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Design and Implementation of FPGA based Instrumentation for Separation and Evaluation of Cholesterol Using Empirical Law and RBF ANN

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ABSTRACT

In the present day automation, the researchers have been using microcomputers and its allies to carryout processing of physical quantities. The latest trend is to use FPGA counter parts, as these devices offer many advantages in comparison with Programmable devices. These devices are very fast and involve hardwired logic. FPGA are dedicated hardware for processing logic and do not have an operating system. That means that speeds can be very fast and multiple control loops can run on a single FPGA device at different rates. In this paper, an attempt is being made to develop an instrumentation system to sense the Cholesterol, RBC & WBC from blood sample which finds the counts of cholesterol, RBC and WBC using empirical law. The count values of Cholesterol, RBC and WBC are classified using Radial Basis function (RBF) Artificial Neural Network. The count values of Cholesterol, RBC and WBC are displayed on LCD.

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INTRODUCTION

The History of centrifuge method has evolved since bygone days starting from the crudest method involving egg beaters, and manual rotating mechanisms involving spring. Later the improved versions employed electrically driven motors to achieve the centrifuge mechanism. Of late due to the tremendous improvement in power electronic technology, the centrifuge with precision control has been used. This paper involves a mechanically indigenously designed centrifuge to avoid vibrations and achieve the required goal with precision by incorporating power electronic control that spins the centrifuge at variable speeds (Kumara, G., 2015; Chen, S., 1993; Kirti, B., 2014; Ujwala Bollampalli, 2013 Dr. B.S. Grewal). The system also uses a FPGA module interfaced to 12 bit ADC (successive approximation type) to get the voltage levels by suitable sensors built in the mechanical set up. A LCD panel is also interfaced to FPGA to record the values of Cholesterol RBC and WBC count, which are obtained by judiciously implemented software. A hit and miss method was used by conducting several experiments to determine the best fit to select the hematocrit (Capillary). Finally we arrived at the conclusion that a capillary with the dimension of 2mm (dia) and 100mm (length) was selected. The table 1 shows a series of experiments performed on the centrifuge assembly to critically evaluate the counts of RBC and WBC depending upon the speed of the motor. From the table it is identified that the counts of RBC and WBC are acceptable when the centrifuge speed is about 10,000 rpm. Hence a dc motor having the capability to rotate at this speed is selected (3-18). . The count values of Cholesterol, RBC and WBC are classified using Radial Basis function (RBF) Artificial Neural Network (Kumara, G., 2015)

MATERIALS AND METHODS

I. *Methodology:*

The figure 1 shows the mechanical assembly drawn to scale on solid edge platform and all dimensions are in millimeters.

The mechanical assembly is fabricated using steel components to get the required strength. The motor is rigidly held with vice (variable), so that any size of the motor can be placed in the event of replacement. A capillary holder is mounted on the shaft of the motor made of plastic. The plastic holder has intermittent openings to allow the light rays from IR LED to pass through the capillary tube and fall on the photo transistor as Photo Detector for further processing by

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the electronic counterpart. The figure 1 clearly depict the mechanical structure of the low cost centrifuge designed. The bearing used to suspend the capillary along the rotor axis is achieved using a high speed bearing with 22,000 rpm. This speed can be set by the power electronic card to achieve the required speed. In order to achieve the desired speed, oiled cooled high speed bearing is used. This bearing also reduces the friction with the reduction in noise levels.

TABLE I. OPTIMIZATION OF CAPILLARY TUBE

Sl. No.	Diameter (mm) of capillary tube	DC Motor Speed (rpm)	Spinning time (min)	Observation of blood sample in capillary
1	2	1000 - 10000	3	No layers formed
	2	1000 - 10000	4	No layers formed
	2	1000 - 6000	5	No layers formed
	2	6001 - 9000	5	Interleaving of RBC, WBC & plasma
	2	10000	5	Three distinct layers formed
2	3	1000 - 10000	3	No layers formed
	3	1000 - 10000	4	No layers formed
	3	7000	5	Interleaving of WBC and plasma
3	4	1000 - 10000	3-5	No layers formed
4	6	1000 - 10000	3-5	No layers formed

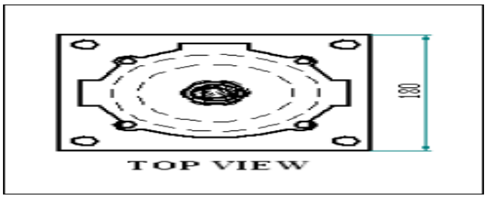

Fig. 1a: Top View of the Separation part mechanical assembly.

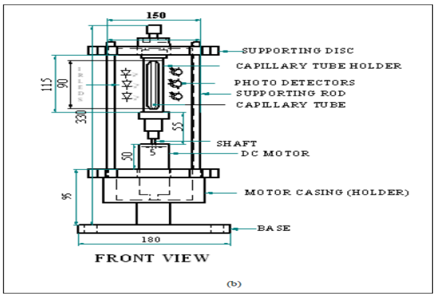

Fig. 1b: Front view of the Separation part mechanical assembly.

A. Hardware of the Electronic Setup:

The figure 2 shows the electronic hardware built around a FPGA along with the ADC, drive, SSR and the display units. Field Programmable Gate Arrays (FPGA) is integrated circuit with Programmable logic cells and interconnections. The FPGAs are flexible and functionality can be changed as needed (Kirti, B., 2014; Ujwala Bollampalli, 2013; Sindhu, T. and C. Nagavani., 2015). The technology is concurrent, and new modules can be added without altering the existing design. These properties make it possible to add new features and perform system maintenance at a low cost and engineering effort. A fully tested and verified FPGA design can easily be transferred to a full custom Application Specific Integrated Circuit (ASIC) facilitating large scale production. The combination of concurrency, flexibility and low power consumption, makes the FPGA well suited to portable systems (Raja Thilagam, A. and Dr. R. Suresh Babu., 2015).

B. Driver Card:

This card is having a chopper circuit designed with thyristors of high current rating. The PWM technique involved enables to achieve variable speeds through the pot which serves as an input command.

C. Solid State Relay:

A solid state relay is used as an interface between the FPGA and the motor drive card. This helps to isolate the high power circuit and the FPGA platform. The relay also snubs any high voltage surge and current resulting from the inductive component present in the motor winding.

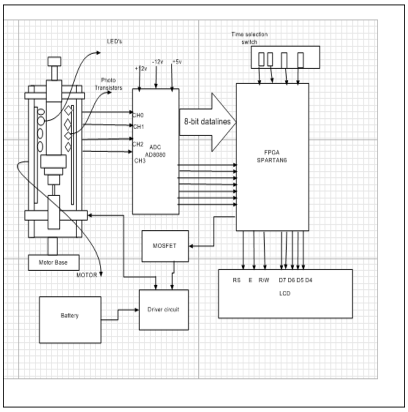

Fig. 2: Circuit diagram of the FPGA based instrumentation System.

A. IR LED's:

The IR LEDs, placed co-axially with the photo transistor, develop a voltage in the range of 0-5V that is assimilated by the 12 bit ADC. This digital value obtained is processed by the soft processor built in the FPGA to evaluate the RBC and WBC count values. The logic developed to achieve this is purely based upon an empirical relationship defined by equation 1.

B. LCD Panel:

The LCD panel used is capable of displaying the cholesterol, RBC and WBC count values obtained by the ADC in alpha numerical format. The specifications of the LCD panel used are 16 characters in two rows (Moorthi, V.R., 2009). The fig. 3 shows the separation of RBC and WBC segments after centrifuge is spinned for a various time period (Kalaiselvan, S.A., 2015).

A. Real Time blood sample in the plasma tube:

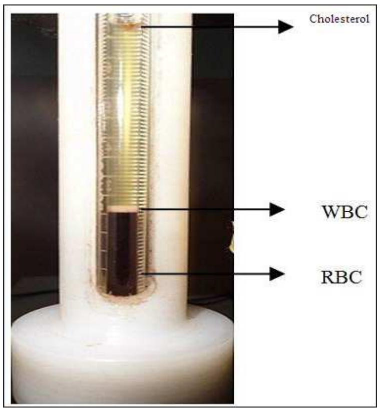

Fig. 3: Cholesterol in Blood sample in plasma tube.

The collected blood samples are placed in the plasma tube as in Fig 3.The plasma tube is placed in the DC motor tube which will be rotated at 10,000 rpm. The speed will be measured using tachometer for various duration. After five minutes three different layers will be formed as shown in Fig 3. The bottom layer is RBC, top layer is Cholesterol and middle is WBC (Emimanothaya, A. and Dr. R. Suresh Babu., 2015).

I. Realization Of The Software:

In many instances it is required to express a given data, obtained from observations, in the form of a law connecting the two variables involved. Such a law, inferred by some scheme, is known as the Empirical law. In our case, it is required to obtain the law connecting the voltage measured and the evaluation of cholesterol, RBC and WBC at various voltages obtained by the photo transistor. Several equations of different types can be obtained to express the given data approximately. But the problem is to find the equation of the curve of best fit which may be most suitable for predicting the unknown values. The process of finding such an equation of best fit is known as Curve-fitting. This method is expressed by the equations 1 to 9 that can be reduced to a linear one. This law reduces the data obtained in a linear fashion and this law is described below. The law is used to determine RBC and WBC count values from the digital data sensed from the ADC, indicating the way this can be reduced to the linear form by suitable substitutions:

The derivation of the empirical law based on least square fitting is discussed below.

$y=ab^x$-------------- (1)

Taking log on both sides, equation 1 becomes

$\text{Log } y=\log (ab^x)$

$\text{Log } y= \log a +\log b^x$

$\text{Log } y= \log a+x\log b$

$Y= A+xB$-------------- (2)

Where Y = log y, A= log a and B=log b,

Normal equation From equation 2

$\varepsilon Y=nA+B\varepsilon x$-------------- (3)

$\varepsilon xY=A\varepsilon x+B\varepsilon x^2$-------------- (4)

Where n is the total number of observations

Solving equations 3 and 4, we get A &B values

a=eA, b=eB-------------- (5)

For RBC n=19, The eqn 3 & 4 becomes

292.6351=19A+16.29B -------------- (6)

249.3857=16.29A + 15.7737B -------------- (7)

Solve eqn. 6 and 7

A=16.1184 B= -0.8358

Eqn. 5 becomes

a=10003043.95 b=0.43352

By equating different values of x in eqn.1 and obtain the different values of RBC count as shown in Table 2. An example is given below to show the validity of the results. eg. x=1.25 Then y=3518792.

Similarly for WBC n=19, the eqn. 3 and 4 becomes

168.2=19A+33.95B-------------- (8)

299.33=33.95A+61.5027B -------------- (9)

Solve eqn. 8 and 9

A=11.4429073 B= -1.449638844

Eqn. 5 becomes

a=93237 b=0.234

By equating different values of x in Eqn1 and obtain the different values of WBC count as shown in Table 3.

For eg. x= 1.88 Then

y=6077

Based on the above equation the values of cholesterol, RBC and WBC are mathematically calculated from Equation 1 and these values are displayed on the LCD.

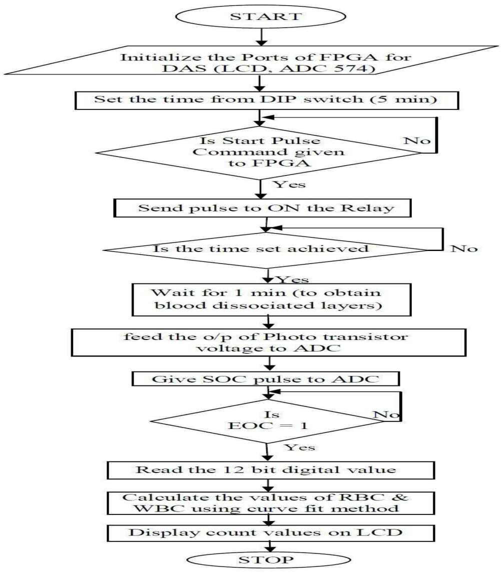

Fig. 4: A Flow chart of the instrumentation System.

In order to attain the required cholesterol, RBC and WBC count values a 8 bit ADC of successive approximation is used as it is readily available in the market at low cost and also exhibits fast conversion rates at micro seconds. Once the IR LED and Photo transistor sense the sedimentation by the light incident on the photo transistor, a voltage is generated based on the opaqueness of the regions formed. This voltage is digitized by ADC to get the binary outputs for further processing. The firmware developed is empirically derived using curve fitting method to get the RBC and WBC count values to mimic the readings obtained from standard test equipment (Viswanath, K. and R. Gunasundari, 2015). The experimentation is carried out repeatedly to prove the effectiveness of the empirical relationship. This relationship is mathematically expressed in equation $y=ab^{x.}$ The total firmware developed is explained as shown in the flowchart (figures 4a & 4b).

I. Multilayer Back Propagation Network (MBPN):

Multilayer networks solve the classification problem for nonlinear sets by employing *hidden layers*, whose input neurons are not directly connected to the output (Handouts Introduction to FPGAs", 2009). The additional hidden layers can be interpreted geometrically as additional hyper-planes, which enhance the separation capacity of the network. A complete architecture in training and making decision on kidney class using multi-layer back propagation network has two sections namely training and application sections. In training section the networks are trained and their weights are stored. In application section the weights and a new data are used by the networks to produce the output. The outputs of the specialized networks are then fed into the integrated network. The step-by-step processes in multi back propagation network application and the role of integrating network are as follows:

Step 1:

For each specialized networks
Loading : Load input data
Load weights values
Testing : Feed into the network
Apply the weights
Output : Store the output.

The training ANN network with automatic weight update to classify Cholesterol, RBC and WBC layers after 10,000 rpm of DC motor. After 5 minutes all three layers are formed. The ADC reads the analog data from all three layers and converts into digital. The digital bits are processed by empirical law and processed values by empirical law will be classified by RBF ANN.

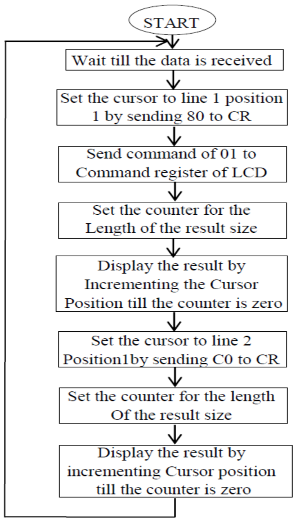

Fig. 4: b) Flow chart of LCD.

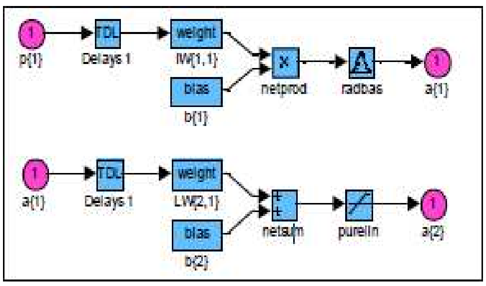

Fig. 5: Hidden and output layer of RBF.

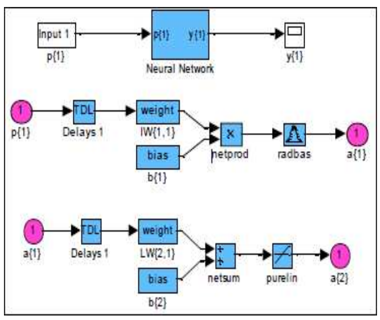

Fig. 6: RBF Simulink model for classification.

I. *Results:*

Table 2 , Table 3 and Table 4 show the empirically evaluated results with respect to Standard values of RBC, WBC and cholesterol obtained by standard test equipment's (Standard hematology Analyzer, UBM Fx-19 Plus).

TABLE II. RBC Vs ADC VOLTAGE READOUTS

RBC Vs ADC readouts					
x (voltage in volts)	$Y=\log_e y$	x^2	xY	$Y=ab^x$ (Experimental Value) RBC count / µl	UBM Fx-19plus (Standard reading - Auto hematology Analyzer) RBC count / µl
1.35	14.949	1.8225	20.18208	3236640	3100000
1.30	15.0094	1.69	19.51222	3374769	3300000
1.25	15.0739	1.5625	18.842375	3518792	3520000
1.16	15.1509	1.3456	17.575044	3793698	3800000
1.10	15.2018	1.21	16.72198	3988799	4000000
1.09	15.2142	1.1881	16.583478	4022278	4050000
1.00	15.2857	1.00	15.2857	4336519	4350000
0.96	15.3199	0.9216	14.707104	4483951	4500000
0.93	15.3524	0.8649	14.277732	4597806	4650000
0.91	15.3736	0.8281	13.989976	4675310	4750000
0.85	15.4249	0.7225	13.111165	4915751	5000000
0.79	15.4832	0.6241	12.231728	5168558	5300000
0.76	15.5111	0.5776	11.788436	5299795	5450000
0.65	15.5905	0.4225	10.133825	5810160	5900000
0.58	15.640	0.3364	9.0712	6160237	6200000
0.48	15.7026	0.2304	7.537248	6697250	6600000
0.40	15.7614	0.16	6.30456	7160376	7000000
0.38	15.7798	0.1444	5.996324	7281077	7130000
0.35	15.8102	0.1225	5.53357	7465955	7350000
$\sum x=$ 16.29	$\sum Y=$ 292.6351	$\sum x^2=$ 15.7737	$\sum xY=$ 249.3857		

TABLE III. WBC Vs ADC VOLTAGE READOUTS

WBC Vs ADC readouts					
x (voltage in volts)	$Y=\log_e y$	x^2	xY	$Y=ab^x$ (Experimental Value) WBC count / µl	UBM Fx-19plus (Standard reading - Auto hematology Analyzer) WBC count / µl
1.49	9.259	2.2201	13.79591	10708	10500
1.51	9.2399	2.2801	13.95220	10401	10300
1.53	9.1590	2.3409	14.01327	10100	9500
1.55	9.13777	2.4025	14.16354	9814	9300
1.60	9.10498	2.5600	14.567968	9127	9000
1.64	9.04782	2.6896	14.8384248	8612	8500
1.66	9.03599	2.7556	14.9997434	8365	8400
1.69	9.01797	2.8561	15.2403693	8008	8250
1.72	8.96188	2.9584	15.4144336	7667	7800
1.76	8.93590	3.0976	15.727184	7234	7600
1.79	8.88183	3.2041	15.8984757	6926	7200
1.83	8.77955	3.3489	16.0665765	6535	6500
1.88	8.69951	3.5344	16.3550788	6077	6000
1.92	8.66561	3.6864	16.6379712	5734	5800
1.97	8.63052	3.8809	17.0021244	5333	5600
2.05	8.52714	4.2025	17.480637	4748	5050
2.09	8.42288	4.3681	17.6038192	4480	4550
2.13	8.34283	4.5369	17.7702279	4226	4200
2.14	8.31874	4.5796	17.8021036	4165	4100
$\sum x=$ 33.95	$\sum Y=$ 168.2	$\sum x^2=$ 61.5027	$\sum xY=$ 299.33		

I. *Discussion:*

The experimental set up realized by FPGA platform gives precise results and complies with the results obtained by standard equipment. The cost of the set-up is very economical and can be further slashed on mass production. The system can be made handy and economic if the Whole hardware can be compiled into ASIC design, and can be a promising instrumentation for the physicians working in the rural areas as the system requires power available from a battery source. Since the power source is derived from the 12V battery, it is safe to handle. The power consumption of the entire set up is in the order of 200 Watts. The battery used requires to be charged once in a fortnight to be efficiently used.

Table IV: Cholesterol Vs Voltage Readout.

Cholesterol Vs ADC readouts					
X (voltage in volts)	$Y=\log_e y$	x^2	xY	$Y=ab^x$(Experimental value)RBC Count/µl	UBM Fx-19plus (standard reading auto hematology Analyzer) RBC count/µl
2.13	6.241	4.5369	13.2933	1744427	174420
2.15	6.328	4.6228	13.6052	2130241	2130235
2.17	6.4152	4.7089	13.9209	2601387	2601390
2.20	6.5453	4.84	14.3996	3510501	3510500
2.25	6.7623	5.0625	15.2151	5785079	5785075
2.27	6.84908	5.152	15.5472	7064564	7064560
2.29	6.93586	5.244	15.882	8627033	8627030
2.35	7.196	5.522	16.910	15710495	15710490
2.42	7.4999	5.856	18.1478	31615935	31615930
2.47	7.7168	6.1009	19.0604	52101025	52101020
2.51	7.8903	6.3001	19.80	17695955	17695950
2.55	7.06395	6.502	18.01	11586455	11586450
2.62	7.36766	6.86	19.301	23316685	23316680
2.69	6.67138	7.236	17.942	4692275	4692270
2.71	7.758	7.344	21.02	57300605	57300600
2.75	6.93171	7.562	19.062	8544985	8544980
2.85	7.3655	8.1225	20.99	23205545	23205540
2.95	7.7994	8.70	23.07	63019105	63019100
3.00	7-01641	9	21.00	10385142	10385140
$\sum x=$ 47.33	$\sum y=$ 127.3373	$\sum x^2=$ 119.2726	$\sum x\,y=$ 336.1765		

Fig. 6: Dispalying of Cholesterol, *RBC and WBC.*

I. Conclusion:

The entire setup was built by using add on cards for each section i.e., ADC 12 bit AD574, FPGA XC6S40t and LCD DEM 16216. A dc motor (12V, 3.3 A) capable of running at a speed of 10,000 rpm along with drive card was used to get the desired result. The empirical law and RBF ANN are calculated exact values of Cholesterol, RBC and WBC values and displays on LCD.

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