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The Application of a Neural Network in the Reworking of Accu-Chek to Wrist Bands to Monitor Blood Glucose in the Human Body

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***Abstract*—**The issue of high blood sugar level, the effects of which might end up as diabetes mellitus, is now becoming a rampant cardiovascular disorder in our community. In recent times, a lack of awareness among most people makes this disease a silent killer. The situation calls for urgency, hence the need to design a device that serves as a monitoring tool such as a wrist watch to give an alert of the danger a head of time to those living with high blood glucose, as well as to introduce a mechanism for checks and balances. The neural network architecture assumed 8-15-10 configuration with eight neurons at the input stage including a bias, 15 neurons at the hidden layer at the processing stage, and 10 neurons at the output stage indicating likely symptoms cases. The inputs are formed using the exclusive OR (XOR), with the expectation of getting an XOR output as the threshold value for diabetic symptom cases. The neural algorithm is coded in Java language with 1000 epoch runs to bring the errors into the barest minimum. The internal circuitry of the device comprises the compatible hardware requirement that matches the nature of each of the input neurons. The light emitting diodes (LED) of red, green, and yellow colors are used as the output for the neural network to show pattern recognition for severe cases, pre-hypertensive cases and normal without the traces of diabetes mellitus. The research concluded that neural network is an efficient Accu-Chek design tool for the proper monitoring of high glucose levels than the conventional methods of carrying out blood test.

***Keywords*—**Accu-Chek, diabetes, neural network, pattern recognition.

I. INTRODUCTION

DIABETES mellitus has been defined by many researchers as a group of metabolic disorders where there is an excessive quantity of blood sugar levels over a prolonged period. The broad objective of this research is to find an urgent solution to reduce the effects of detecting the symptoms early using a monitoring meter in the form of a wrist band to show the severity of this vascular disorder. High glucose levels, if left untreated on time, can lead to the vascular disorder called diabetes mellitus and many complications [1]. The complications can include diabetic ketoacidosis, hyperosmolar hyperglycemic state, or death [2]. The long-term complications associated with this include cardiovascular disease, stroke, chronic kidney disease, foot ulcers, and damage to the eyes. The causes and effects of diabetes are due to the malfunctioning of the organ responsible for the production of the enzyme that coverts sugar to glucose. The reported cases and their causes in recent studies can be classified into three categories of severity:

1. Type I diabetes mellitus is a condition where a damaged or malfunctioning pancreas is unable to produce adequate insulin to convert the excess blood sugar.
2. Type II diabetes is a condition of mellitus that occurs when there is resistance, as the result of nerve cells failing to respond to insulin activation.
3. Gestational diabetes is the third common case that occurs in pregnant women who develop high insulin levels as a result of certain biological changes and who have no genetic traces [2].

The research intends to be modeled into a measuring meter to monitor the early stage of diabetes and to provide a remedy before it reaches into an advanced stage. Diabetes has become a leading cause of death worldwide. Presently, there is no cure for diabetes, but blood glucose monitoring combined with appropriate medication can enhance treatment efficiency, alleviate the symptoms, as well as diminish the complication which is the focus of the current research.

This research focuses on current growth areas of CGM (continuous glucose monitoring) technologies, specifically focusing on subcutaneous implantable electrochemical glucose sensors. Firstly, the superiority of CGM systems is introduced, and then the strategies for reworking the Accu-Chek device will be introduced. Blood glucose concentrations in diabetic situations undulate significantly throughout a day, and left untreated, this can lead to serious consequences including kidney failure, strokes, heart attacks, high blood pressure, blindness and coma [3]. The emergence of glucose sensors would be introduced by the measuring device in this research which would provide patients the ability to self-monitor blood glucose levels so as to manage insulin levels, and thus control mortality through diabetes mellitus in the early stages.

A. Blood Glucose Measurement

The Accu-Chek, as used in this research, is a blood glucose monitoring device used for the assessment of various symptoms, and the quantitative measurement of glucose

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(sugar) in fresh capillaries, arteries and veins blood samples without drawing from the fingertips, forearm, upper arm, or palm. The Accu-Chek blood glucose monitoring system is intended to be used by a single person for self-testing outside the body (in vitro diagnostic use) by those with diabetes at home as an aid to monitor the effectiveness of diabetes control.

II. The Concept of Blood Glucose Systems

The blood sugar concentration or blood glucose level is the amount or quantity of glucose (sugar) present in the blood of a human or animal. The body naturally tightly regulates blood glucose levels as a part of metabolic homeostasis. Under normal conditions of health and a balanced biological system, glucose serves as a source of energy which when activated can be used by all the parts of body; nevertheless, the quantity inside the blood should be regulated, not too much or insufficient, but adequate for the normal metabolism of the body system. The transportation is from the liver or intestine through other parts of the body where energy is needed to carryout normal metabolic activities. Any values above the normal volume needed may result in vascular disorders [5].

III. International Reference Limit

A. Units

The internationally accepted values in terms of concentrations required for blood glucose in all cases, as used in this research, can be measured as follows; given the molecular weight of glucose sugar as C_6 $H_{12}O_6$ which is equivalent to 180 g, when this is dissolved in a normal solution, it is measured in mill mole per liter (mmol/L) or mM.

B. Normal Values in Humans

The following measurements of different categories of cardiovascular conditions are observed by many researchers studying the abnormalities of excessive blood glucose level:

1. The non-symptom operating condition is estimated between 4.4-6.1 mmol/L, these estimated values can vary according to different genetic makeup and human diversity.
2. The normal glucose level for non-symptom cases of diabetes is estimated between 3.9-5.5 mmol/L, this is also subject to certain variation factors each day.
3. The normal glucose levels for non-symptom case with no fasting condition are estimated at less than 6.9 mmol/L.
4. The normal value for the average human being after meal is estimated at $\geq$7.8 mmol/L.
5. The estimated glucose level for diabetes cases before a meal is between 5.0-7.2 mmol/L and less than 10 mmol/L after a meal.
6. The expected quantity of glucose level required by the body fluid is 5.55.5 mmol/L, which is obtainable from 75 kg of complex sugar dissolved in 5 liters of blood [4], [6].

IV. Methodology of Reworking Accu-Chek to Wristband

The research intends to design a wearable monitoring device in the form of a digital meter which continuously measures the status of some cardiovascular parameters. This will help monitor the health status of the individual wearer using the pattern recognition ability of neural networks [7].

Therefore there is need for adequate control measures to curb the effects of early death due to diabetes conditions derived from various aspects of our societies.

A. The Variable to Be Used as Input Neurons

The human body is complex with diverse genetic makeup; therefore, a complex neural algorithm would be used for neuron computing. Thus, the following cardiovascular parameters are used as input neurons:

B. Blood Vessels

Blood vessels are the main transportation channels in the body and can be classified as: Arteries, capillaries and veins. The factors that are used are based on the symptoms of an infected person and the effects as vascular complications:

The effects of excess sugar in the blood vessels causes the narrowing of blood cells, therefore the cells in the blood swell up as a result of sugar accumulation. The input neurons are given three states of weights classified as: normal person without the effects using the values obtained in the research conducted by [8], which found the size of radial and ulna Artery in the local population. The research shown that for the right and left radial artery, the values were found around 2.3±0.4 mm and 2.2±0.4 mm, respectively. In this research they are coded with digit 0 in the algorithm.

For the purpose of this research, the neural network is trained to recognize these values for a normal human, while the threshold value of $\geq$6.5mm is set for those living with these vascular disorders, and it is coded with digit 1. This value was given a higher weight to enable the neurons to recognize it as a symptom condition to detect.

C. Nerve Cells

Without insulin, sugar is not properly used by the nerve cells, as result, the blood sugar accumulates in the cells, thereby causing numbness and tingling in the feet and hands. The neurons used as nerve cells are further classified as: numbness, tingling and normal. The indication of these classifications are that the two symptom cases (numbness, tingling) are an indication of the effects of sugar not properly used by the nerve cells and they are coded with digits 1 each for the neurons to establish the disorder, while the normal conditions is coded 0. The neuron effects to be used in this study are numbness and tingling in the feet and hands. The two abnormal conditions are given threshold values to be recognized by the neurons when either is present.

D. Blood Pressure

Blood pressure is the pressure of circulating blood on the walls of blood vessels. It is usually expressed in the terms of systolic pressure (maximum during one heart beat) over diastolic pressure (minimum in between two heart beats) and is measured in mercury (mmHg). The effect is that when glucose stays in the blood too long, it acts like a slow poison. The input neuron to be used for the recognition exercise is blood pressure, which is classified as: Normal blood pressure (120 mmHg/80 mmHg) representing the diastolic and systolic pressure, this is coded with digit 0; high blood pressure (130-139 mmHg/80-89 mmHg), this is coded with digit 1 to be recognized by the neurons as pre-hypertensive condition, while the third classification; hypertension with a range of values (140-159 mmHg/90-99 mmHg) is also coded with digit 1. The neural network is expected to assign the threshold values to the two abnormal conditions as pre-hypertension and severe case of hypertension.

E. Human Pulse

The human pulse has two dimensions indicators, which are: the pulse rate and pulse pressure. The heart rate increases during a hypoglycemic episode when blood sugar levels drop below normal [9]. Pulse pressure is the difference between the systolic and diastolic blood pressure, it represents the force that the heart generates each time it contracts.

Diabetes damages blood vessels causing them to harden, which results in an increased pulse pressure [10]. In this study, the pulse rate values to be used as input neurons are between 60-100 bpm for normal cases and are coded as 0, while cases less than 40 bpm suggest the likelihood of a diabetic condition and are coded as 1. A value above 120 bpm is a hypertensive cases, it is also coded with digit 1 and it is given a threshold value to be output by the neuron. The effect is that the heartbeat works slowly and the value guides the neurons to get closer to the threshold output.

F. Skin Disorders Progression and Potential Outcomes

The input neuron to use for this condition is the color of the skin. The neuron can be classified as: normal skin, (dark, light) with code 0, this condition of skin indicates no disorder, while the skin disorder (brown, yellow, red) is coded with digit 1. The early stage of skin disorders such (xerosis, callus and fissures) are neglected by the neurons, as they are under diagnosed [10]. Lack of diagnosis and treatment of early-stage skin disorders can lead to clinical worsening and progression to foot neuropathy, ulcers and even amputation [11].

G. Body Temperature

Insulin increases temperature in type I diabetes, due to the absence of insulin, while it leads to chronic conditions for type II. The normal temperature for a non-diabetic case is 37°C, this coded with 0, while a temperature at about 50°C is coded as 1. Temperatures below 30°C are also considered abnormal and a sign of a diabetic situation and coded as 1.

H. How the Connecting Variables Are Framed into Neural Network

All the variables above are connected to the symptoms that give the indications for the presence of the disorders, e.g. high blood pressure and combining them into a body of intelligent detecting devices (sensors) representing each neuron. The sensors that are used have the attributes that replicates each neuron in terms of signals and are used for the detecting purposes.

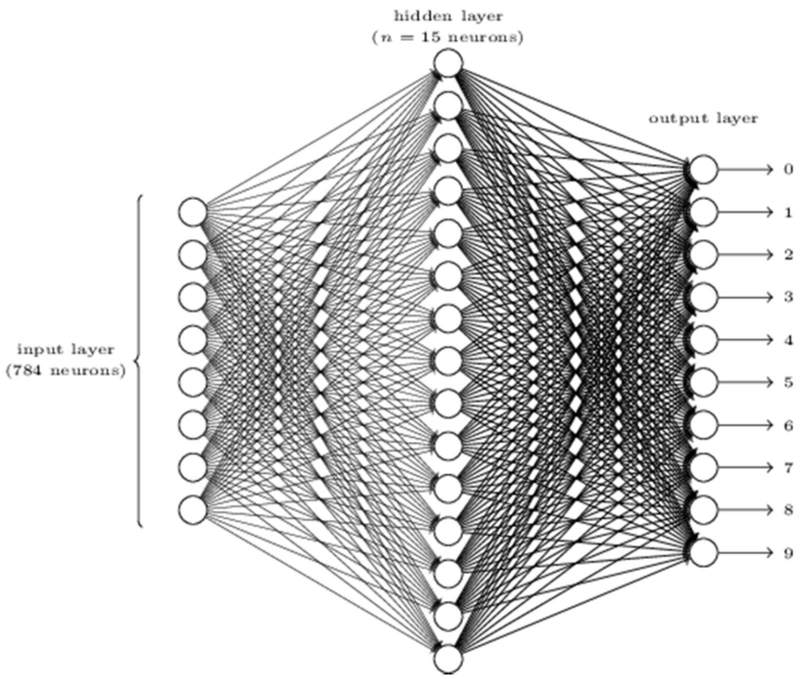

Fig. 1 The Neural Network Architecture

V. The Neural Network Architecture

Neural network used in this research intends to mimic the human brain in terms of acting and receiving information from the outside world to form an intelligent system [12]. The neural network architecture is made up seven neurons as exclusive OR (XOR) inputs, and hidden layers of 15 neurons as the processor before the output, as shown in Fig. 1.

A. Coding Method and Assignment

The methods of coding and assignment adopted in this research are born out of the fact that certain cardiovascular parameters can be used to express diabetic condition. The input neurons are taken separately with their classifications as a continuous input. For example the blood vessel, classified as arteries, veins and capillaries, as discussed below.

The first input neurons and their classifications used for the detection of the symptoms in the blood vessels are: arteries, capillaries and veins. The concept behind this coding is born out of the fact that resistance arteries are small arteries or arterioles with smaller diameter and can contribute to creations of the blood flow resistance. In line with the research conducted by [8], here the normal size of the ulna and radial artery were found to be 2.2±0.4 mm, 2.3±0.4 mm, these estimated values have been used in the coding procedures. Five classifications are used to link the input neurons to the hidden layers as follows: Arteries (normal, lower level, normal upper level, symptom cases) which are equivalent to (2.2, 2.3, 2.6, 2.7 0.5), capillaries (2.2, 2.3, 2.6, 2.7, 0.5), veins (2.2, 2.3, 2.6, 2.7, 0.5), all measured in millimeters and the last value is regarded as the symptom cases. The normal values are coded with digit 0, while the last values indicating the symptom cases are coded with digit 1.

The second input neuron is the nerve cells, which has the following classifications to guide the neurons in recognizing the status of a person as having or not the high blood glucose levels. The symptoms such as fever, headache, fatigue, weight loss and rashes are used as classifiers that link the hidden layers. They are coded all through with digit 1.

The third input neurons is the blood pressure and their classifications as normal, high, and hypertensive; these are further classified using the standard values of diastolic and systolic cases; The combinations making up the third neuron (Blood pressure) are classified as: standard normal values, (diastolic, systolic), high blood pressure (diastolic, systolic) and hypertension (diastolic, systolic). Their respective values are: 120 mmHg, 110 mmHg, 100 mmHg, 70 mmHg and 80 mmHg; these values are all coded with digit 0 as the threshold value for a normal person with no trace of high blood glucose levels that leads to diabetes cases. The high blood glucose and their respective values are 139 mmHg, 130 mmHg, 89 mmHg, and 85mmHg; these are coded with digit 1 to guide the neurons to output 1 as the threshold value for pre-hypertensive condition and the likelihood of the person having traces of high blood glucose levels that lead to diabetes. The hypertensive cases input neuron classifiers are 159 mmHg, 130 mmHg, 140 mmHg, 99 mmHg, and 90 mmHg. These values are all coded with digit 1 to guide the neurons to output 1 as the threshold value for the hypertensive condition, and represent the likelihood of a person having a high degree of raised blood glucose levels that lead to diabetes.

The fourth input neuron is the human pulse rate and their classifications as normal, diabetic, high sugar level. These are further classified as: Normal (100 bpm, 90 bpm, 80 bpm, 70 bpm, and 60 bpm), which is coded with digit 0 to guide the neurons to the output 0 command for a normal person with a regular pulse rate. Diabetic (40 bpm, 30 bpm, 20 bpm, 15 bpm, and 10 bpm), which is coded with digit 1 to guide the neurons to output 1 as the threshold value for a person with a high pulse rate and high sugar level (8.0 mmol, 7.0 mmol, 6.0 mmol, 5.0 mmol, and 4.6 mmol). These are coded with digit 1 to guide the neurons that sugar levels have dropped with the increase in pulse rate of about 120bpm.

The fifth input neuron and their classifications is skin disorder, which is further classified as dark, light, brown, reddish and yellow colors. The neuron can be classified as: Normal skin, (dark, light) with code 0; this condition of skin indicates no disorder, while the skin disorder (brown, yellow, red) are coded with digit 1 to guide the neurons to the output digit 1 as the threshold value for symptom cases. The early stage of skin disorders such (xerosis, callus and fissures) are neglected by the neurons, as they are under diagnosed.

The sixth input neuron and their classification is body temperature. The normal temperature for a non-diabetic case is 37 °C; this is coded with digit 0, while a temperature at about 50 °C is coded with digit 1 to guide the neurons for symptom cases. The classifications for normal, abnormal, and hypertensive with values of 37 ºC, 30-50 ºC and 60 ºC, respectively, were used in the coding as: 01111, indicating the normal, abnormal, and hypertensive cases.

The seventh input neuron and their classification is the blood flow rate/flow resistance measured in terms of Hydrostatic pressures (130 mmHg, 86 mmHg, 14 mmHg, 4 mmHg and 2 mmHg), the arteries size, and hydrostatic pressure. The various continuous input vales for arteries size are: 2.3 mm, 2.7 mm, 2.6 mm, 1.8 mm, and 6.5 mm; the first four values are for a normal human with no case of diabetes and is coded with digit 0, while the last value is the threshold value that the neuron is looking for to assign the symptom case. For the last classification, Hydrostatic pressure (139 mmHg, 138 mmHg, 120 mmHg, 110 mmHg and 80 mmHg), and the normal values (80-120 mmHg) are coded with digit 0, while higher Hydrostatic pressures are coded with digit 1 as the threshold value to guide the neurons.

The last digit is always coded with digit 1, and they are biases connected to all the input neurons for easier classification.

B. Selection Procedures

The selection process is that in each of the variables $X_{1,} X_2, X_{3,} X_{4,} X_{5,} X_{6,} X_{7,} 1$ the inner products are chosen in order; $x_1^1, x_1^2, x_1^3, x_1^4, x_1^5, x_1^6, x_1^7$,1; the last digit is always the bias node attached with each layer. Table I represents the selection process as they are supplied to the neural algorithm.

TABLE I
RECORDED CASES AND CODING SHEET

A_1	0	1	0	0	0	0	0	1
B_1	0	1	0	0	0	1	0	1
C_1	0	1	0	0	1	1	0	1
D_1	0	1	0	0	1	1	0	1
E_1	1	1	0	0	1	1	1	1
A_2	0	1	1	1	0	0	0	1
B_2	0	1	1	1	0	1	0	1
C_2	0	1	1	1	1	1	1	1
D_2	0	1	1	1	1	1	1	1
E_2	1	1	1	1	1	1	1	1
A_3	0	1	1	1	0	0	1	1
B_3	0	1	1	1	0	1	1	1
C_3	0	1	1	1	1	1	0	1
D_3	0	1	1	1	1	1	0	1
E_3	1	1	1	1	1	1	0	1

VI. RESULTS AND DISCUSSION

The hardware requirements for the complete design of a wearable monitoring meter that continuously measures the status of some cardiovascular parameters is that they must be conformable to a particular sensory device which is used as input sensor neurons. In this process, each neuron was configured to a particular sensor which measures the input signals and relates the message to the hidden layers through the sigmoid activation function, and to the output neurons which are the LEDs to show that a symptom exists or not. In this regard, 10 LEDs were used with designated colors; WHITE represents a normal condition without the high glucose levels that lead to diabetic conditions. RED was used as an indication for the neurons to output a severe case of hypertension, while YELLOW was used to warn of skin disorders, which is one of the symptoms of high glucose levels. The BLUE LED is to inform the neurons and give an indication that a patient has some abnormality associated with their blood vessels such as constriction of the wall of the arteries which results in restriction in the flow of blood.

The neural network was supplied with an input and expected output result in an XOR pattern, which means that the network is expected to provide a result when either of the cases exist. The machine learning procedures used in this research suggested other color pigments of the LEDs for some output which ordinarily are too complex to provide an answer or intricate for human prediction.

The color differentiations are used in the model and design of the metering device to show the severity of symptoms in particular cases of persons living with high glucose levels.

VII. CONCLUSION

The neurons showed that the device is actually intelligent in predicting future occurrences, through the early detection of symptoms requiring intervention. The machine learning algorithm is efficient to be used as a generic type for the modeling of a health monitoring device.

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