Simulation Study of Intracranial Pressure under Hydrocephalus Conditions Developed in the Human Brain by Electromagnetic Radiations Using Fuzzy Logic

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***ABSTRACT*— Human brain is one of the most complex organs in the human body. The accumulation of cerebrospinal fluid CSF in the human ventricles and subarachnoid space is called "hydrocephalus". Fluid flow and mass transfer in human brain tissues takes place in a highly synchronised and well regulated manner. The transfer of molecules is an essential bio-process describing physiological and pathological processes associated with the brain functioning. The brain produces roughly 500ml CSF per day at the rate 25ml per hour. Due to some internal and external factors, especially by electromagnetic radiations emitted by mobile towers, resulting in some unbalanced circulation and absorption, the CSF dynamics may cause a situation known as "hydrocephalus" and is responsible in increasing the pressure in the human skull which is referred to as Intracranial Pressure (ICP). A series of mathematical models have been developed to understand the dynamics of CSF, ICP and hydrocephalus based on fluid flow and mechanics. The models are highly non-linear, time variant and complex. Moreover, the models are imprecise, uncertain, and coupled. In this paper a fuzzy logic based solution is presented to simulate the CSF dynamics using MATLAB platform.**

Keywords— Intracranial Pressure, CSF, hydrocephalus disease, QoS, fuzzy logic, impact of electromagnetic radiation, simulation study

I. INTRODUCTION

One of the common perception of microwave towers is that they represent symbols of economic growth as sustainable development. Medical perception of microwave tower is that they are classified as "tower of concern". The development of fifth generation (5G) wireless communication services requires the installation of next generation microwave towers over the territory and the wide adaptation of 5G user equipment. In this context, the population is concerned about the potential health risks associated with EMR emitted from 5G equipment. In this research, a simulation study is carried out to assess the impact of electromagnetic radiation on human brain and variation of fluid flow in various segmented human brain.

Human brain is a highly complex organ in the human body. It is composed of more than 100 million nerve cells (neurons) that communicate through trillion connecting cells (synapses). It is a massive biological network which is responsible for processing and controlling several activities in human body. Thus, human brain is the command centre of human nervous system. Fluid flow and mass transfer in human brain tissue and compartments take place in a well regulated, synchronized, and strictly controlled environment resulting from the coordinated actions of different interfaces located in the blood and extra cellular fluids of brain. Therefore the auto co regulation is the ability of the brain to maintain constant blood flow despite change in perfusion [9].

When a human body is exposed to the electromagnetic radiation, it absorbs radiation, because human body consists of 70% liquid [32]. It is similar to that of cooking in the microwave oven where the water in the food content is heated first. Radiation absorption effect is much more significant by the body parts which contain more fluid (water, blood, etc.), like the brain which consists of about 90% water. When electromagnetic waves radiated from mobile towers directly pass through human brain, a significant portion of radiated power is absorbed by the human brain tissues in the form of heat [32].

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The absorbed radiation can be measured with the help of SAR (Specific Absorption Rate). These radiations are absorbed in the form of heat subsequently increasing the temperature of brain tissue. The change in brain tissue temperature at any time *t* results from lack of equilibrium between amount of heat absorbed (radiated from mobile towers) and heat dissipated into the cerebral blood. This imbalance between heat absorption and heat dissipation by brain tissue will increase the brain metabolism function [33]. The potential change in CBF can be seen due to change in cerebral metabolic activity. In other words, any change in CBF will affect cerebral blood volume (CBV) as well as the subarachnoid space, where CSF is absorbed, which is responsible to increase the pressure in the human skull and referred as Intracranial Pressure (ICP) [33].

The rest of the paper is organized as; Section II, a detailed discussion of CSF dynamics and its component are proposed. In Section III, introduction of fuzzy logic, architecture and its advantages and disadvantages are discussed. Section IV undertakes fuzzy logic based modelling.

Table I
STANDARD CSF PARAMETERS

S. No.	Parameter	Normal Range
1	Total CSF Volume	125-150ml
2	Resting CSF pressure	150-180mm H_2O
3	CSF production rate	0.36ml/min (approx.)

In Section V, simulation results and conclusions are summarized. A fuzzy logic based analysis of CSF dynamics is carried out. The study can be utilizes to develop descriptive, preventive, predictive and diagnostic model, for bio-marker design.

II. WHAT IS CEREBROSPINAL FLUID FLOW?

Column 1	Column 2	Column 3 [a]
xx1	yyy1	zzz1
xxx2	yy2	zzz2
xxx3	yyy3	zz3
xxx4	yy4	z zzz4
xxx5	yyyyyy5	zz5

Cerebrospinal fluid (CSF) is a colorless fluid that is contained in cavities called 'ventricles' and covers the surface of the complete central nervous system. It is produced by a structure called 'choroid plexus' present in the ventricles. In the superior sagittal sinus structures called 'arachnoid villi', acting as unidirectional valves are present that are responsible for absorption of the CSF in the blood stream. Some major functions of CSF are:

1. Protecting the brain from impact by providing cushioning.
2. Reducing pressure at the base of brain due to buoyancy by approx. 97%, as the net weight of brain reduces approx. from 1400 gm. to 50 gm.
3. Excreting potentially harmful substances away from the brain owing to one-way flow from CSF to blood.
4. Transporting hormones released in the CSF to remote parts in the brain.

Owing to some pathological conditions there might be

a. Over production of CSF or
b. Obstruction in ventricular system preventing CSF flow or
c. Under absorption of CSF or
d. increase of brain temperature due to RF radiation.

These conditions might lead to an imbalance between CSF flow and its absorption in the blood stream causing its buildup-a condition called 'Hydrocephalus'.

Some standard parametric values for CSF are as tabulated in Table 1

Another parameter related with CSF dynamics is "Intracranial Pressure" (ICP). ICP is determined by three components within skull-brain tissues, blood and CSF which works together in a highly synchronised and well auto-regulated manner [11]. In order to understand the ICP and CSF dynamics many researchers have proposed a series of mathematical models [17-19] based on the first principle of thermo dynamics to understand the highly complex bio-processes in the brain. Some main characteristics of the models are:

1. Highly non-linear
2. Imprecise
3. Vague
4. Multivariable and coupled
5. High computational cost

Thus, conventional mathematical tools and techniques do not yield desired results.

Some early models of the brain vasculature have simplified the dynamics by lumping numerous compartments [23-26]. Other approaches use bundles of tubes to represent different types of cerebral blood vessels [27]. Monro's first model [31] of the intracranial cavity consisted of two compartments, brain and blood. This model was expanded by Karni to contain several fluid structures, including arterial, capillary, venous, venous sinus, jugular bulb, and CSF pathways [23].

To refine the model, Karni et al., [24] added an additional component, brain tissue, to the previous six compartments model.

Piechnik and collaborators developed a mathematical model to study auto-regulation and cerebral species transport in the human brain [28]. Marmarou derived a widely used mathematical model that describes intracranial pressure (ICP) dynamics [29]. However, his model does not explicitly incorporate brain vasculature or the porous parenchyma in the calculations. Many researchers have based their experimental work on this model which correlates well with experimental data, but does not predict blood alterations or brain water content change [30].

A set of enabling technologies, fuzzy logic, AI, ML, GA, Swarm intelligence under the domain "soft computing" that are capable of creative and smooth solutions of bio-processes are fast developing. It is virtually impossible to describe the relationship between various biological parameters by a set of mathematical equations.

III. INTRODUCTION TO FUZZY LOGIC

Fuzzy logic (FL) is a subset of soft computing techniques. The term fuzzy logic represents the conditions which are not clear or having vagueness. FL is a multi-valued logic in which the truth values of a variable may be real numbers between '0' and '1' both inclusive. FL is very efficient method for providing human like reasoning in situations which are imprecise and create non-numerical data set.

Thus Fuzzy sets are the representatives of vagueness and imprecision associated with the information or process. Such models have the capabilities of recognizing, representing, manipulating, interpreting and utilizing data and inaccuracies.

A. Fuzzy Logic Architecture

The fuzzy logic architecture basically represents a set of sequences needed to central fuzzy logic operations. It is composed of four parts as shown in Fig. 1.

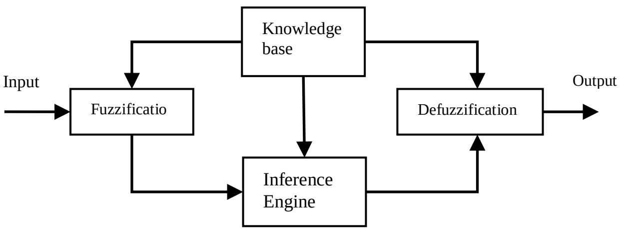


Fig. 1. Block Diagram of fuzzy Logic Architecture.

1) Knowledge Base

Every system which works on the soft computing (AI, GA, ML) has a strong knowledge base. FL is a knowledge based system. Knowledge base of FL defines the rules of FL set theory that are stored. These rules are defined in the form "IF-THEN" statements developed by the experts to control the decision based on linguistic inferences.

2) Fuzzification

It is a process of transforming a crisp set to a fuzzy set. Basically this operation translates accurately crisp input values into linguistic variables with graded degree of membership in the interval [0, 1] and the system can search for it in its knowledge base.

3) Inference Engine

It is responsible for determining the matching degree of the current Fuzzy input w.r.t to each rule and suggest appropriate action to be fired according to input. Next the fired rules are combined to form the control action.

4) *Defuzzification:*

It is used to convert the fuzzy sets obtained by inference engine into crisp sets.

B. Advantages of Fuzzy Logic

- Provides human like solutions of a complex system
- Fuzzy set consists of few values, rules and control actions that are required
- Gradual transition from one linguistic value to a continuous linguistic value. This process brings continuity and robustness in the fuzzy system
- Highly suitable to estimate the effects of multivariable parameters
- Knowledge of system modelling parameters is not needed that creates better solutions
- Faster prototyping is possible
- Easy to design and cost effective solutions
- Knowledge acquisition and representation become simple
- A FL system is able to accommodate uncertainty, vagueness, and non-linearity and is a powerful technology to manage complexity.

C. Disadvantages of Fuzzy Logic

- It is an expert based system. Thus, the expert must have deep knowledge of the system to be modelled by F.L.
- Performance depends on designed rule base.

- Accuracy is compromised.

D. Fuzzy logic Applications in the health care sector

The following are the characteristics of medical data set

1. 5 Vs: velocity, volume, variety, varsity and value
2. Complex
3. Full of uncertainties
4. Time Variant
5. Special frequency spectrum
6. Difficult to model accurately due to lack of knowledge of bio parameters
7. Low amplitude
8. Lack of precise measurement techniques
9. High imprecision associated with medical information
10. Heterogeneous data
11. Lack of support of decision making system
12. Sensitive to environmental conditions
13. Unpredictable demographic

More research or efforts are needed to design and develop smart bio sensors, faster data acquisition and processing and AI based embedded devices to handle complex medical data set.

Consequently, FL has wide range of applications in medical domain.

- Big data analytics
- Clustering analysis
- QOS estimation for biomarkers
- Classification studies
- Pattern recognition
- Feature selection
- Early detection of brain cancer
- Expert system in medicine
- Correlation between bio-signals generated from various organs of human body

IV. Fuzzy Logic Based Model Of ICP And CSF

Prior to fuzzy modeling, a lot of research papers [1-18] and medical literature [19-21] have been studied about the dynamics of intracranial pressure and circulation of cerebral spinal fluid. Based on collected data from literature, the required values for the fuzzy simulation modeling are as follows:

- The total production rate of CSF is about 0.35 ml/min (500 ml/day) and the entire volume of CSF is turnover 3 to 4 times per day. Production rate and absorption rate of CSF is approximately equal in normal brain conditions and absorption rate of CSF is affected by the intracranial pressure (ICP).
- The normal range of intracranial pressure is 5-15 mm Hg, but for simulation modelling we consider the range 0 to 100 mmHg.
- The normal range of arterial blood pressure is 60/120 mmHg and with fluctuation of 20 to 30 mmHg the average value is 90 mmHg.

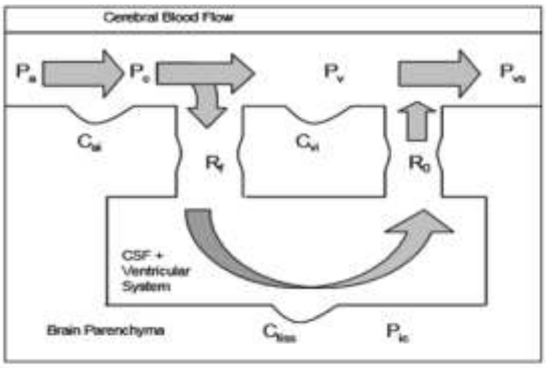


Fig. 2: Concept of cerebral system [10]

A. Fuzzy simulation parameters

1. Input parameters

i) ABP (Arterial blood pressure): In fuzzy modelling consider the range of arterial blood pressure is 0 to 200 mmHg. In order to construct the rules for the ABP, it was first necessary to identify and elicit the fuzzy set membership functions for it. Model assigned the values to the linguistic classes: low arterial blood pressure (L.ABP), normal arterial blood pressure (N.ABP) and high arterial blood pressure (H.ABP) as shown in fig. 3. [12]

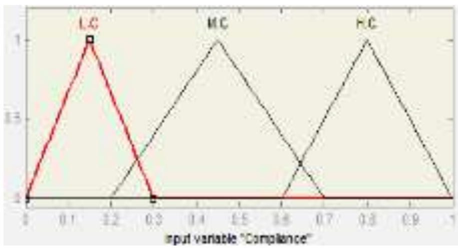
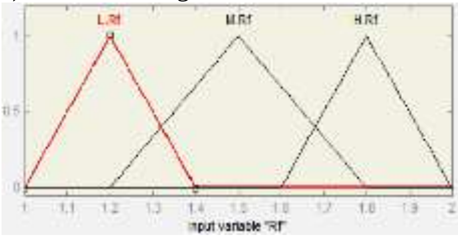


Fig. 3 and 4: Fuzzy membership functions of ABP and Compliance

ii) C (Compliance): Compliance is defined as any change in ABP that will cause of change in arterial blood volume. For fuzzy simulation the considered range of compliance is 0 to 1 and linguistic classes are: low compliance (L.C), medium compliance (M.C) and high compliance (H.C) as shown in fig. 4.

iii) R_f (Forward resistance): The cerebrospinal fluid is produced in capillaries of the brain and shifts into ventricular system through resistance R_f as shown in fig. 2. The considered simulation range of R_f is 1Ω to 2Ω and their linguistic classes are: low forward resistance (L.R_f), medium forward resistance ($M.R_f$) and high forward resistance ($H.R_f$) as shown in fig. 5.



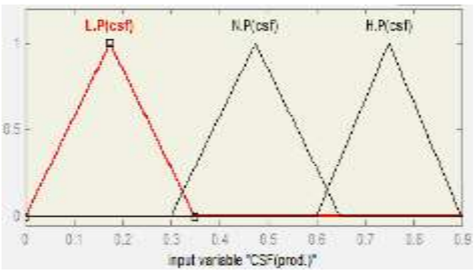


Fig. 5 and 6: Fuzzy membership functions of R_f and CSF_p

iv) CSF_P (Cerebrospinal fluid): The produced amount of cerebrospinal fluid in capillary system is classified into three linguistic classes: low production of CSF ($L.CSF_P$), normal production ($N.\ CSF_P$) and high production ($H.\ CSF_P$) as shown in fig. 6. The normal range of CSF production is 0.3 ml/min to 0.6 ml/min [22] and for simulation consider range is 0 to 0.9 ml/min.

v) R_0 (Back resistance): The ventricular system and venous system of the brain are connected by back resistance R_0 as shown in fig. 2. The considered simulation range of R_0 is 1Ω to 10Ω and their linguistic classes are: low back resistance ($L.R_0$), medium back resistance ($M.R_0$) and high back resistance ($H.R_0$) as shown in fig. 7.

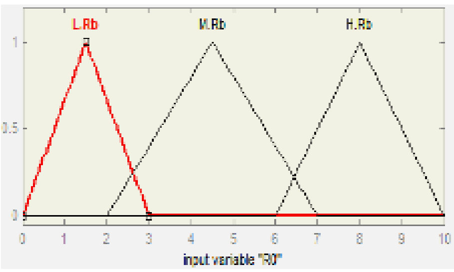
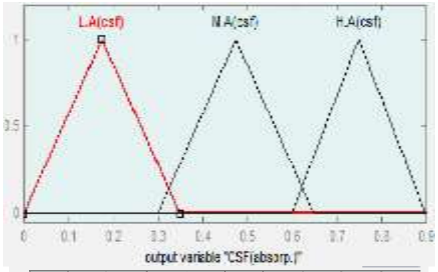


Fig. 7: Fuzzy membership functions of R_0

2. Output parameters

i) CSF_A (absorbed cerebrospinal fluid): The absorbed amount of cerebrospinal fluid in venous system is classified into three linguistic classes: low absorption of CSF ($L.CSF_A$), medium absorption of CSF ($M.\ CSF_A$) and high absorption ($H.\ CSF_A$) as shown in fig. 8. The simulation range is 0 to 0.9 ml/min.



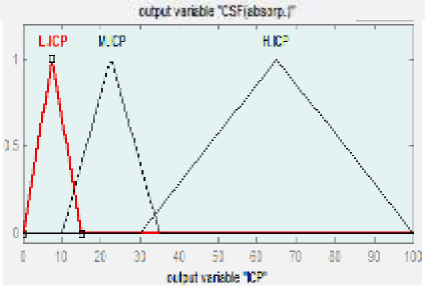


Fig. 8 and 9: Fuzzy membership functions of CSF_A and ICP

ii) ICP (Intracranial pressure): The fuzzy simulation range for intracranial pressure is 0 to 100 mmHg and linguistic classes are: low ICP (L.ICP), medium ICP (M.ICP) and high ICP (H.ICP) as shown in fig. 9.

3. Fuzzy simulation rules

Table-II describes the fuzzy simulation rules corresponding to linguistic classes. List of abbreviations used in the fuzzy rules is present in Table III.

TABLE-II: FUZZY RULES

S. No	Inputs					Outputs	
	ABP	C	R_f	CSF_P	R_o	CSF_A	ICP
1.	L	L	L	H	L	H	L
2.	L	L	L	H	M	M	M
3.	L	L	L	H	H	L	H
4.	L	L	M	M	L	H	L
5.	L	L	M	M	M	M	M
6.	L	L	M	M	H	L	H
7.	L	L	H	L	L	H	L
8.	L	L	H	L	M	M	M
9.	L	L	H	L	H	L	H
10.	N	M	L	H	L	H	L
11.	N	M	L	H	M	M	M
12.	N	M	L	H	H	L	H
13.	N	M	M	M	L	H	L
14.	N	M	M	M	M	M	M
15.	N	M	M	M	H	L	H
16.	N	M	H	L	L	H	L
17.	N	M	H	L	M	M	M
18.	N	M	H	L	H	L	H
19.	H	H	L	H	L	H	L
20.	H	H	L	H	M	M	M
21.	H	H	L	H	H	L	H
22.	H	H	M	M	L	H	L
23.	H	H	M	M	M	M	M
24.	H	H	M	M	H	L	H
25.	H	H	H	L	L	H	L
26.	H	H	H	L	M	M	M
27.	H	H	H	L	H	L	H

TABLE-III: LIST OF ABBREVIATION

Abbreviation	Interpretation
ABP	Arterial blood pressure

C	Compliance of artery
CSF_P	Produced amount of cerebrospinal fluid
R_f	Forward resistance
R_0	Back resistance
CSF_A	Absorbed amount of cerebrospinal fluid
ICP	Intracranial pressure

V. SIMULATION RESULTS AND CONCLUSION

The purpose of this fuzzy modeling was to study and establish the relationship between hydrocephalus condition of the brain and intracranial pressure of the brain. From simulation results shown in Fig. 10 we conclude that intracranial pressure of the system is decreasing with increased value of arterial compliance and the compliance is directly proportional to the arterial blood pressure. Fig. 11 indicates that the absorbed amount of cerebrospinal fluid in venous system is decreasing with increasing the value of back resistance.

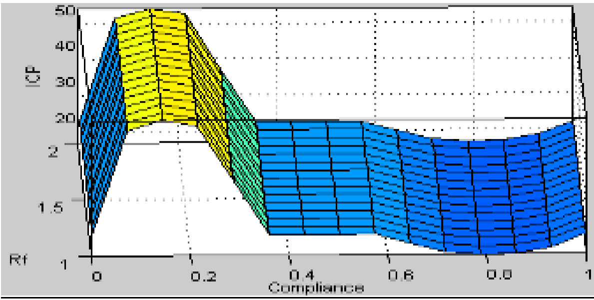


Fig. 10: ICP vs. compliance

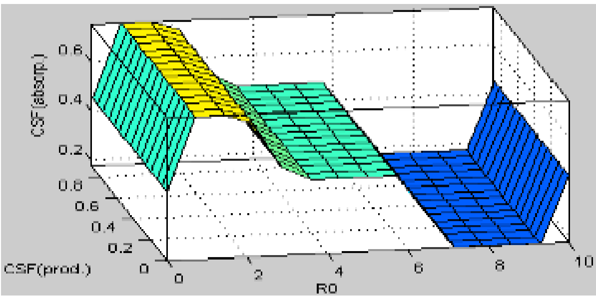


Fig. 11: CSF_A in ventricular system vs. R_0

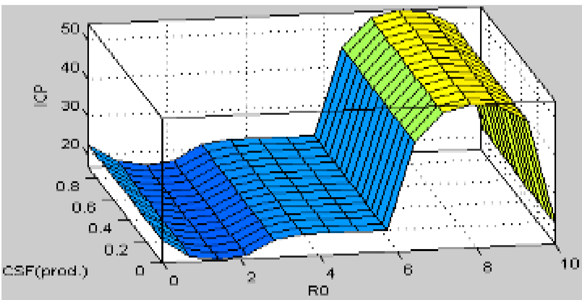


Fig. 12: Changes in ICP vs. R_0

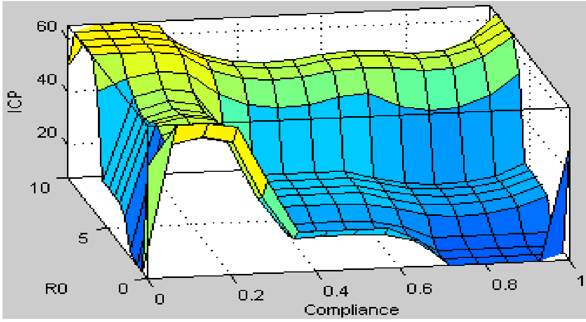


Fig. 13: ICP vs. compliance with variation in R_0

When the absorbed CSF in venous system will decrease then CSF amount will increase in the ventricular system and finally, this large amount of CSF will increase the intracranial pressure as shown in Fig. 12. Fig. 13 shows that how the ICP changing with combined variation of back resistance and compliance of the system. From inspecting the results of this fuzzy modeling, it is clear that all parameters are coupled to each other and intracranial pressure of the brain is directly proportional to the volume of CSF present in the brain. It is stated that the present model does not consider the input parameters like capillary pressure and compliance of intracranial system. The proposed simulation analysis is conducted using fuzzy logic that is capable to develop an intelligent framework to design bio-marker protocols.

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