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Optimising Pace Maker Function Using Graph Theory: A Novel Approache

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Abstract:

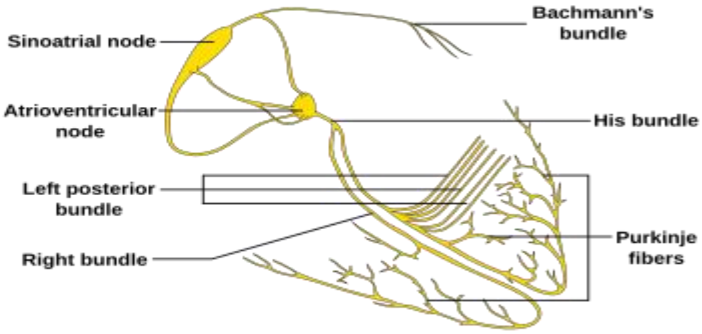
A pacemaker is a small medical device that helps regulate the heartbeat by generating electrical impulses that stimulate the heart to beat. In this work we have presented the techniques of graph theory and developed a model for micro cardiac network system. The sinoatrial node, a cluster of specialized pace making cells in the right atrium of the heart, spontaneously generates an electro-chemical wave that spreads through the atria and the cardiac conduction system to the ventricles, initiating the contraction of cardiac muscle essential for pumping blood to the body. The main concept is to get the blood flow system in human heart with respect to oxygenated and d-oxygenated blood circulation using the network graph theory. The crossing numbers are the most important parameters for obtaining exact results in an electrical circuit represented by a planar graph. This concept may help in blood flow system in human heart. The graph theory and its applications in human heart are presented in this paper. The graph theory and its applications in human heart are presented in this paper. The stereographic projection of a graph is presented with an algorithm in order to improve the performance of the model.

***Index Terms*: Graph, Human Heart, networks, algorithms, pace maker.**

I. I. INTRODUCTION:

The cardiac pacemaker is the heart's natural rhythm generator. It employs pacemaker cells that produce electrical impulses, known as cardiac action potentials, which control the rate of contraction of the cardiac muscle, that is, the heart rate. In most humans, these cells are concentrated in the sinoatrial node (SA), the primary pacemaker, which regulates the heart's sinus rhythm. Sometimes a secondary pacemaker sets the pace, if the SA node is damaged or if the electrical conduction system of the heart has problems. Cardiac arrhythmias can cause heart block, in which the contractions lose their rhythm. In humans, and sometimes in other animals, a mechanical device called an artificial pacemaker (or simply "pacemaker") may be used after damage to the body's intrinsic conduction system to produce these impulses synthetically.

The artificial pacemaker is one of the great medical inventions of the 20th century. Cardiac pacing has evolved from a hazardous experiment in the 1930s, to a routine, safe, and sophisticated treatment used worldwide. Artificial pacemakers have benefited immensely from advances in engineering, notably with the advent of transistors, programmable circuits, lithium batteries, and internet-connected devices. Additional breakthroughs have been achieved in recent years, with the leadless pacemaker being the most promising improvement.



Components of a Pacemaker:

- ➢ Pulse Generator: This is the main component of the pacemaker that generates electrical impulses.
- ➢ Battery: Powers the pacemaker.
- ➢ Lead: A thin, insulated wire that carries the electrical impulses from the pacemaker to the heart.
- ➢ Electrode: A small device at the tip of the lead that senses the heart's electrical activity.

Working Function of a Pacemaker:

- Sensing: The electrode senses the heart's natural electrical activity and sends this information back to the pacemaker.
- Decision: The pacemaker analyses the heart's electrical activity and decides whether to generate an electrical impulse.
- Stimulation: If the pacemaker decides to generate an impulse, it sends an electrical signal through the lead to the heart.
- Heartbeat: The electrical signal stimulates the heart to beat, maintaining a regular heartbeat.
- Adjustment: The pacemaker continuously monitors the heart's activity and adjusts its impulses as needed to maintain a normal heartbeat.

Types of Pacemaker Functions:

- ➢ Demand pacing: The pacemaker generates impulses only when the heart's natural rate falls below a predetermined level.
- ➢ Fixed-rate pacing: The pacemaker generates impulses at a fixed rate, regardless of the heart's natural activity.
- ➢ Rate-adaptive pacing: The pacemaker adjusts its rate based on the body's physical activity.

Benefits of a Pacemaker

1. Regulates heartbeat: Maintains a normal heartbeat, reducing the risk of complications.
2. Improves symptoms: Relieves symptoms such as fatigue, dizziness, and shortness of breath.
3. Increases energy: Allows for increased physical activity and improved overall quality of life.

There are different types of traditional pacemakers:

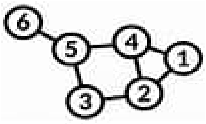
- Single-lead pacemakers use one lead, usually placed in the right ventricle (the lower right chamber of your heart).
- Dual-lead pacemakers use one lead in the right atrium and one lead in the right ventricle.
- Biventricular pacemakers (also called cardiac resynchronization therapy or CRT) use three leads. They are placed in the right atrium, right ventricle and left ventricle.

Wireless pacemakers are smaller than traditional ones. The pulse generator and electrodes are all in one device. Placement of the pacemaker doesn’t require surgery. It’s placed inside your heart through a catheter (small tube) inserted through one of your veins. Once in place, the pacemaker sends impulses to the right ventricle.

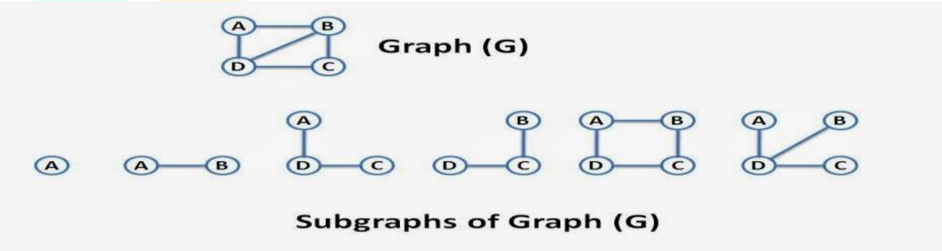
Graph theory is one of the most important branches of mathematics particularly discrete mathematics which is also called as the mathematics of network. In computers it has many applications such as syntactic analysis, fault detection etc. It plays a very important role in engineering and technology. The development of many tools such as medical imaging, face recognition system, remote sensing, optical character recognition system (OCR) and many more are the examples of its application. From the past two decades’ graph theory is playing a vital part in image segmentation techniques especially in medical image processing which is the most active research topic nowadays. In this paper we have presented the techniques of graph theory and developed a model for micro cardiac network system. The main concept is to get the blood flow system in human heart with respect to oxygenated and deoxygenated blood circulation using the network graph theory. The crossing numbers are the most important parameters for obtaining exact results in an electrical circuit represented by a planar graph. This concept may help in blood flow system in human heart. The stereographic projection of a graph is presented with an algorithm in order to improve the performance of the model. This work will definitely helpful to develop a tool in solving the blood flow system in human heart.

II. GRAPH TERMINOLOGY:

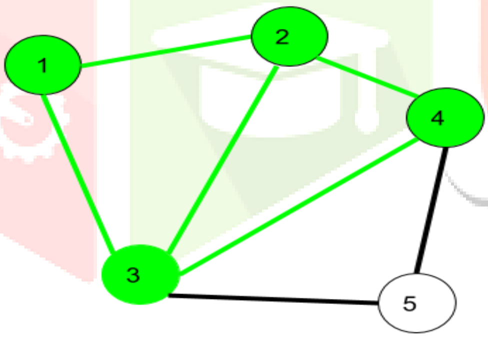
Graph: A graph is made up of *vertices* (also called *nodes* or *points*) which are connected by *edges* (also called *arcs*, *links* or *lines*).



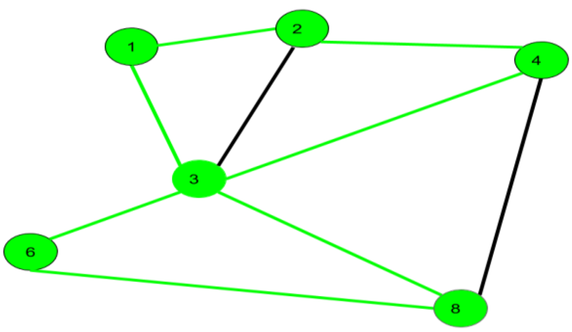
Sub Graph: a subgraph is a **graph formed from a subset of the vertices and edges of another graph**. Subgraphs plays an important role in understanding the structure and properties of larger graphs by examining their smaller, constituent parts.



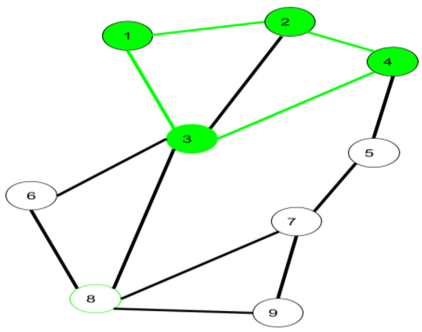
Walk: A walk is a sequence of vertices and edges of a graph i.e. if we traverse a graph then we get a walk. Edge and Vertices can both be repeated. Here, 1->2->3->4->2->1->3 is a walk.



Circuit: Traversing a graph such that not an edge is repeated but vertex can be repeated, and it is closed also i.e. it is a closed trail.
Vertex can be repeated.
Edge cannot be repeated.

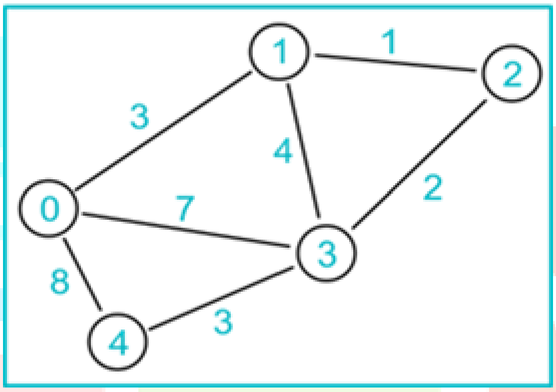


Cycle: Traversing a graph such that we do not repeat a vertex, nor we repeat an edge but the starting and ending vertex must be same i.e. we can repeat starting and ending vertex only then we get a cycle. In other words, cycle can be defined as the closed path.



Here 1->2->4->3->1 is a cycle.

Weight: a weighted graph in graph theory, each edge is assigned a numeric value known as a weight.



Some of the graph theory concepts used in pacemaker development include:

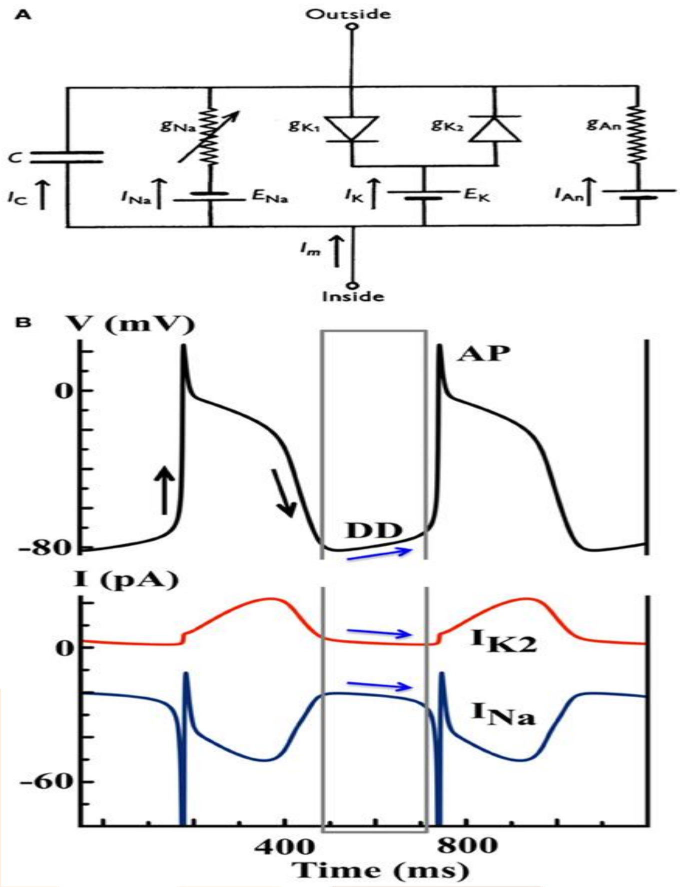
- Graph connectivity: analysing how different parts of the heart are connected and how electrical signals propagate through the heart.
- Graph centrality: identifying the most important nodes (e.g., the sinoatrial node) in the heart's electrical conduction system.
- Graph clustering: grouping nodes (e.g., different regions of the heart) based on their electrical activity patterns.
- Graph spectral analysis: analysing the frequency content of the heart's electrical activity to detect arrhythmias or optimize pacemaker settings.

Graph theory in Pace maker:

Graph theory plays a significant role in the development and functioning of pacemakers in the heart. Here are some ways graph theory is applied:

1. Modelling the Heart's Electrical Conduction System:

Graph theory is used to model the heart's electrical conduction system, which consists of nodes (e.g., the sinoatrial node, atrioventricular node) and edges (e.g., electrical pathways). This model helps understand how electrical signals propagate through the heart.



2. Analysing Pacemaker-Heart Interactions

Graph theory is used to analyse the interactions between the pacemaker and the heart. By representing the pacemaker and heart as nodes and edges, researchers can study how the pacemaker's electrical signals interact with the heart's electrical conduction system.

3. Optimizing Pacemaker Settings

Graph theory can be used to optimize pacemaker settings, such as the pacing rate, amplitude, and duration. By modelling the heart's response to different pacemaker settings, researchers can identify the optimal settings for a given patient.

4. Detecting Arrhythmias

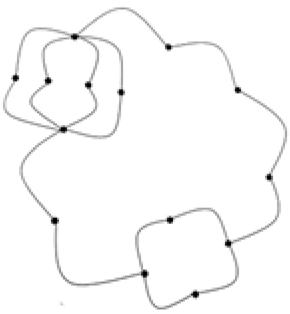
Graph theory can be used to detect arrhythmias, such as atrial fibrillation or ventricular tachycardia. By analysing the graph structure of the heart's electrical activity, researchers can identify patterns indicative of arrhythmias.

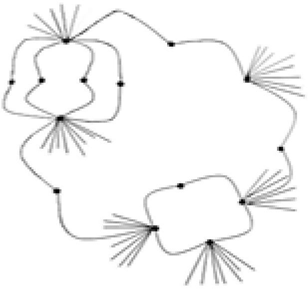
5. Developing Personalized Pacemaker Algorithms

Graph theory can be used to develop personalized pacemaker algorithms that take into account a patient's unique heart anatomy and electrical conduction system. By modelling the patient's heart as a graph, researchers can develop algorithms that optimize pacemaker settings for that specific patient.

III. HUMAN MICRO CARDIAC NETWORK SYSTEM:

The circulation of blood in human cardiac system is itself planned by the nature. So we have observed and studied planarity and the Hamiltonian or Eulerian graphs in cardiac network system. We modified the blood circulation system of heart with applications show in Figure. We collected infrastructure connectivity graphs in human body with the blood circulation system in the heart and we called them as "Micro-Cardiac Network Graph". Further we studied this concept in terms of network graphs. Our attempt is to show that there is a Hamiltonian or Eulerian path system in human heart functioning and we came to conclusion to give sketches of this system. Our investigations allow solving the problems of the thickly crowded dense micro cardiac network system which is shown in the Figure. The extended edge connectivity may help the cardiac network system.





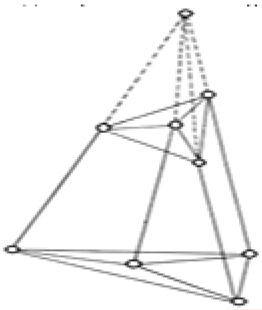
Micro Cardiac Network Graph Thickly crowded Micro Cardiac Network System

Construction of Micro-Cardiac Network Graph.

Stereographic Projection of a Graph:

Embedding a graph in the plane is equivalent to embedding it on the sphere. This equivalence can be seen with the aid of Stereographic Projection. Euler discovered the formula for simply connected graph in 1752 and therefore connected planar graph is named after him. The Stereographic Projection is shown in Fig.

Stereographic projection of a graph



The Human Heart: Structure and Function

The human heart is a muscular organ, approximately the size of a closed palm, responsible for pumping blood throughout the body's circulatory system.

Location and Position

The heart is situated in the thoracic cavity, between the lungs and posterior to the sternum. Its base is attached to the aorta, veins, vena cava, and pulmonary arteries, while the lower tip (apex) rests above the diaphragm.

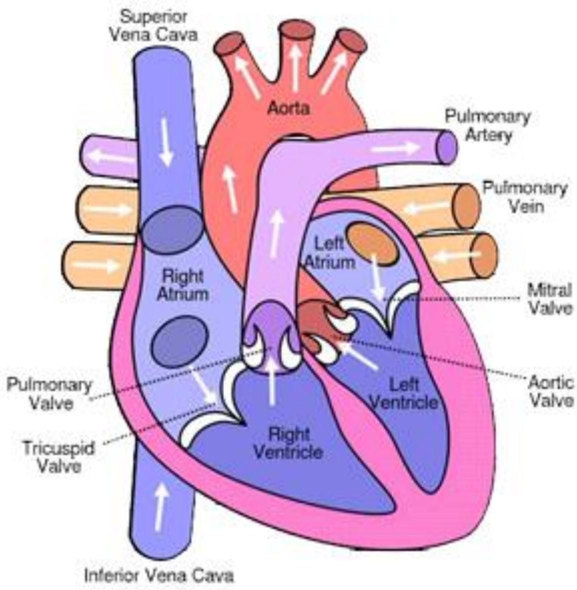
Orientation and Mass Distribution

The heart is positioned with its base facing upward and its apex pointing toward the left side. Approximately 2/3 of the heart's mass is located on the left side of the body, while the remaining 1/3 is on the right.

Key Components

The human heart consists of several vital parts, including:

1. Atria: The upper chambers that receive blood.
2. Ventricles: The lower chambers that pump blood out of the heart.
3. Septum: The wall separating the left and right sides of the heart.
4. Valves: The structures that control blood flow between chambers.
5. Blood vessels: Arteries, veins, and capillaries that transport blood throughout the body.



Human Micro Cardiac Network System

IV. ALGORITHMS USED PACE MAKER:

Here are some graph theory algorithms that can be applied to a pacemaker for the heart:

1. Breadth-First Search (BFS)

BFS can be used to analyse the heart's electrical conduction system and identify potential areas of blockage or abnormal electrical activity.

2. Depth-First Search (DFS)

DFS can be used to detect arrhythmias, such as atrial fibrillation or ventricular tachycardia, by analysing the graph structure of the heart's electrical activity.

3. Dijkstra's Algorithm

Dijkstra's algorithm can be used to find the shortest path to deliver electrical signals to the heart's ventricles, ensuring efficient and effective pacing.

4. Bellman-Ford Algorithm

The Bellman-Ford algorithm can be used to detect negative weight cycles in the heart's electrical conduction system, which can indicate abnormal electrical activity.

5. Floyd-Warshall Algorithm

The Floyd-Warshall algorithm can be used to find the shortest path between all pairs of nodes in the heart's electrical conduction system, providing a comprehensive understanding of the system.

6. Topological Sort

A topological sort can be used to analyse the heart's electrical conduction system and identify potential areas of blockage or abnormal electrical activity.

7. Minimum Spanning Tree (MST)

An MST can be used to identify the most efficient path for electrical signals to propagate through the heart's electrical conduction system.

8. Graph Clustering

Graph clustering algorithms can be used to group nodes (e.g., different regions of the heart) based on their electrical activity patterns, providing insights into the heart's electrical conduction system.

9. Graph Neural Networks (GNNs)

GNNs can be used to analyse the graph structure of the heart's electrical activity and predict optimal pacing strategies.

10. Shortest Path Algorithms

Shortest path algorithms can be used to find the shortest path to deliver electrical signals to the heart's ventricles, ensuring efficient and effective pacing.

These algorithms can be applied to various aspects of pacemaker development, including:
- Optimizing pacing strategies
- Detecting arrhythmias
- Analysing the heart's electrical conduction system
- Developing personalized pacing algorithms.

V. CONCLUSION:

In this paper we are explain the brief idea about the heart function through pace maker. Graph theory is used to represent the heart's electrical conduction system as a network of nodes (representing different regions of the heart) and edges (representing electrical connections). algorithms are used to analyse the network's structure, including node degrees, edge weights, and network motifs. Graph theory's stereographic projection algorithm is used to visualize the heart's electrical network in 3D, facilitating a better understanding of the heart's complex electrical anatomy, and finally applying graph theory to pacemaker development, researchers and clinicians can create more efficient, effective, and personalized pacing strategies, ultimately improving patient outcomes.

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