Intelligent Identification of Acute Kidney Injury Empowered with Heterogeneous Mamdani Fuzzy Inference System

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Abstract
In this article, a new Heterogeneous-Layered Mamdani Fuzzy Inference System (HL-MFIS) is proposed to detect the Acute Kidney Injury. The proposed computerized system Detect of AKI Using Heterogeneous Mamdani Fuzzy Inference System (DAKI-HL-MFIS) Expert System, can detect the Acute Kidney Injury or No-AKI. The Expert System has two input variables at layer-I and seven input variables at layers-II. At layer-I input variables are Creatinine and BUN that detects the output condition of a Kidney to be Normal, or Acute Kidney Injury. The further input variables at layer-II are Glomerular filtration rate, urine Albumin, sodium, potassium, chloride, calcium and phosphorus that determine the output condition of Kidneys like Acute kidney Injury and other reasons that arise due to enzyme vaccination or due to past Kidney Injury. The overall accuracy of the DAKI-HL-MFIS Expert system is 90.5%.

Keywords:
MFIS, Creatinine, AKI, Albumin creatinine ratio, BUN, Sodium, Potassium, Chloride, Calcium, Phosphorus, Albumin, DAKI-HL-MFIS, ES

1. Introduction

Analysis of disease is the main factor in the area of medicine and the health sector. An improper analysis of a disease is a major cause of an inappropriate treatment that results in complications that finally lead to death. What are the crucial causes and signs of a disease and its degree of indications on the body parts? When this is solved treatment can be done most effectively on time and it requires a lot of information about the disease and record of the patient. It is compulsory to observe the disease on time and note its symptoms (Ntaganda, et al, 2015).

Acute Kidney Injury (AKI) is categorized by an abrupt reduction in Glomerular filtration rate (GFR), demonstrated by addition in serum creatinine concentration and characterized by level and reason (Mehta, et al, 2015). AKI happens when your kidneys immediately fails to sieve waste products from your blood. When your kidneys fail their sieving ability dangerous amounts of wastes can aggregate and your blood's chemical composition can be unstable AKI also known as acute renal failure. AKI is mostly found in people who are already under treatment, especially in seriously ill patients who required more care. AKI may also dangerous and need deep treatment, AKI can be curable if you have pleasant health you can acquire natural or close to nature kidney task (Bagshaw SM, et al, 2010). Major reasons of kidney injury involve blood loss, blood pressure Medicare, heart issues, liver failure, serious dehydration, blood clots in veins and arteries around the kidney, bladder cancer, kidney stones, prostate cancer, kidney stones, prostate cancer, diabetes (Bagshaw SM, et al, 2015). If your symptoms relate any of these symptoms of acute kidney injury your doctor suggests some tests and procedures to diagnose your disease. These tests include a certain urine test, blood tests, some ultrasounds, kidney biopsy etc (Bagshaw SM, et al, 2008). The requirement for laboratory tests based on clinical setup if your volume level is not correct, the doctor suggests early therapeutic tests for the observation of volume level, urine output, SCC and GFR within 8-12 hours. If urine output, SCC and GFR increased. It recommends AKI due to volume depletion if not increased then it recommends some other reasons for AKI, these reasons include urine appearance, the chemistry of sodium, urea, nitrogen, creatinine albumin and total protein etc (Licurse A, et al, 2010). URINE CULTURE mostly recommends however urinary tract infection can be a reason for AKI other tests for urine concentration was early suggested for the observation of illogic AKI to differentiate kidney perfusion from ATN (Perazella MA, et al, 2012) (Miller, et al, 1978).

Lack of urine concentration shows improper tubular action. The partial secretion of sodium and urea may be comprised easily from synchronic serum and urine samples. Diuretic therapy lessens sodium re-absorption more than urea re-absorption so a short FE urea more suitable test for differential less kidney perfusion from ATN than a short FE Na in patients with recent diuretic therapy. For diagnosis of kidney disease in adults albumin tests are more suitable than total protein (Levey AS, et al. 2015). But both can support in diagnosis of AICI shortage of albumin in urine is the sign of glomerular destruction and found in mostly parenchymal kidney disease other than Another urine drastic is more delicate to albumin than other

Manuscript received December 5, 2025
Manuscript revised December 20, 2025
https://doi.org/10.22937/IJCSNS.2025.25.12.18

serum proteins, so for the significant observation ACR(Albumin to creatinine ratio) and PCRC (protein to creatinine ratio) test are performed but urine creatinine secretion lessen when SCC increase which can be a reason of wrong albumin to creatinine or protein to creatinine ratio. Some other tests also performed for diagnosis reasons and factors of AKI. Serum urea nitrogen and electrolytes like sodium, potassium, chloride, bicarbonate, calcium, phosphorus, magnesium levels must be analyzed, other tests include whole blood count, liver function test, muscles, enzymes and imaging of lung, liver and heart diseases must be observed fluid cultures for blood and body and serologic test for infections issues, autoantibodies, complement components and inflammatory signs can be measured (Licurse A, et al, 2010).

AKI is a particular morbidity in the seriously ill patient both in the medical and surgical intensive care unit (ICUs). Almost 6% of seriously ill patients with AKI are considered with renal replacement therapy (RRT) throughout their stay in ICU (Uchino S, et al, 2005).AKI incidence differs with the population studies 1% of hospital admissions directed in the united states with AKI. There are lots of reasons for AKI in the serious care setting, with sensitive tubular necrosis leaving the most common. The procedure is mostly consisting of many factors such as sepsis, nephrotoxic drugs, contract agents and post-surgical (Bagshaw SM, et al, 2008). This categorization was located on two fundamental frameworks, changes in serum creatinine (SCr)from baseline and urine output. The severity of the renal failure was examined by the more critical of two frameworks. Three phases of RIFLE are described which contain risk, Injury and failure all of them expanding by the increase in SCr from basis (Koustova E, et al, 2002) (Rhee P, et al, 1998).

The basic results observed were death and renal failure compelling dialysis. The conclusion observed an enhancing danger of death at 90 days and a large requirement for RRT with 6% HES relative to LR (Perner A, et al, 2012). Correspondingly the chest study revealed another central testing of 7000 patients correlated 6% HES and adequate saline. These conclusions revealed no comparison in death but again the requirement for RRT was increased in the HES category (Lissauer ME, et al, 2011).

. Computational Intelligence approaches like Fuzzy system (Areej, et al, 2019) (Hussain et al, 2019), Neural Network (Ayesha, et al, 2019), Swarm Intelligence (Khan, et al, 2019) & Evolutionary Computing (Khan, et al, 2015) like Genetic Algorithm (Khan, et al, 2013) (Ali, et al, 2016), DE, Island GA (Umair, et al, 2015), Island DE (Khan, et al, 2015) are strong candidate solution in the field of smart city (Wang et.al, 2019) (Kashif, et al, 2018), wireless communication (Asad, et al 2018) etc.

2. Proposed Methodology

Proposed Detect Acute Kidney Injury (DAKI) using Heterogeneous-Layered Mamdani Fuzzy Inference System (MFIS) based Expert System (DAKI-HL-MFIS ES) is explained in this section. The fig.1 displays the steps of the proposed DAKI-HL-MFIS Expert system. The DAKI-HL-MFIS Expert System consists of two layers as shown in fig. 2. In layer-I detect the Acute Kidney Injury (No/Yes) using two input variables Creatinine, (BUN) Blood Urea Test as shown in fig. 3.

The value of ACR and GFR are also used to build up a lookup table given in Table-1 to evaluate the status of Acute Kidney Injury (AKI). If Layer 1 detects (AKI) then Layer-II is active. Layer-II diagnoses the stage of the Acute Kidney Injury based on seven input variables as shown in fig. 4. Layer-II input variables are shown in Table-2.

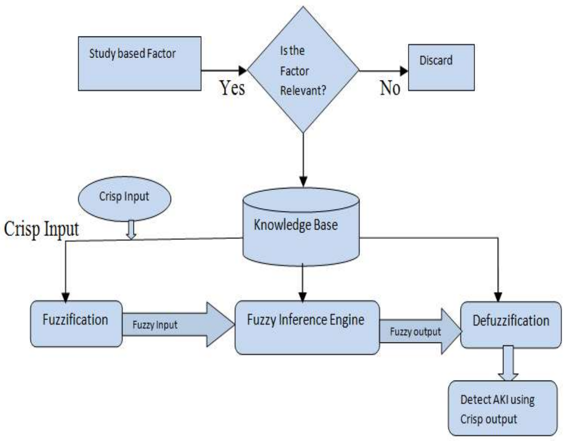

Figure. 1 Proposed DAKI-HL-MFIS based Expert System Methodology

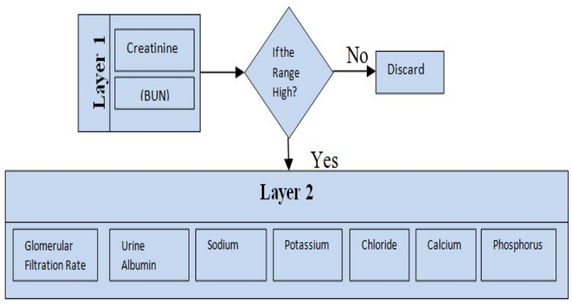

Figure. 2. Proposed DAKI-HL-MFIS Expert System

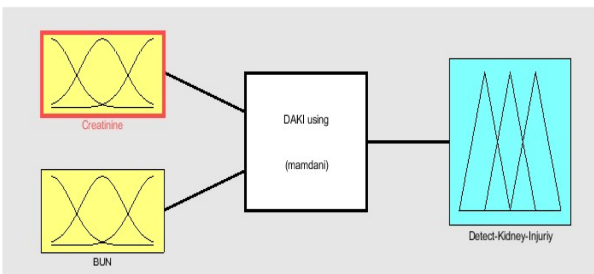

Figure. 3. Layer- 1 Proposed DAKI-HL-MFIS Expert System

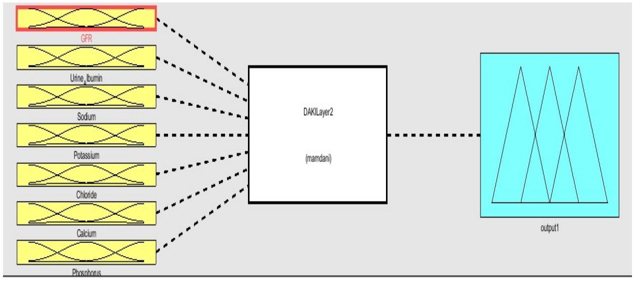

Figure. 4. Layer-2 Proposed DAKI-HL-MFIS Expert System

2.1 Input Fuzzy Sets

Fuzzy input variables are statistical values that are used to diagnose the Acute Kidney Injury. In this search, a total of ten different types of input variables are used on both layers. Two variables are used at layer-I and the rest of the variables are used at layers-II. The details of these input variables with their ranges are shown in table1 & 2.

2.2 Output Fuzzy Sets

In this search, Heterogeneous-layered architecture is proposed to diagnose Acute Kidney Injury. If the Layer-I output is yes, then layer-II is activated. Output variables for both layers are shown in table3.

Table 1. Layer- 1 Input Variable Proposed DAKI-HL-MFIS Expert System [22]

Sr#	Input Parameter	Ranges	Semantic Sign	Reference Range/ Cut off Value
1	Scrum Creatinine	B/W 0.5-1.3 mg/dL	Normal	0.5-1.3 mg/dL
		B/W 1.4-2.0 mg/dL	Moderately High	
		GT>2.1 mg/dL	High Value	
2	Blood Urea Test (BUN)	B/W 7-25 mg/dL	Normal	25 mg/g
		B/W 26-32 mg/dL	Moderately High	
		GT>32 mg/dL	High Value	
GT=Greater Than, B/W=Between, mg/dl=milligrams deciliter, mg/g=milligram per gram				

Table 2. Layer- 2 Input Variable Proposed DAKI-HL-MFIS Expert System [19,20,21]

Sr#	Input Parameter	Ranges	Semantic Sign	Reference Range/ Cut off Value
1	Glomerular Filtration Rate	B/W 60-90mL/min /1.73m	Normal	>60mL /min/1.73m
		LT< 60mL/min /1.73m	Low Value	
2	Urine Albumin	L/T < 30.0 mg/g	Normal	< 30.0 mg/g
		B/W 30-300 mg/dL	High Value	
3	Sodium	B/W 133-144 mmol/L	Normal	133 mmol/L
		LT < 133 mmol/L	Low Value	
4	Potassium	B/W 3.5-5.1 mmol/L	Normal	5.1 mmol/L
		GT > 5.1 mmol/L	High Value	
5	Chloride	B/W 98-107 mmol/L	Normal	107 mmol/L
		GT > 107 mmol/L	High Value	
6	Calcium	B/W 8.6-10.3 mg/dL	Normal	10.3 mg/dL
		GT > 10.3 mg/dL	High Value	
7	Phosphorus	B/W 2.5-4.5 mg/dL	Normal	4.5 mg/dL
		GT > 4.5 mg/dL	High Value	
LT=Less Than, GT=Greater Than, B/W=Between, mg/dl=miligrams deciliter, mg/g=milligram per gram, mL/min= milliliter per minute, mEq/l=milliequivalents/liter, mmol/L=millimoles per liter, g/dL=grams per deciliter				

Table 3. Layer-I &II output variable of proposed DAKI-HL-MFIS Expert System

Sr #	Layers	Output Variable	Semantic Sign
1	Layer- I	Kidney Injury	No
			Yes
2	Layer- II	DAKI	Acute Kidney Injury
			Due to the previous Infection

2.3 Membership Functions

The membership function of this system gives curve values between 0, 1 and also provides a mathematical function that offers statistical values of input and output variables. Graphical and mathematical representations of proposed DAKI-HL-MFIS Expert System member functions of I/O variables of both layers are shown in table-.

This MF is developed after the discussion with medical experts from Kidney Department of Indus Hospital, Multan, Pakistan.

2.4 Lookup Table

The lookup table for the proposed DAKI-HL-MFIS based Expert System contains 20 input-output rules. A few of them are shown in the table. This lookup table is developed with the help of medical experts from Kidney Department of Indus Hospital, Multan, Pakistan.

Table 4 Lookup Table for Proposed DAKI-HL-MFIS

SR.no	Creatinine	BUN	Glomerular Filtration Rate	Urine Albumin/Cr ratio	Sodium	Potassium	Chloride	Calcium	Phosphorus	Results
1	H	H	H	H	N	H	H	L	N	AKI
2	H	H	H	H	N	H	N	N	N	AKI
3	H	N	H	N	N	N	H	N	N	AKI
4	H	N	H	H	N	H	N	N	H	AKI
5	H	H	H	H	N	N	N	L	N	AKI
6	H	H	H	H	N	N	H	L	N	AKI
7	H	H	H	H	N	H	H	N	N	AKI
8	H	H	H	H	N	H	H	N	N	AKI
9	H	H	H	H	N	N	N	N	H	AKI
10	H	H	H	H	L	N	H	N	N	AKI

2.4.1 Rule Based

I/O Rules an analytical aspect in any Fuzzy Inference System (FIS). The accuracy of any expert system depends upon these rules. I/O rules are developed using a lookup table as shown in table/Proposed I/O rules based on DAKI-HL-MFIS Expert System is shown in fig 5 & 6.

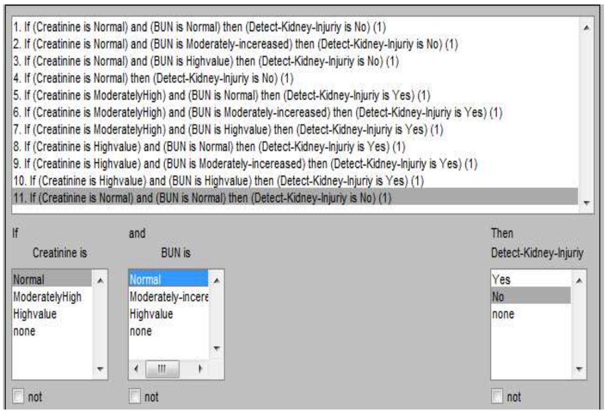

Figure. 5 Layer-1 I/O rules for proposed DAKI-HL-MFIS Expert System

Figure. 6 Layer-2 I/O rules for proposed DAKI-HL-MFIS Expert System

2.5 Fuzzification and Defuzzification

This design has been divided into several steps. This MAMDANI model used the minimum method interface that does not use OR operator, Implication method used is minimum.

3. Simulation Results

To design the system, the FIS tool in MATLAB R2018a is used. MATLAB is a systemic tool for simulation, data analysis, visualization and computing. For simulation results, nine input and one output DAKI variable are used. Figure 8(a) shown that if Creatinine is Normal and BUN is Normal then layer's one chance of AKI is No. The proposed DAKI-HL-MFIS based Expert system detects Acute Kidney Injury. Layer- II detects not only AKI but also informs the stage of the patient as shown in figure 8 (b). Figure 7a is representing the 3D view by prevailing Creatinine and BUN to detect acute kidney injury. It shows that if creatinine is 1.5 and BUN is 10 then acute kidney injury will be 0.2.

Figure 7b is representing the 3D view by prevailing Urine Albumin and GFR to detect acute kidney injury. It shows that if Urine Albumin is 25 and GFR is 75 then acute kidney injury will be 0.35.

Figure 7c is representing the 3D view by prevailing Potassium and Sodium to detect acute kidney injury. It shows that if Potassium is 5 and Sodium is 140 then acute kidney injury will be 0.5.

Figure 7d is representing the 3D view by prevailing Phosphorus and Chloride to detect acute kidney injury. It shows that if Phosphorus is 5 and Chloride is 110 then acute kidney injury will be 0.3.

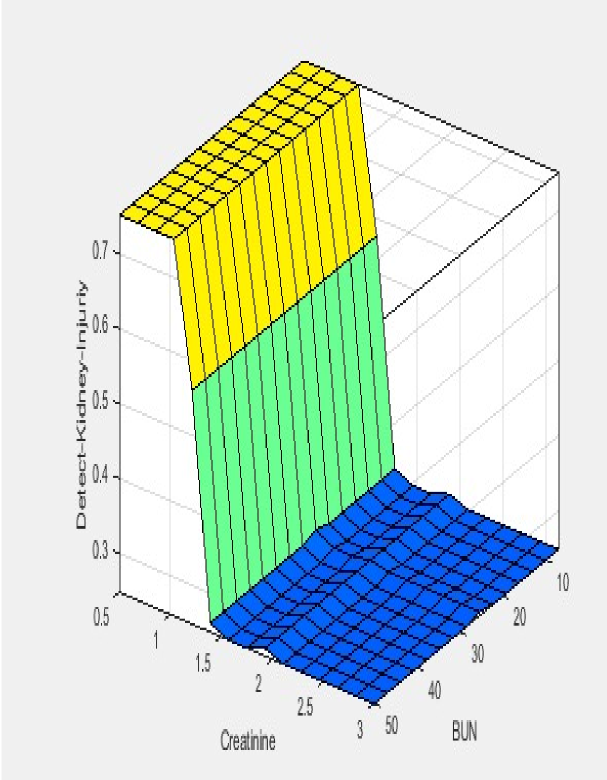

Figure.7a Layer-1 Rule Surface for Creatinine and BUN

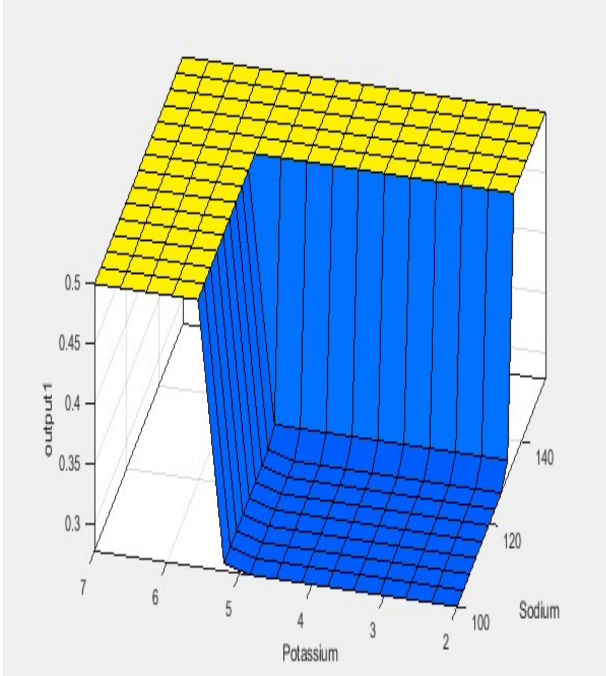

Figure 7c. Layer-2 Rule Surface for sodium and potassium

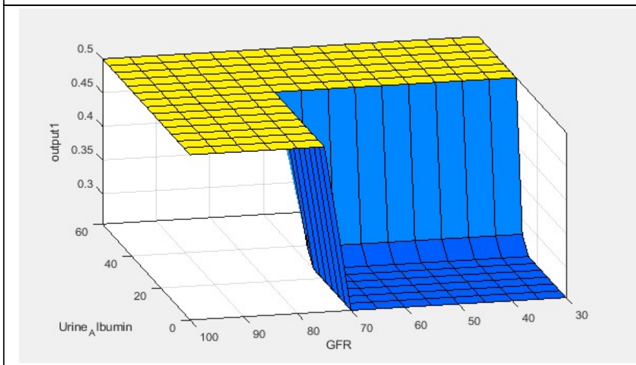

Figure. 7b. Layer-2 Rule surface for Urine-Albumin and GFR

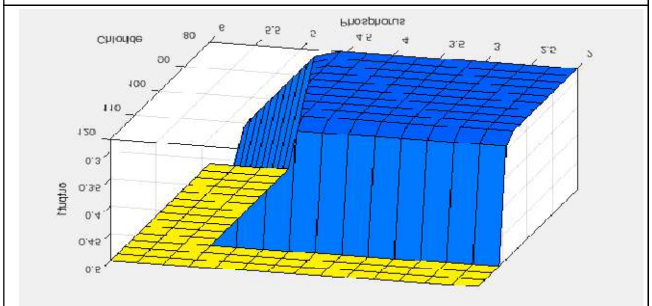

Figure. 7d. Layer-2 Rule Surface for chloride and phosphorus

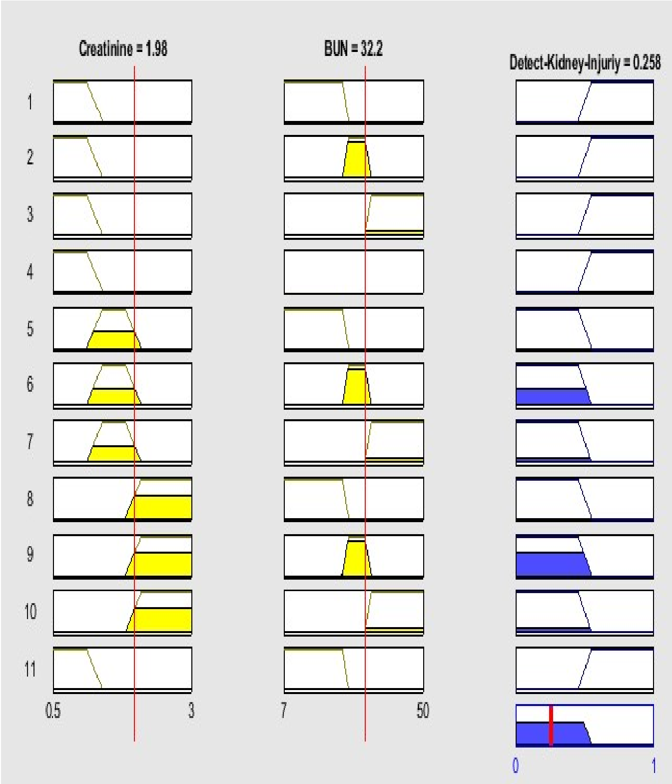

Figure 8a Layer-1 Look up diagram yes Kidney Injury.

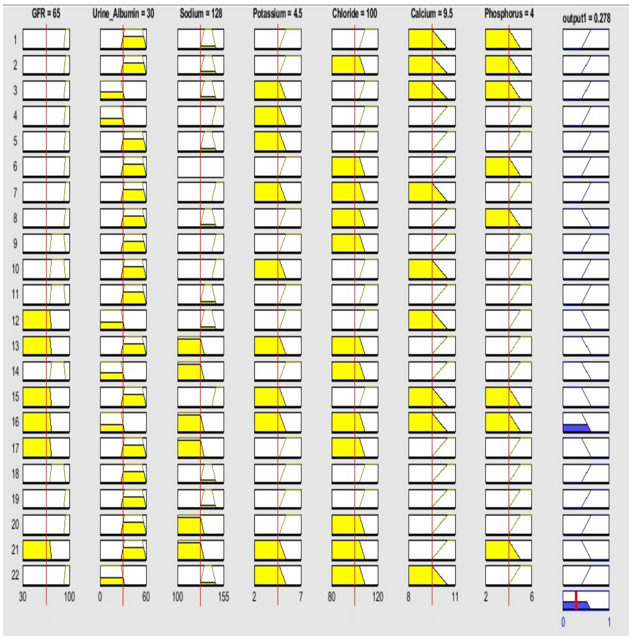

Figure 8b Layer-2 Look up diagram Detect Acute Kidney Injury.

4. Conclusions

In this paper, a Fuzzy expert system is presented to detect of Acute Kidney Injury. There are two input variable at layer-1 and seven variables are at layer-2 are used proposed DAKI-HL-MFIS Expert system is very simple used every person which is a non-medical expert can also diagnose the status of Acute kidney failure by using the input test values. The overall DAKI-HL-MFIS Expert system is 90.5% accuracy. A combination of fuzzy logic and expert system increases the system performance. In the future, this article can improve by using the ANN technique and this research can be extended into chronic kidney injury.

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