EXPERIMENTAL IMPLEMENTATION OF EMBARRASINGLY PARALLEL PROCESS IN ANALYSIS OF BLOOD GLUCOSE CONCENTRATION USING ATMEGA32 MICROCONTROLLERS

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ABSTRACT

This paper explains the development of a embedded based parallel system to measure glucose concentration of the blood samples. The developed instrument works on the principle of absorbance transmittance photometry using ATmega32 microcontrollers. In order to handle more blood samples and reduce the response time of glucose analyzing process in large number of blood samples, the embarrassing parallel measurement operation is implemented. The proposed system architecture and the co-design of hardware and software are discussed in detail. The system is evaluated using the parameters of Speedup Factor, Efficiency and Throughput are studied. The result shows that system attained the linear speedup in measurement of blood samples.

KEYWORDS

Parallel Process, Embedded System, Glucose Concentration, Microcontroller, Clinical Blood Analyzer.

1. INTRODUCTION

Diabetes has become a development issue and it threatens the health and economic prosperity of people in low and middle-income countries, the International Diabetic Federation (IDF) report said. It also predicted that diabetes would cost the world economy at least $376 billion in 2013..2. India leads the world in the number of people suffering from diabetes and by 2030, nearly 9 per cent of the country's population is likely to be affected from the disease. Unless serious action will be taken the epidemic of diabetes would increase from 7 million new cases to 10 million new cases in this year [1].

Diabetes is a common disease related to endocrine metabolism. At present there is no method which can cure diabetes totally. The main therapy is to prevent or alleviate the occurrence of complications through frequent monitoring and adjustment of glucose level. Physicians suggest that the glucose level should be tested at least four times per day. Nowadays the diabetes patients are taking treatment at a specialized centre, in which the great number of blood samples should be analyzed in effectively with stipulated period and prepare the analyzes report.

The methods of clinical analyzing can be classified as direct method and indirect method. The clinical laboratories are following mostly indirect methods to analyze the blood contents. In indirect methods the techniques of spectro photometric, polarometric, amperometric, electrochemical, coulometric, polarography, radiochemical and fluorescence are available [2,3]. The instrument proposed in this paper is designed using the principle of absorbance transmittance photometry. It is a high performance multi-microcontroller-based, photometric biochemical analyzer to measure the glucose concentration. It also modifiable to measure various biochemical parameters such as blood Sodium, Potassium, Chloride, Urea and Bilirubin.

In recent years, automation in clinical chemistry has progressed with a change from rigid to very flexible instruments. Automation of clinical instruments has brought about a revolution in the field of medical instrumentation. It has reduced the workload on clinical laboratories largely by reducing the time taken in the test and minimizing the involvement of laboratory staff. The functioning instrument in clinical process is distinguished as serial and parallel system. By using serial system, only one test can be conducted at a time, but the parallel system provides the advantages of high throughput and minimum response time.

It is necessary, screening the people for their blood glucose level monitoring should be intensified and provided necessary precaution steps by conducting Medical Camps. To do the glucose measurement in mass number of blood samples at a Medical Camp, the performance of serial clinical blood analyzer may not be enough by the view of time consuming and fault tolerance. In order to overcome the above problems, the Parallel Clinical blood analyzer could be a solution. The identified potential users of parallel blood analyzing system are Specialized Diabetic Centers, Primary Health Centers, Community Health Centers and District Hospitals. This work focused as an enhanced system in parallel environment to analyze the blood samples for glucose and other parameters. The proposed parallel measurement is designed using off-the-self microcontroller of ATmega32. The performance of the system is analyzed using more number of blood samples as workloads. A PC based solution is also possible for this work, but microcontroller based solution is more independent, hopefully more reliable, with cheaper running cost.

2. METHOD OF GLUCOSE ANALYSIS

The microcontroller-based instrument is designed using the principle of absorbance transmittance photometry. According to Lambert and Beer's law, when monochromatic light is passed through colored solution, the intensity of the transmitted light de-creases exponentially with the increase in concentration of the absorbing substance. The value of absorption of light energy is dependent on the number of molecules present in absorbing material and the thickness of the medium. Thus, intensity of light energy leaving the absorbing substance is used as an indication of concentration of that particular substance [4,3].

If I_0 is the intensity of incident light in colored solution and I_t is the transmitted light, then according to Beer's law

$$I_t = I_0 e^{-kct} \quad \ldots . \quad (1)$$

and transmission

$$T = I_t/I_o = e^{-kct} \quad \ldots . \quad (2)$$

or

$$\log_e T = -kct \quad \ldots . \quad (3)$$

or

$$\log_e (1/T) = kct \quad \ldots . \quad (4)$$

Where 'c' is the concentration of absorbing sample,'t' thickness of the light path, and 'k' absorption constant.

The quantity (-log T) or log (1/T) is termed as extinction E/OD or the absorbance.
A = log (1/T) = log 100 / (%transmission),
A = 2 - log (% transmission). …. (5)
Therefore A = kct. If t is constant, then A α c.

In this system, the basis requirement is to measure optical density/absorbance and then concentration of the test parameter under run accurately.

3. REQUIREMENT AND SCHEME OF PARALLELISM

The parallel-based glucose analyzing system is necessary when the large number of blood samples to be analyzed in a particular time span. Normally the blood glucose levels of diabetic patients are measuring before and after the breakfast. Therefore, the laboratory of specialized hospital, which is exclusive for diabetic patients get hundreds of blood samples for analyzing glucose level during morning session. By the way, introducing parallel measurement system, the turnaround time of a blood sample analysis will be minimized.

Parallel processing involves dividing a problem into parts in which separate processors perform the computation of the parts. An ideal parallel computation is one that can be immediately divided into completely independent parts that can be executed simultaneously. This is picturesquely called embarrassingly parallel or naturally parallel. Parallelizing these problems should be obvious and requires no special techniques or algorithm to obtain a working solution. Ideally, there would be no communication between the separate processors; that is, a completely disconnected computational graph, as shown in Figure-3. This situation will give the maximum possible speedup if all the available processors can be assigned process for the total duration of the computation. The only constructs required here are simply to distribute the task and to start the processes [6].

In a practical embarrassingly parallel computation, tasks are distribute to the different processors and results collected and combined in some way. This suggests that initially and finally a single processor must be operating alone. A common approach is the master-slave organization. The master processor is responsible to start and send initial data to all slave processors as well as collects the result from the slaves. The resulting structure is shown in Figure-4. In this work, the task of the measurement of glucose for the blood samples using absorbance method is implemented as embarrassingly parallel environment.

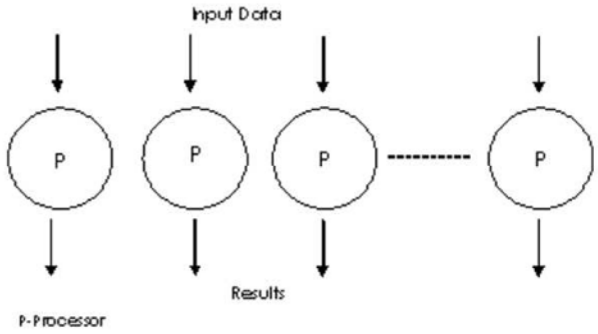

Figure 3 Graph for embarrassingly parallel problem.

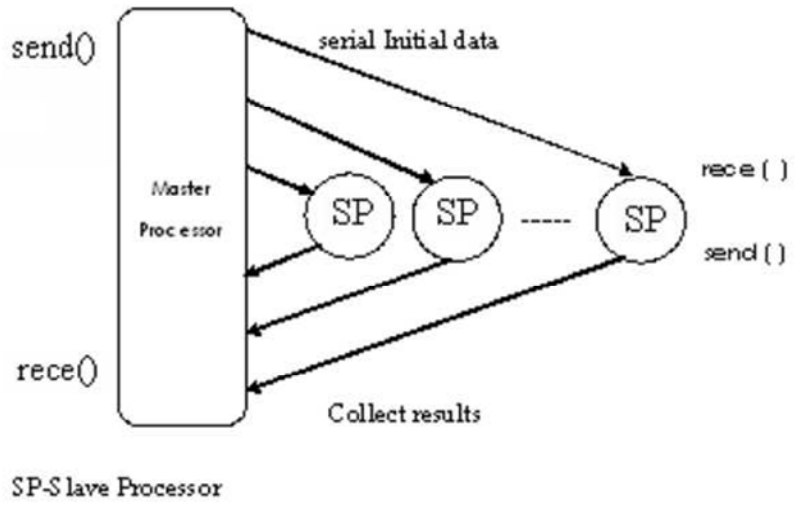

Figure 4 Practical embarrassingly parallel process graph with Master slave approach

4. DESIGN OF PARALLEL GLUCOSE ANALYSER

The parallel glucose analyzer is a complete system that consists of one master node and three sensor nodes. The master node acts as co-ordinate node, which is able to send commands to sensor nodes and receive the data from the same. The sensor nodes are connected with master node using I^2C bus and function as slave nodes [7,8]. The proposed system is able to handle four blood samples concurrently instead of one sample. The embarrassingly parallelism scheme, as depicted in Figure-4 is implemented using Atmega32 microcontrollers, which is shown in Figure-5.

The ATmega32 microcontroller has been found appropriate for this parallel blood analysis system. It is an 8-bit, CMOS, low power device composed of standard on-chip peripherals. The AVR core combines a rich powerful instruction set (131 instructions) with 32 general purpose working registers along with 8 bit CPU. This chip has 32k bytes of in-system programmable flash memory, 1024 byte EEPROM, 2k byte SDRAM, Master/Slave SPI serial interface, 32 general purpose I/O lines, flexible timer and counter with compare modes, internal and external interrupts and a programmable watch dog timer with power saving mode.

In the Figure-5, the master node is interfaced with 20 characters x 8 lines alphanumeric LCD display through Port-B. The Port-C is assigned to connect a key board, from which the user can activate the analyzer either in Mode-1 or Mode-2 operation. In Mode-1 all sensor nodes are assigned to measure the glucose level in blood sample by issuing command from master node. In Mode-2 each sensor node is exclusively assigned by master node to measure either glucose or sodium or potassium or urea contents in blood sample. Therefore, Mode-1 is used to measure the glucose level in all blood samples, which are loaded in the system. The Mode-2 is preferred when the blood samples are need to complete-analysis of three more parameters. The LCD panel is used to display the interactive menu to choose the option, date and time from the RT-clock, status of sensor nodes and its result. A thermal mini printer is interfaced through port-D, which is used for hard copy of the results, which are analyzed and sent by the sensor nodes.

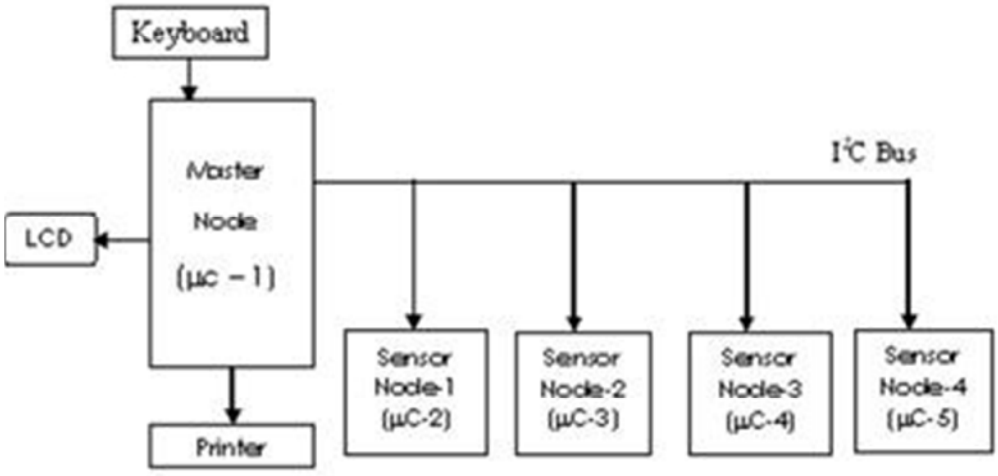

Figure 5 Master slave arrangements of microcontrollers for glucose measurement process.

The block diagram of sensor node arrangement is shown in Figure-6. Block-A is referred as light source, in which LED is used as source of light. In order to get required wave length of light to be passed, four different colors of LEDs have been mounted on a rotational disk. By choosing appropriate LED, the sensor node can be used to measure any one of the parameters along with suitable reagents. The rotation of the LED disk is controlled by a stepper motor, which is connected through the port-B (3 lines used) of microcontroller. Pulses are generated according to required sequence to rotate the motor at required angle, which brings the selected LED in front of light-path and activate that.

Block-B contains, sample holder, flow cell, peristaltic pump. The flow cell is used to mix the blood sample and reagents. The light beam of particular wave length is penetrated through the flow cell and come out from a narrow hole of opposite side. The port-B of sensor node is interfaced with a stepper motor that drives the roller type peristaltic pump. This pump is used in the system is aspirating the required volume of sample and reagents, washing the flow cell. While conducting the test, the contents of flow cell keeps at required temperature. The temperature sensor LM35 is used to measure the inside temperature of flow cell, which is connected to built in A/D converter through Port-A of processor. The peltier device is used to maintain the temperature of sample in required level, it works in both directions for cooling and heating. The Port-C has been assigned for the device.

Block-C contains photodiode sensor, which senses the light from the flow cell as input and produces the current with proportional to the light intensity. The amplified output of the photodiode has given to A/D converter through Port-A. The temperature sensor is also connected to A/D converter using Port-A to find the temperature of blood sample, which is in flow cell. Block-D has a four row 16 characters alphanumeric display, which is used to display the mode of operation, measuring parameters and its value, report of result sent to master node. The communication interface unit is in Block-E, the port-D (PD0 and PD1) is used to communicate with master node.

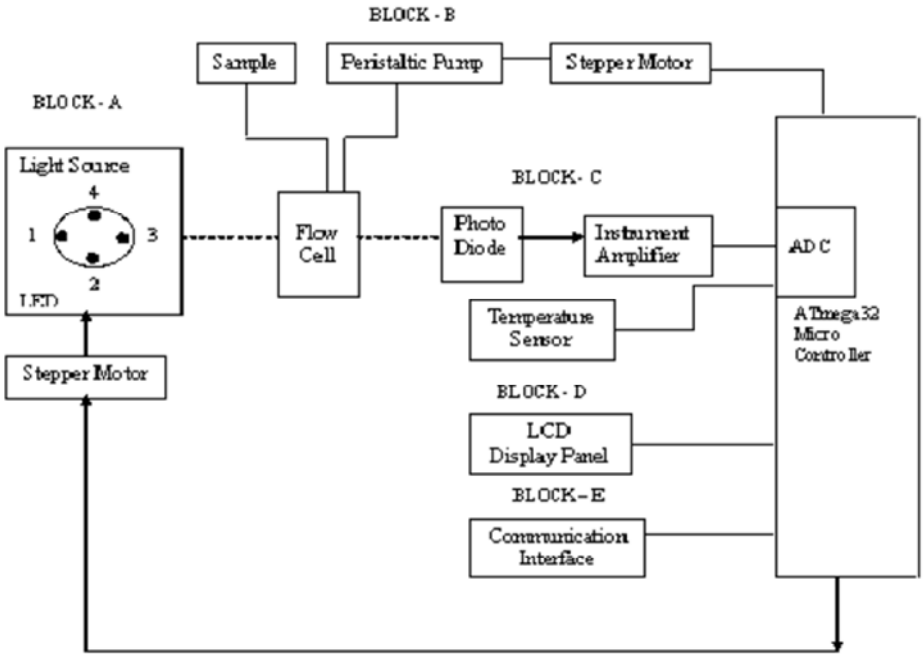

Figure 6 Block diagram of sensor node.

5. SYSTEM IMPLEMENTATION

The proposed parallel measurement is implemented as open loop system to measure the glucose concentration in blood samples. The software required for this system has been developed using 'C' cross compiler for ATmega32 in modular form. The software can be focused around two sides, i.e. one is master side and other one is slave sides. After the development of software, the program is stored into the EEPROM of microcontrollers. The layout of the steps followed in the development has been provided in the flow chart shown in Figures 8 and 9, as roll of the master node and sensor nodes respectively. The Talker-Listener principle is followed mutually while exchanging data among the microcontrollers. When the sensor nodes are communicate with master without collision by using 'Newhall-type loop' based method is adopted in coding level [9,10].

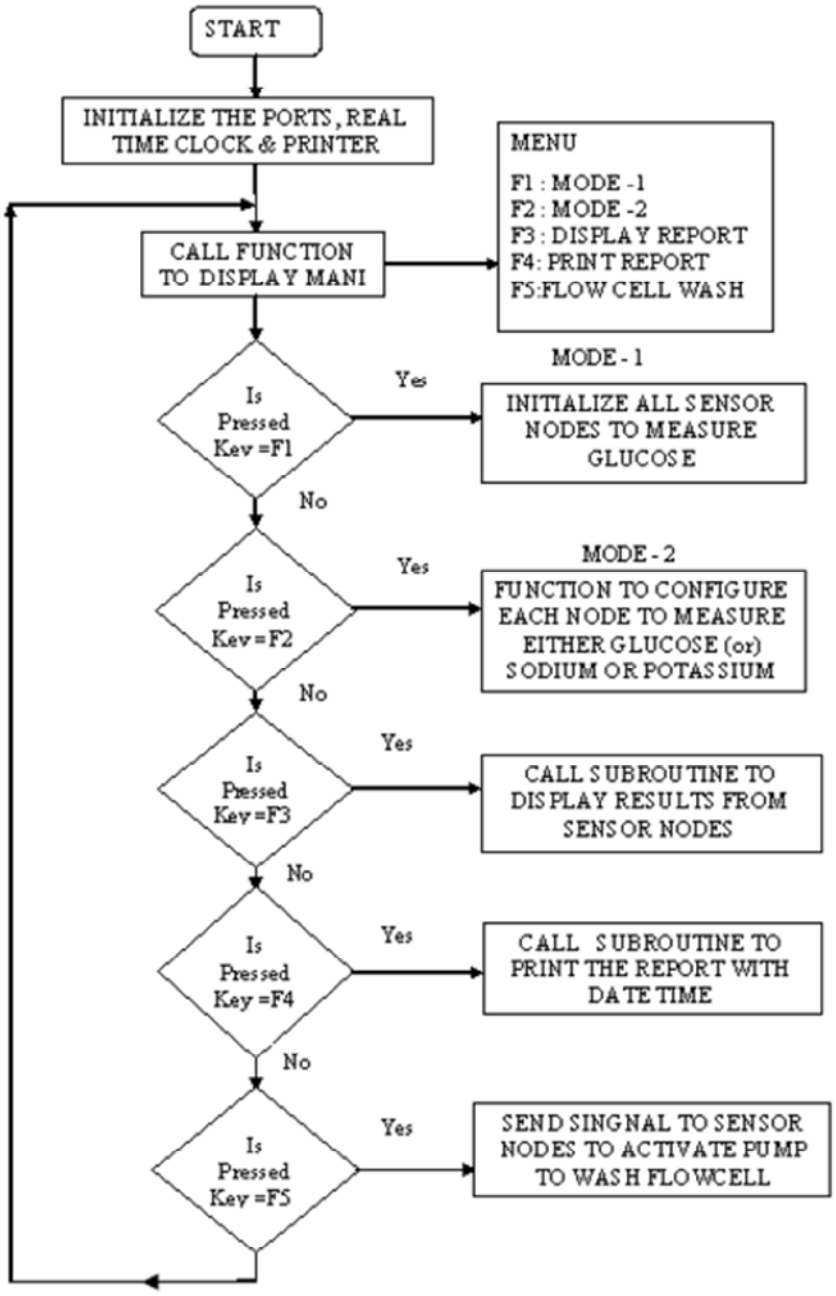

Figure 7 Flow diagrams for master node function.

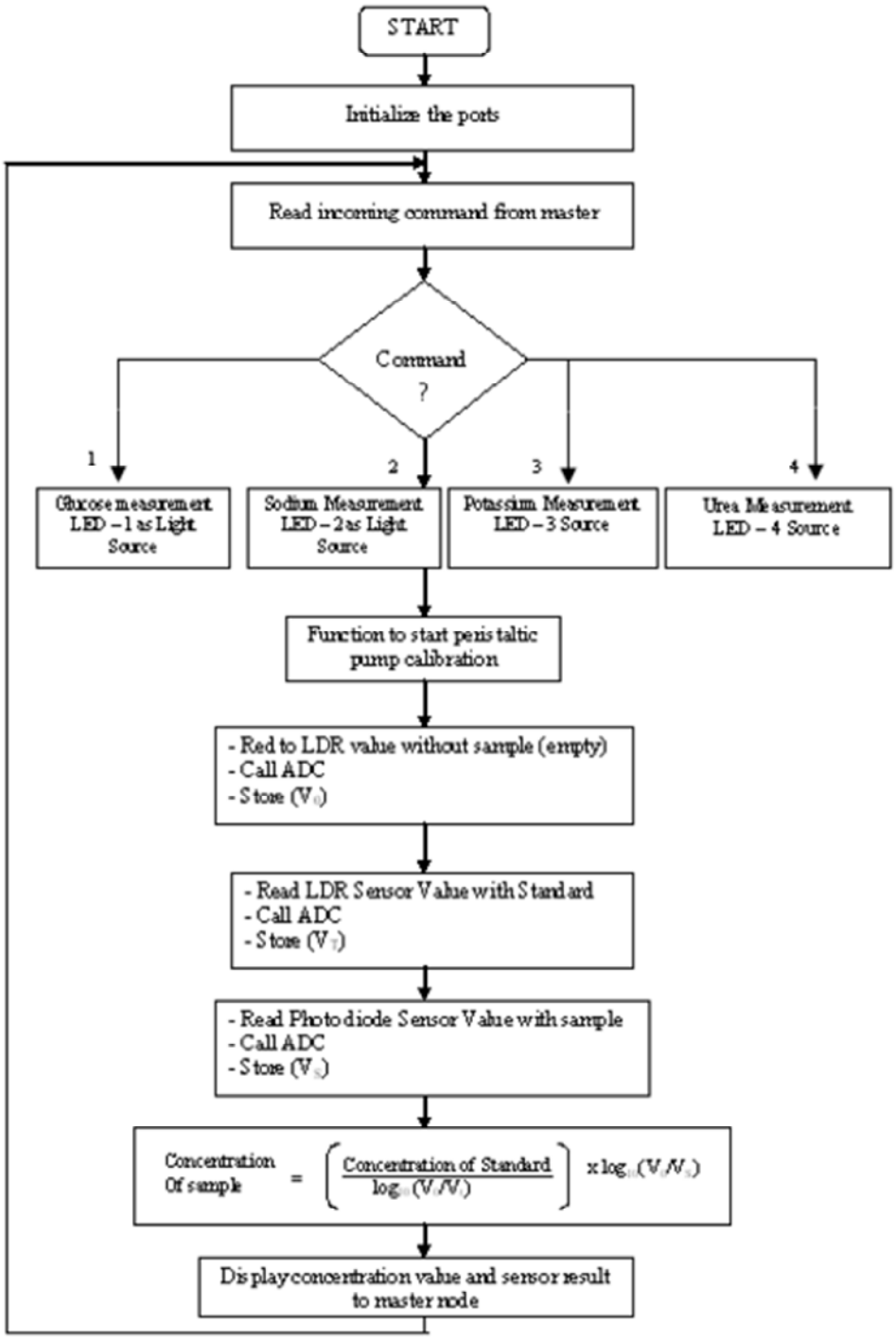

Figure 8 Flow diagram for slave/sensor nodes function.

6. METHODS OF SCHEDULING AND MEASUREMENT

On a single processor, the scheduling of blood samples for measurement is one-dimensional. On a parallel system, the scheduling is two-dimensional. The scheduling method has to decide

from the group of blood samples, which sample to analyze and which sensor node to analyze it on. The proposed parallel system has been designed to function in two Modes (1 & 2) in order to get the increased throughput and reduced response time respectively. The method of sample handling is differed in each mode. In Mode-1 'Gang' scheduling method is followed and in Mode-2 'Distributed Gang' scheduling is adopted [11,12,13].

In Mode-1, the function of all sensor nodes is set as to measure the glucose level of blood samples, which are loaded in the system. Here, all nodes do the identical process of glucose measurement, so the Gang scheduling is followed to bring out better performance, the Gang scheduling method has 3 parts.

1. Groups of sample formed as unit or a gang.
2. All members of gang measured simultaneously on different sensor nodes.
3. All gang members start and end their time slices together.

The Figure-9 shows the method of Gang scheduling applied in blood samples. If the proposed parallel blood analyzer with 4 sensor nodes get number of blood samples to analyze is 16, marked as S_0,S_1,S_2…….S_{15}. During time slot 0, samples S_0,S_1,S_2 and S_3 are scheduled to admit in to the system for measurement of Glucose. During time slot-1 samples A_4 through A_7 are scheduled to measure. Then the cycle repeats till the sample group A_{12} to A_{15} is measured.

The Mode-2 is implemented, when a group of blood samples need to complete analysis. Upon this mode, Sensor Node-1 is assigned to measure parameter of Glucose, Sensor Node-2,3 and 4 is allotted to measure Sodium, Potassium and Urea respectively. The single sample volume is distributed among the four sensor nodes and measure the corresponding parameters. The Distributed Gang Scheduling is mapped in this mode of operation, which is shown in the Figure-10. The gang is formed by grouping a blood sample as its sub groups. Blood Sample A_0 has sub- grouped as like S_{0g}, S_{0s}, S_{0p}, and S_{0u}. The sample group S_{0g} is used for glucose, S_{0s} for sodium, S_{0p} for potassium and S_{0u} for Urea.

	Sensor Nodes				
	1	2	3	4	
Time slots	GLUCOSE	GLUCOSE	GLUCOSE	GLUCOSE	
0	S_0	S_1	S_2	S_3	Gang-1
1	S_4	S_5	S_6	S_7	Gang-2
2	S_8	S_9	S_{10}	S_{11}	Gang-3
3	S_{12}	S_{13}	S_{14}	S_{15}	Gang-4

S_0 ..... S_{15} **Designated as blood samples**

Figure 9 Gang scheduling of blood sample feeding in mode-1.

	Sensor Nodes				
	1	2	3	4	
Time slots	GLUCOSE	SODIUM	POTTASSIUM	UREA	
0	S_{0G}	S_{0S}	S_{0P}	S_{0U}	Gang-1
1.	S_{1G}	S_{1S}	S_{1P}	S_{1U}	Gang-2
2.	S_{2G}	S_{2S}	S_{2P}	S_{2U}	Gang-3
3.	S_{3G}	S_{3S}	S_{3P}	S_{3U}	Gang-4

G - Glucose, P – Potassium, U – Urea, S – Sodium

Figure 10 Distributed gang scheduling of blood sample feeding in mode-2.

7. RESULT AND DISCUSSION:

Generally the roll of parallel system in measurement process is either increased the throughput or reduce the turnaround time . In this work of parallel processing in blood analyzer is supports both of the throughput as well as earlier response time, by way of implementing two modes of operation. The Mode-1 is increased the throughput of the system and the Mode-2 is giving speedup of the complete analysis process and submits the earlier response of results.

Evaluating the performance of a system is meaningful only in the context of a workload, that is, what the system is being asked to do. The parallel system is evaluated by using a group blood samples both in mode-1 and mode-2. The performance of parallel system is compared with against the single processor system with same group of blood samples.

The performance of the microcontroller based parallel system is evaluated using the time required to find the glucose level from the workload of 16 blood samples in Mode-1. The Table-1 described the execution time required to measure the glucose level in the form of module names, which is executed on the single processor system. The measurement time of blood samples in a sensor node is sum of $\sum(a+b+c)$ calculated as 30185 mille seconds.

The measurement time of 16 samples using single node with against the four parallel sensor nodes is shown in the Figure-11(a and b) as time space diagram. These two implementations must be comparable so that fair conclusion can be drawn from the measurement results. From the Table-1, the time consumed to predict the glucose concentration for 16 blood samples using single sensing node (Ts) is 482960 mille seconds. The time consumed in parallel analyzer with the same number of sample is required (Tp) 120740 mille seconds. The communication between Master and Slave nodes establish in two incidents, first phase is distribution of commands to each sensor node to configure either in Mode 1 or Mode 2 by the master node, the second phase is measured glucose level by sensor nodes to the master nodes. The time required for the first phase is 1092 mille seconds and the time consumed in the second phase is calculated as 1375 micro seconds, which is maximum time required to send results for 16 blood samples. The total communication time Tc found as 2467 mille seconds. The speedup factor (Ts/(Tp+Tc)) of distributed system is 3.9 and the efficiency is 0.975 with against the value of 1. The computation and communication time calculated using the pin- pong method [6,14]. The computation/communication ratio is 49%. The measurement and computation time is 49% higher than the communication time. By this low communication ratio, this system can likely to support the architecture scalability by adding more sensor nodes. The Throughput reflects the measurement power of parallel blood analyzer, which can be defined as the no of results that can be completed by per unit time. The observed period is 31.5 seconds and number of blood sample analyzed is 4.

The Figure-12 shows the time space diagram of complete analysis of a blood sample. The time taken by the single node for analysis of glucose, sodium, potassium and urea of single blood sample is 1, 26,240 mille seconds; the same test conducted on parallel system is consumed only 31560 mille seconds. The turnaround time of a sample for complete analysis is reduced as considerable amount. The Table-2 and Figure-13 are describing the measured metrics of performance of the system.

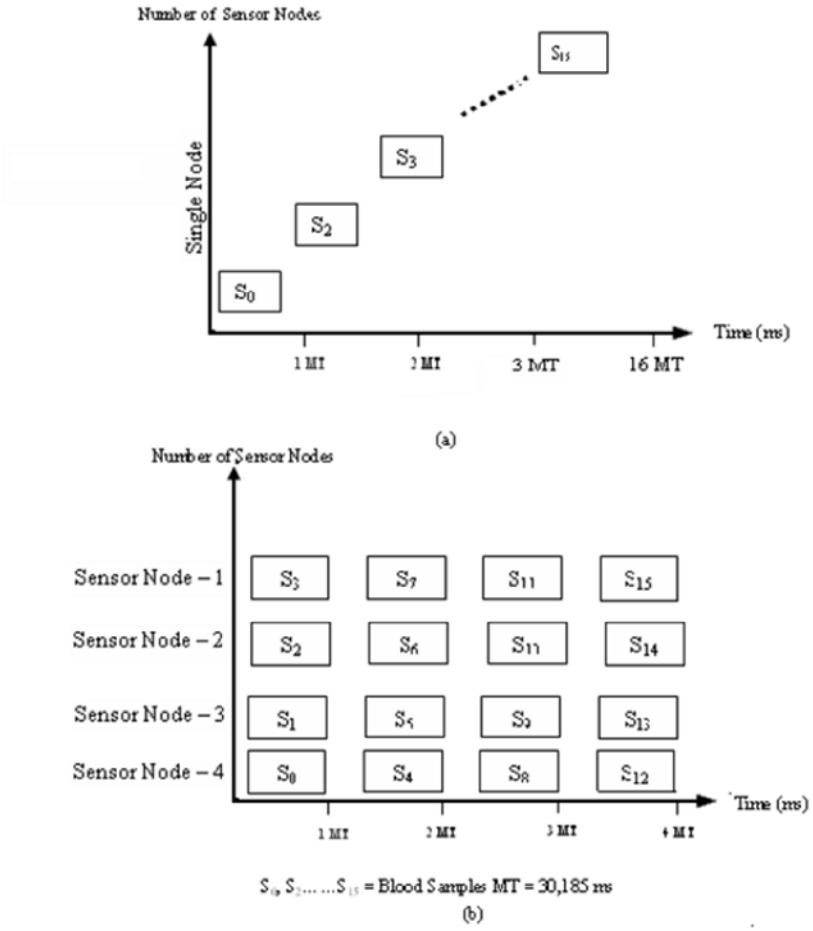

Figure 11. Time Space diagrams for analysis of 16 blood samples in mode-1 (a) Time required by single sensor node (b) Time required by four sensor nodes.

Table1. Execution time required by the modules in a single node system.

Modules	**Execution Time (ms)**
(a) Peristaltic pump activation for mixing of sample and reagent	20,000
(b) Duration of light pass on sample	10,000
(c) Temperature and Photo diode sensors reading	105
(d) Calculation and display of result	
(e) Communication time to send results to master node with sample number	80

Measured Parameters	Value
Speedup	3.9
Efficiency	97%
Throughput	4 Nos. /31.5 s
Computation and communication ratio	49%
Turnaround Time reduced	75%

Table 2. Performance based values of parallel system using four sensor nodes.

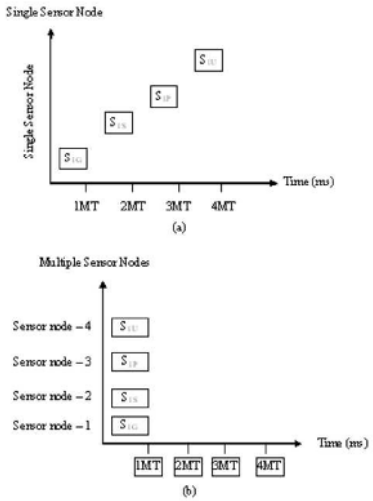

Figure 12 Time space diagram of complete analysis of a single blood sample

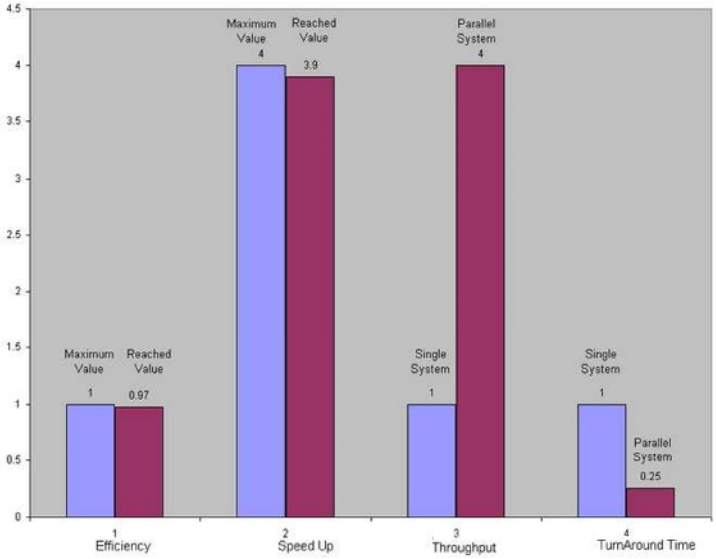

Figure 13 Graph for performance analysis

8. CONCLUSION

The embarrassingly parallel process based blood analyzer is designed using ATmega32 microcontrollers as a loosely coupled multiprocessor system, in order to reduce the blood analyzing time in group of blood samples. The performance of the system is studied and obtained the speedup, efficiency and throughput values. The performance achieved by this multiprocessor system can be replaced by a single faster processor, when the faster runs, the more heat it generates and it is to get rid of this heat. But, the proposed parallel system is constructed by using multiple off-the- self components of microcontrollers, which are runs at normal speed and produce minimum heat, but which collectively have far more processing power that a single faster processor. In this way, this parallel blood analyzer can be viewed as an eco- friendly system.

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