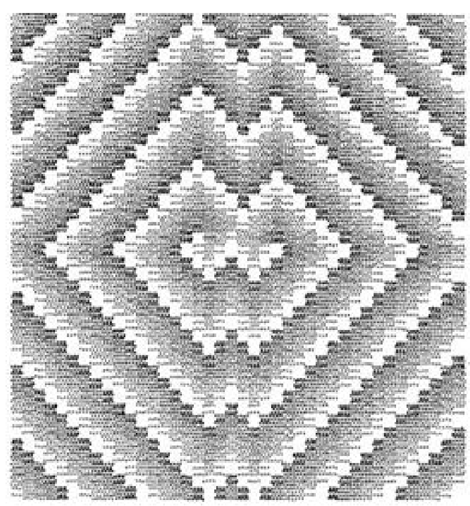


Fig. 5: E-1. This State showing spiral wave pair in an Excitable Automata.

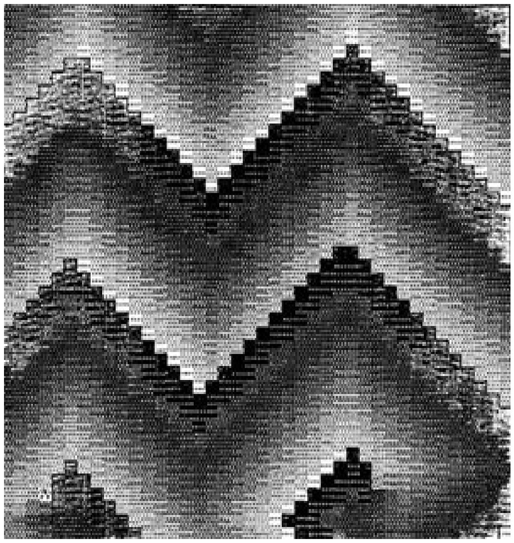


Fig. 6: E-2. 2D symmetrical pattern of wave

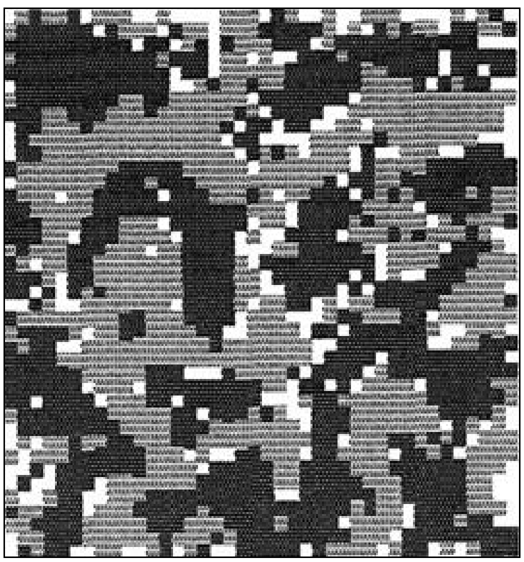


Fig. 7: E-3. Unsymmetrical cells of ocular dominance columns of third state.

This CA Model basically controls many arrhythmias analysis associated with cardiac contraction and relaxation. This model also includes many aspects of management of electrical activity of cardiac cells process with curvature. It shows much advancement in computation as well as highly efficient model. Other hand it would also simulate electrophysiological factors of cardiac electrical activity based on minimum complexity (Monteiro *et al*., 1998).

A Neural Network Model

Neural Network Model is very useful in many aspects of Cardiac activities such as pattern recognition of Electrogram classification of different states of cardiac impulse which are formed as a result of muscular contraction. Neural Network composed of neurotic computational units for analysis (Clancy *et al*., 2003).

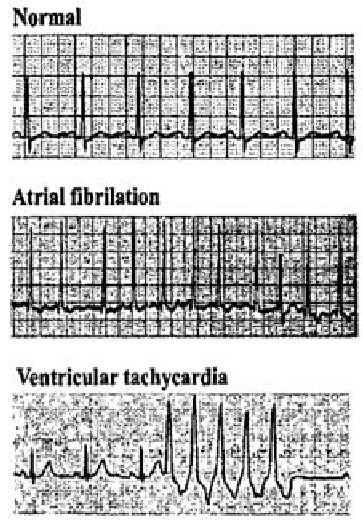


Fig. 8: ECG Recording Patterns showing Normal atrial fibrillation and a ventricular tachycardia.

In Pattern analysis and Recognition Artificial Neural Networks commonly used and for their Neural Network Classifier is one of the best tools for the classification of various diseases like: Complete Herat Block, Ventricular fibrillation - sick sinus syndrome, Sinus Rhythm and cardiomyopathy (dilated).

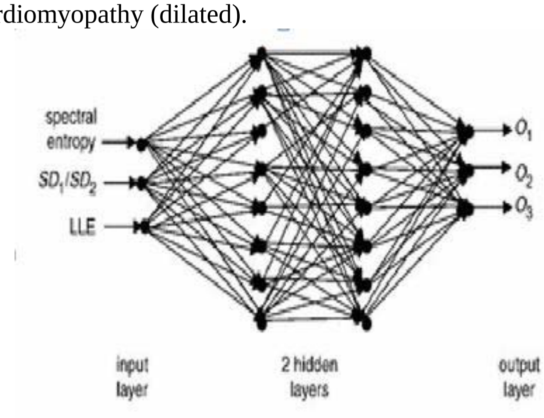


Fig. 9: 4-layer Artificial Neural Network Classifier.

Comparison between neural network model and cellular automata model

Neural Network Model provides cardiac AP (Action Potential) Diagrammatical pattern recognition but does not give efficient stimulation as compared to Cellular Automata Model, Neural Model can work on different frequencies but cellular model works on macroscopic portions of activation and does not provide any illustration about genetically diseases pattern and ionic channels but work efficiently with high speed of computation on electrical activities (Moe *et al*., 1964).

Neural Network solves some complex lattice one-dimensional structures by using Mean-Field Theory. It is powerful tool to describe the relationship between core aspects which furthermore used to demonstrate the main model. Neural Network basically works on Input Output Device function which converts input into single output Clancy *et al*., 2003).

General formula of ANN- Artificial Neural Network:

$$F = F(x1, \ldots, xM)^{n} = g \sum_{k=1}^{M} wjxj - t^{n}$$

Notations: "F" is an Output of non-linear function "g". "W" are weights as inputs. Output F is equal to weighted sum of the input minus Threshold "t" (given already).

So, this equation is also a brief form of Neural Network model in comparison of Cellular Automata Model.

Hybrid model

Another efficient model works on the basis of Hybrid automata for complex cardiac system by discontinuous graphs with dynamic continuous structure.

It give different efficient patterns for the electrical activity of heart but not much efficient as Cellular automata system. It gives significant computation framework of wave pattern on the different a conditions of cardiac activities by patterned their excitable cells.

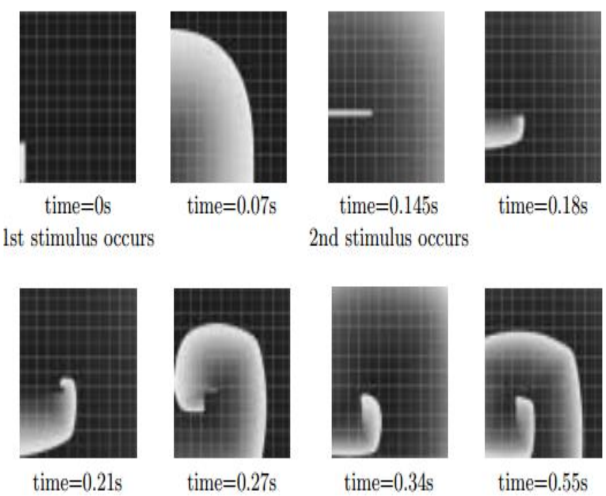


Fig. 10: H. Snapshots of different Hybrid model pattern of spatial propagation of excited cardiac cells.

Likewise Cellular automata this model also give less computation burden in fast and efficient manner but Cellular automata model provides clear and quick pattern of electrical activity of the excited cells of contraction of heart tissue in one main stream line.

In contrast of Neural Network model cellular Automata also give individual unit / excited cell pattern in cardiac plausibility and complex computation and prove itself as dynamic model.

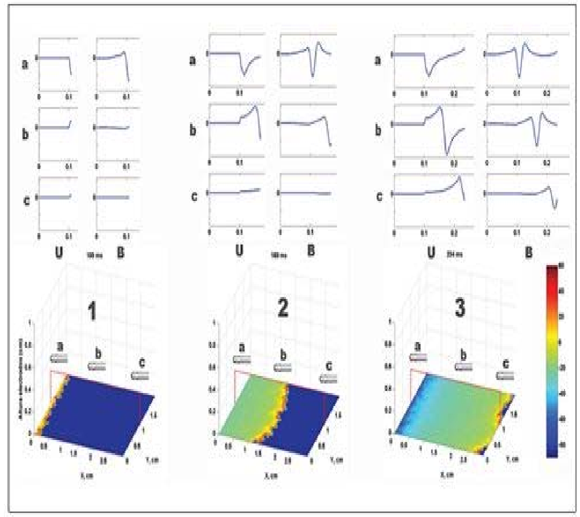


Fig. 11: Showing different stimulated patterns Electrogram of electrical activity through Cellular Automata Modelling.

RESULTS

The first **Resting (Relax and Excitable)** state or phase examined is One-Directional (Dimensional) cycle of cells. This cycle coupled with its closest neighboring cells vertically or horizontally. The speed of active conduction is homogenous (same/constant) throughout the region of cells ring.

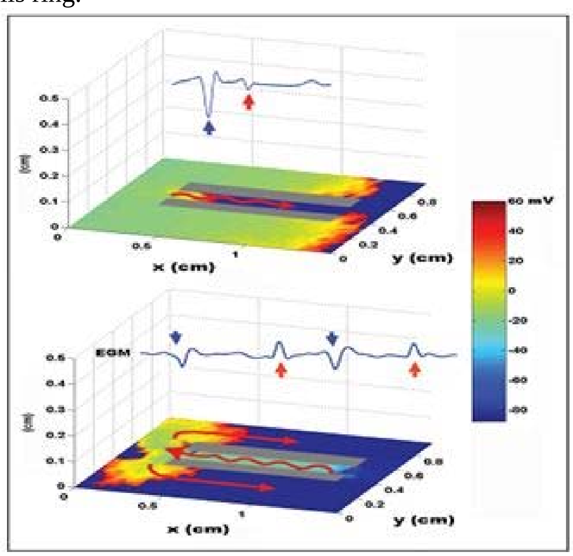


Fig. 12: The Pattern showing spiral wave pair in an Excitable Automata.

The second ARP (Excited but Absolutely Refractory Phase) state or Phase examined is Two-Directional (Dimensional) which is consisting upon 40 X 40 arrays of units (cells). It is a symmetrical state in which each Automaton linked to its 4 closest neighboring cells from all four sides top, bottom, left and right. The speed is constant in both dimensions.

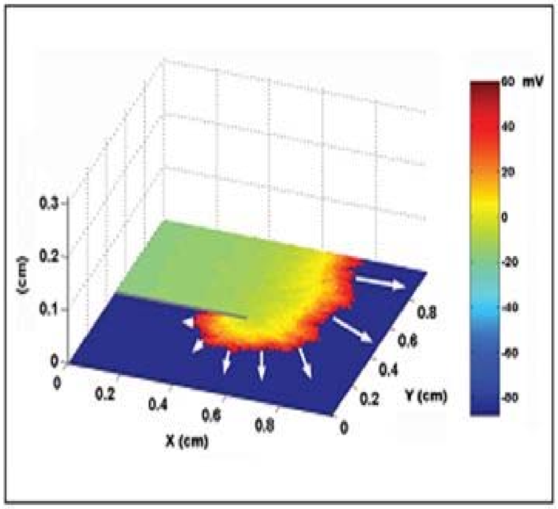


Fig. 13: 2. 2D symmetrical pattern of wave.

The final RRP (Excited but Relatively Refractory Phase) state or phase is also Two-Dimensional but it is Non-Symmetrical and the speed is twice and swift in comparison of 2D-Symmetrical state and it is also in the transverse longitudinal dimensions.

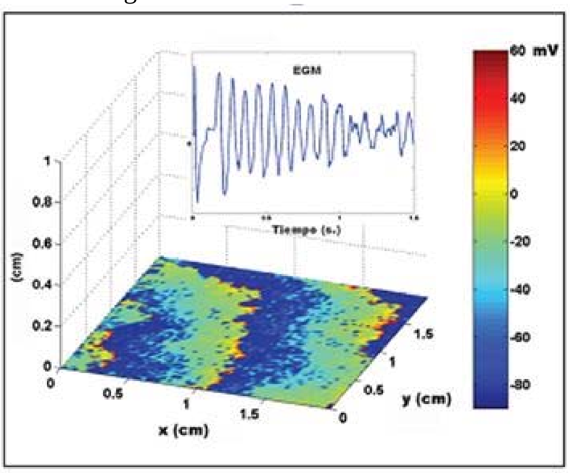


Fig. 14: Unsymmetrical cells pattern of ocular dominance columns of third state.

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