ISSN 1726-5479

SENSORS & TRANSDUCERS

vol. 120
9 /10

TEDS Sensors, IEEE 1451 Standards

International Frequency Sensor Association Publishing

IFSA

Sensors & Transducers

Volume 120, Issue 9, September 2010 **www.sensorsportal.com** **ISSN 1726-5479**

Sensors & Transducers Journal (ISSN 1726-5479) is a peer review international journal published monthly online by International Frequency Sensor Association (IFSA).
Available in electronic and on CD.

Sensors & Transducers Journal

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Volume 120
Issue 9
September 2010

www.sensorsportal.com

ISSN 1726-5479

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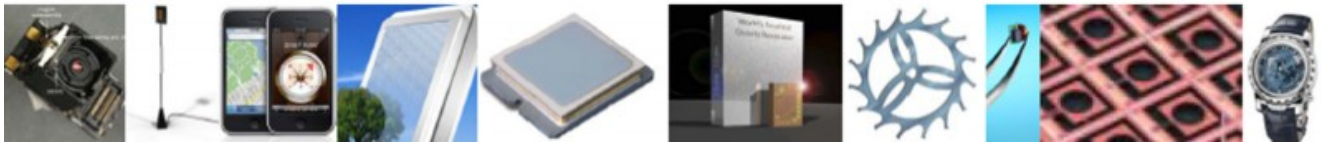

The Sixth International Conference on Systems

ICONS 2011

January 23-28, 2011 - St. Maarten,
The Netherlands Antilles

Important deadlines:

Submission (full paper)	September 25, 2010
Notification	October 20, 2010
Registration	November 5, 2010
Camera ready	November 5, 2010

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- Complex Systems

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Important deadlines:

Submission (full paper)	January 10, 2011
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- EDNA: Emergency Services and Disaster Recovery of Networks and Applications
- IPv6DFI: Deploying the Future Infrastructure
- IPDy: Internet Packet Dynamics
- GOBS: GRID over Optical Burst Switching Networks

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Sensors & Transducers Journal, Vol. 120, Issue 9, September 2010, pp. 171-181

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Implementation of Distributed Measurement Process on Clinical Blood Analyzer

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Received: 11 July 2010 /Accepted: 14 September 2010 /Published: 27 September 2010

Abstract: This paper presents the development of an embedded based distributed system to measure sodium, potassium and chloride ions in blood sample. The developed system consists of P89C668 microcontroller based three sensor nodes and one coordinate node. In order to handle more blood samples and reduce the analyzing time, the temporal based concurrent operation is implemented on the sensor nodes. The proposed system architecture and the co-design of hardware and software are discussed in detail. The performance of the system is evaluated using speedup, efficiency and throughput. The result shows that system attained the sub-linear speedup in measurement of blood samples. *Copyright © 2010 IFSA.*

Keywords: Distributed Embedded System, Decentralization, Temporal Parallelism, Clinical Blood Analyzer.

1. Introduction

The concept of distributed process has been proved to be an effective way of improving a system operation, which can be extended to processor that is some what more complex. The embedded based distributed process is a viable alternative for many mechanical applications including automobiles, industrial robots, production machines, rock drilling machines, safety related tasks, such as vehicle

dynamics control and engine control. With a distributed process approach, hardware and different level of process are spatially distributed to actuators and sensors in the mechanical system. Benefits by a distributed approach include modularity, improved functionality and performance [1, 2]. For distributed applications different hardware structures can be identified with respect to the spatial distribution of the hardware, the communication topology and the structure of nodes. Denham (1977, [3]) discussed three methods of decomposition on the basis of spatial, organizational and dynamic characteristics of the application. The first is a clear relation to I/O bounds, as followed in this work. The second and third methods are relation to hierarchical arrangements and dynamic multivariable systems respectively.

This paper explains a distributed measurement process, which is implemented on microcontroller based clinical blood analyzer. This work can be viewed as the decomposition of centralized blood analysis system into decentralized ones. The Locality-based Distribution (LOC-D) [4] model is formed using four nodes of microcontrollers by applying the decentralization methodology on the integrated blood analyzing unit. The distributed analysis of three parameters on a blood sample made this system as a level three in degree of freedom (DOF). The nodes are functioning with a local clock, process of each node statically allocated, nodes are connected by a serial bus with communication scheduling policy with upper bounded access delay. This system is formed as a test bed for distributed embedded system for the purpose of studying the properties of distributed process.

In this analysis machine the concurrent and overlapped measurement pattern is followed in order to handle more than one blood samples instead of single sample, by which analyzing time is minimized. The loading of blood samples to detect Sodium, Potassium and Calcium ions are followed by the linear pipeline fashion. The arrangement of mechanical movement of blood sample shelf is outside the scope of this paper. This Blood Analyzer is more ultimate for the multi specialty hospital's laboratory or mobile clinic for rural areas, which can produce the blood analysis result with minimum delay for a number of patients. The PC based distributed solution could have designed easier but the microcontroller based solution meant that the system is more independent and hopefully more reliable with cheaper running costs.

2. Application Characteristics

Blood Electrolytes Sodium (Na), Potassium (K) and Chloride (Cl) ions are high significance in deciding the course of therapy during open heart surgeries and renal care. The values of these parameters are very essential for surgeons and general physicians who diagnose the pathological aspects and conditions of patients [5]. The existing system is able to analyze the single blood sample at a time and the analyzing of Na, K, Cl ions in serial fashion and the analyzing time of more than one sample will take considerable delay.

The Ion Selective Electrode (ISE) methodology is used in the proposed system to detect the electrolytes in blood plasma since it is more accurate and easy of sample conditioning. The ISE unit consists of reference half cell (terminal) and ion selective half cell. The electrode potential between the two terminals is directly proportional to the concentration of particular ion in the test solution. The calibration is essential for proper operation and this instrument needs two points calibrator. The calibrator solutions 1 and 2 with low and higher concentrations of sodium, potassium and chloride are used.

The measurement process consists of three functions, which are referred as Conditioning, Calibration and Sampling. The filling of calibrator-1 solution in to the sensor cell is called the Conditioning. During the Calibration process the electrode is dipped in to the calibrator2 solution for measurement [3, 6]. First the instrument reads the potentials at calibrator1 and then reads the potential at calibrator2.

The slope of the calibration is calculated using 'Nermst' relation [7]. In sampling, the calibrated value of slope is used to find out the unknown concentration of the blood sample.

The quantity of Na, K and Cl ions concentration in blood sample is calculated using the relation

$$\frac{(E_x - E_{s1})}{(E_{s1} - E_{S2})} \text{ X } (\log as_1/as_2) = \log a_x/as_1 , \quad (1)$$

where E_x, E_{s1} and E_{s2} are the potentials generated in the sensor at sample, calibrator-1 and calibrator-2 solutions respectively. Similarly as_1, as_2 and ax are concentration values in the corresponding solutions. The instrument verifies and updates the calibration-1 values before and after each sample measurement.

3. Design of Distributed Blood Analyzer

The distributed blood analyzer is a complete system that consists of three sensor nodes and one coordinate node. The first sensor node is used for measurement of Na, second and third sensor nodes are used for measurements of K and Cl ions respectively. The sensor node consists of an ISE sensor, instrumentation amplifier, analog to digital controller, microcontroller, stepper motor, pump motor, and LCD display panel. The coordinate node is used to activate the sensor nodes, to collect the measured values from sensor nodes, to store in EPROM based database, to display the measured values in global LCD panel, to generate blood analyzed report on printer, and to send the result to a remote PC for further reference. The Nodes are communicated using RS-232 interface.

The block diagram of distributed blood analyzer is shown in Fig. 1. The blocks A, B and C indicate the sensor nodes. Each sensor node consists of five sub-blocks. The Coordinate node is marked as block D. The sub-blocks A1, B1, and C1 contains Na, K and Cl ISE sensors, which will output the voltage corresponding to the concentration of Na, K and Cl ions in Blood sample. Since the output of sensors is low, it is amplified by an operational amplifier, which is kept in the sub-blocks of A2, B2, and C2. The sub-blocks A3, B3 and C3 indicate the A/D converters. The Output of an operational amplifier is given to input of an A/D converter, which will convert the analog voltage of concentration value into its corresponding digital voltage. The microcontrollers are kept in the sub-blocks of A4, B4 and C4, which are used to process the signals from A/D converters. The microcontrollers also will carry the work of sensor activation, conditioning, calibration feeding, and measurement calculation, display the result value and send to the coordinate node. The pump motors, stepper motors and LCD panels are interfaced with microcontrollers, which are shown as A5, B5 and C5. The pump motor is used to circulate the calibration-1 solution in ISE sensor. The stepper motor is used to dip the ISE sensor for measurement into the standard calibration-1 solution, calibration-2 solution and blood sample.

The proposed apparatus is able to handle 3 samples simultaneously. The blood samples are kept in a linear shelf and motor arrangement will move the sample from one sensor node to another which is controlled by Coordinate node. As per Loc-D model all nodes work independently without central control, the analyzed outputs only send to the coordinate controller, so that the behavior of apparatus is referred as distributed process.

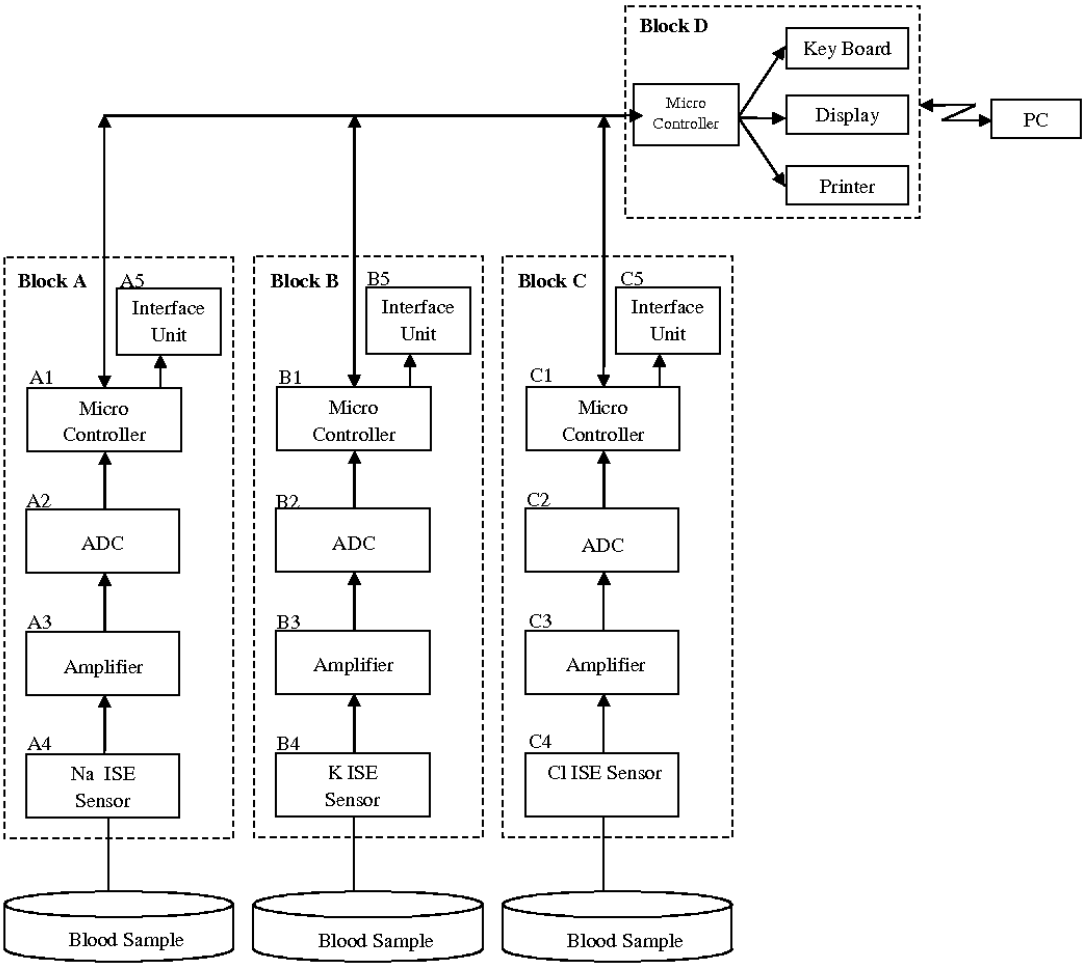

Fig. 1. Block diagram of distributed blood analyzer.

4. Implementation of Design Scheme

The design of clinical pipe line based distributed blood analyzer is mapped as circuit diagram, which is shown in Fig. 2. The Circuit design consists of four stages, which are corresponding to four blocks (A, B, C and D) of Fig. 1. The Stage-I is the Na sensor node, Stage-II and Stage-III are K and Cl sensor nodes respectively. The stage-IV is the coordinate controller. The design of stages II and III are replica of stage-I except the corresponding ISE sensor. The description of circuit design of Stage-I is as follows. The place of an ISE sensor of Sodium is indicated by number 1. The amplification is carried out by the 714 based operational amplifiers, which is denoted by no.2. The amplified signal is connected to the pin number 2 of the MCP3201 based 12 bit A/D converter, which is marked as no.3. The serial output and clock of A/D is connected to port1.1 and port1.0 of microcontroller. The Microcontroller P89C668 has been found appropriate for the control unit on the basics of advantageous features. The position of microcontroller is designated as number 4. The pump motor is interfaced to microcontroller in port 1.7 through the buffer 74S07 and BDX33 transistor, which is indicated by No.5. The L293 motor controller chip is used to control the stepper motor, which is connected to microcontroller using port 1.4 to 1.6 and marked by No.6. A 12 MHz crystal is used by connecting pin no.14 and 15 of microcontroller. The reset circuit is provided at pin no. 4. The Port2.2 to port2.7 is reserved to connect the local LCD display to know the measured values in each sensor node. The coordinate microcontroller and sensor node microcontrollers are interconnected using Tx and Rx lines.

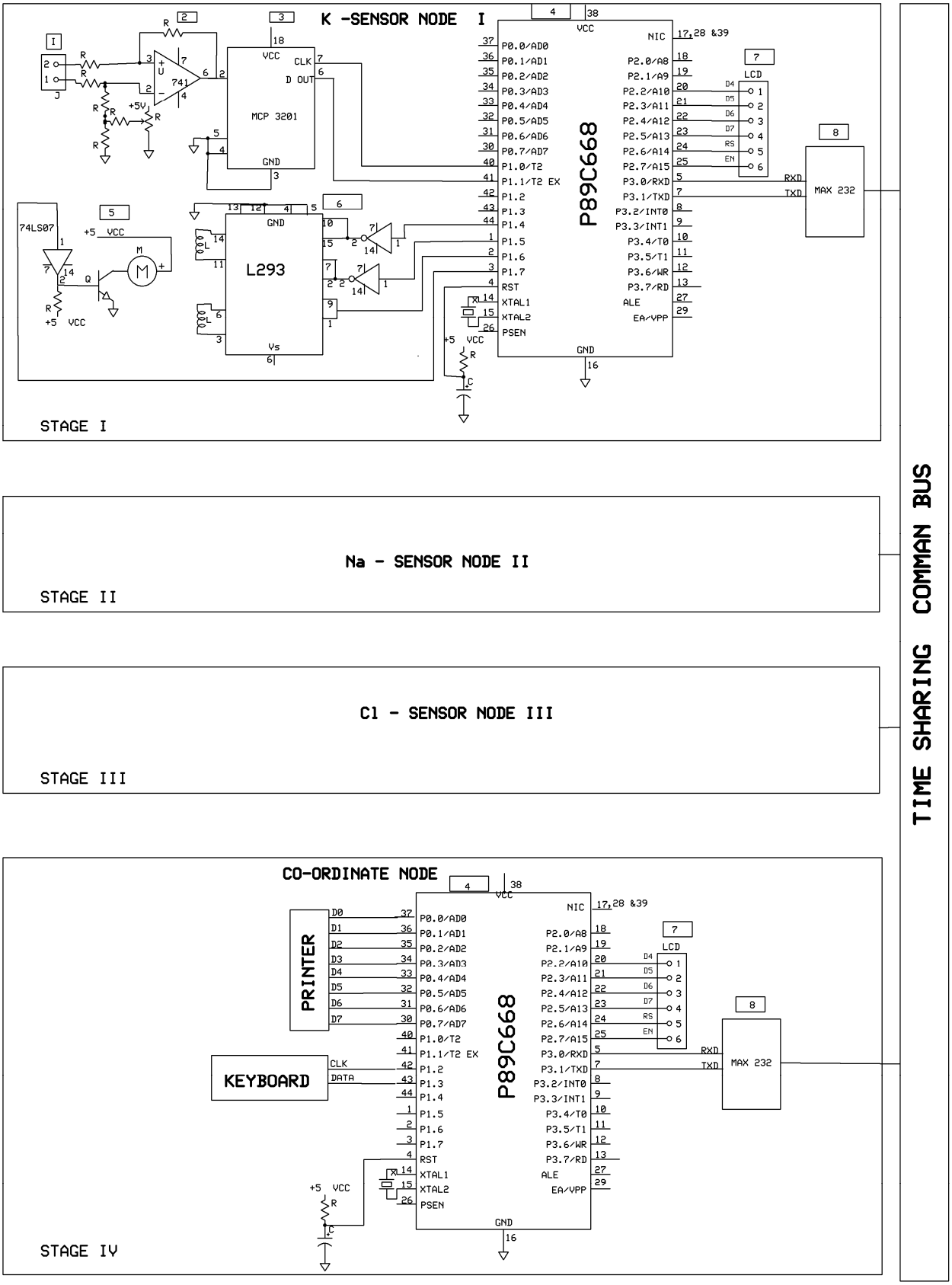

Fig. 2. Circuit diagram of Distributed blood analyzer.

The Port1 and Port 2 of coordinate microcontroller in stage-IV are interfaced with Keyboard and LCD display interface, the port 0 is used to connect the printer.

5. Measurement and Communication

In order to increase the throughput of blood analyzer and decrease the analyzing time of more samples, the decentralization is adopted in this tool, which can be realized by applying different methods of input in feeding of blood samples to sensor nodes. The pipeline based sample feeding method is implemented which is shown in the algorithm of Fig. 3, in which the sensor nodes and its sample holding are indicated. The index value 'I' is updated on the basis of timing. According to the pipeline processing, the sensor nodes are treated as pipeline stages, in which there is no common clock to synchronized the measurement process in all sensor nodes. The sensor nodes carry its corresponding work in asynchronous pattern because of time varying measurements. To ensure the smooth flow of blood samples without bottle neck problem in the nodes, the self synchronization is adopted in the sensor nodes. Each node is assumed to have been given the same time to complete the measurement task. The uniform time period is referred as BTU (Basic Time Unit), this can be treated as value of pipeline cycle.

```
Input          : blood samples[1…max_sample]
Process        : analyze the blood samples for Na, K and Cl ions by sensor nodes.
No. of stages  : 3 (sensor_node[1],sensor_node[2],sensor_node[3])
BTU period     : 50 Seconds (period of pipe line cycle).

i = 1;
repeat
 {
  sensor _ node[1]  :=  blood sample [i];        /*Sodium measurement*/
  sensor _ node[2]  :=  blood  sample [i-1];     /*Potassium measurement*/
  sensor _ node[3]  :=  blood  sample[i-2];      /*Chloride measurement*/
   i = i+1;
  /*  index  variable i changes only in delay of  50 seconds */

 /*  when  the index values are  zero, negative  and
     above the value of  max_ sample , the corresponding sensor_node[]
     represents that there is no sample ie. ideal node */

   }until (sensor_node[3]= blood_sample[max._sample] )

 /*  The blood samples are moved from one node to another by moving
     the input rack  through the stepper motor control  */
```

Fig. 3. Algorithm for pipeline based measurement process.

The measured values from the sensor nodes are collected by coordinate controller using round robin based polling technique. The polling process starts from sensor node 1 and proceeds [8]. The collection of result from the three nodes will be completed with in one BTU time unit. The communication pattern between coordinate node and sensor node is shown in the algorithm Fig. 4. The barrier variable is used to collect and ensure the arrival of data from all sensor nodes for each blood sample.

In this work the empirical value of BTU is found according to the execution time required for measurement process and the time of sample movements between sensor nodes. To maintain the error free BTU the homogeneous based nodes are constructed. With reference to Table 1, the time taken to analyze the blood contents in each stage is denoted by 't_i'. Let 't_l' be the time delay for the sample

movement from one stage to other. From the table the maximum value of 't_i' is added with 't_l' [max (t_i) + t_l], which provided 50 seconds as value of BTU. The snapshot of blood analyzing is illustrated as space-time diagram in Fig. 5. From the diagram it is observed that the staircase effect at the beginning. After the staircase effect, one blood sample is completely analyzed in each BTU.

```
/* Analyzed data from each sensor node is collected by
   coordinate node, the pattern of collection in coordinate
   controller is as follows */

Start()
    {
        Wait (delay of one BTU)
            {signal to get and collect data from
             sensor_node[1];}
        Wait (delay of two BTU)
            {signal to get and collect data from
              sensor_node[1]&[2]}
        Wait (delay of three BTU)
        {
          repeat
            {signal to get and collect data from
             sensor_node[1],[2]&[3]
             Wait (delay of one BTU )
            } until (sensor_node[3]=blood_sample[max_sample]
        }
    }
end;
```

Fig. 4. Communication pattern for result collecting.

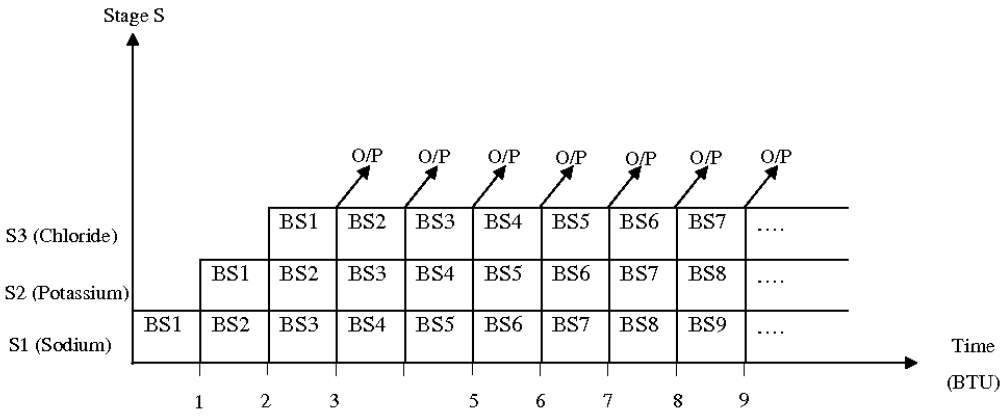

Fig. 5. Space time diagram depicting concurrent measurement process.

6. Performance Evaluation

The pipeline based distributed blood analyzing system is constructed to measure the Na, K and Cl ions and evaluated using the parameters of speedup, efficiency and throughput [9-11]. This maximum accommodation of 12 blood sample is treated as highest load value of the system. The Table 2

provides the attained parameter values and the charts are given, to compare the result values with other standard values.

Table. 1. Estimated Execution time in sensor nodes.

Name of modules	Estimated Execution Time
	T_i
1. Sodium Measurement	40 Seconds
2. Potassium Measurement	43 Seconds
3. Chloride Measurement	45 Seconds
4. Sample Movement	T_l
	5 Seconds

6.1. Speedup

The speedup can be defined as, a pipeline with k stages can process n tasks in T_k= k + (n-1) clock periods. K cycles are used to fill up the pipeline or to complete the execution of first task and n-1 cycles are needed to complete the remaining n-1 tasks. From the snap shot of Fig. 5, the defined speed up is found as follows. The blood analyzer has 3 stages of sensor nodes and it could be loaded by 12 samples, the time taken to fill up the pipeline or time taken to complete the analysis of first sample is 150 seconds. The remaining 11 samples are analyzed in the delay of 50 seconds per sample is 550 seconds. The total time consumed by 12 samples in pipeline fashion T_k is 700 seconds.

The same number of samples is analyzed in a centralized processor Ts is consumed n.k time delay. The time required to examine a blood sample completely is calculated using ping-pong method is 140 seconds. The time required to measure 12 samples is calculated as 1680 seconds.

The speedup of a k-stage distributed processor over a centralized processor as $S_k = T_s/T_k$. The speedup value 2.1 is obtained as against the maximum speedup value of 3 when S_k->k. In Fig. 6, the actual speed up is compared with ideal value, lower-bound ($\log_2$ n) and upper-bound (n/ln n) values.

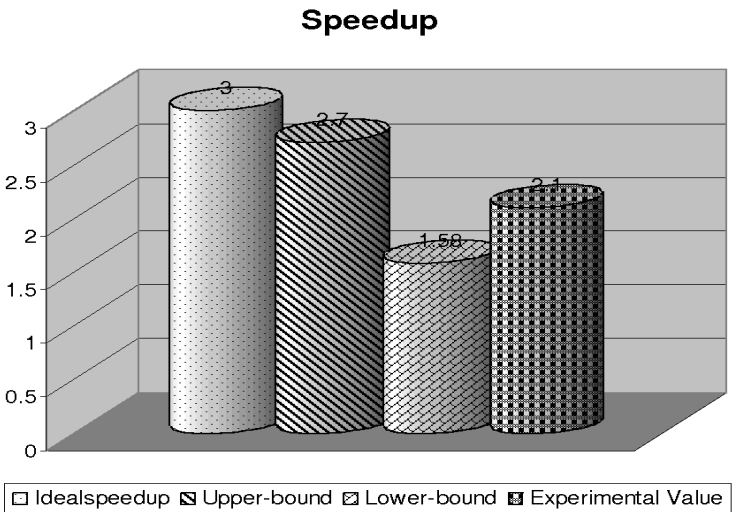

Fig. 6. Analysis of Speedup.

6.2. Efficiency

The efficiency of the pipeline is measured by the percentage of busy time-space spans over the total time-space span, which equals the sum of all busy and idle time-space spans. Let n, k, and t be the number of tasks, the number of pipeline stages, and clock period of a linear pipeline respectively. The efficiency is formulated as n/(k+(n-1), which provided 0.857. Another view of efficiency measurement based on Minsk's conjecture is the ratio between the actual speedup and the ideal speedup, according to this view the value 0.7 is obtained. The Fig. 7 shows the experimental efficiency and compared with the ideal efficiency of 1 and Minsky value.

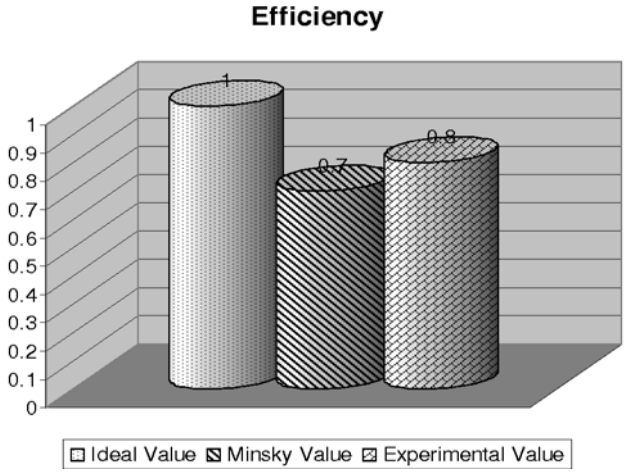

Fig. 7. Analysis of Efficiency.

6.3. Throughput

This rate reflects the measurement power of blood analyzer, which can be defined as the number of results that can be completed by a machine per unit time. In terms of efficiency and clock period, the formula obtained to define the throughput is (n/k t + (n-1) t). Where n equals the total number of tasks being processed during an observation period of k t + (n-1)t. The value of observation period is (3×50 + 11×50) 700 seconds. The obtained throughput value is 0.017 as against the ideal value [1/t] of 0.02, which is shown in Fig. 8.

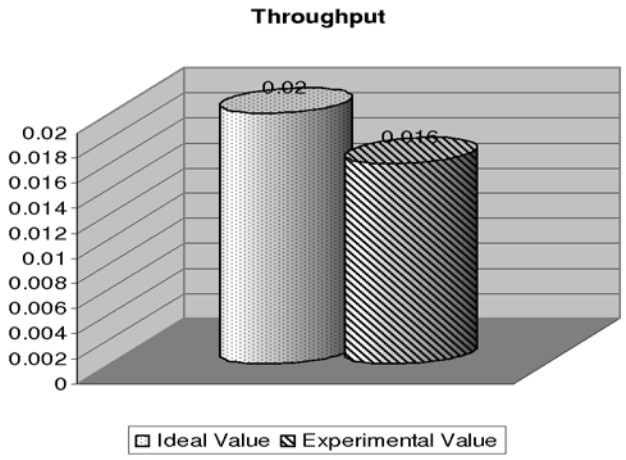

Fig. 8. Analysis of Throughput..

7. Conclusions

The P89C668 microcontroller based distributed blood analyzer is constructed, in order to reduce the delay of blood analyzing time. This tool is ideal for the multi specialty hospital with higher floating of patients and more number of operation theaters to conduct concurrent surgeries. In which the requirement of multiple blood samples should be analyzed simultaneously. The mapping of centralized measurement process of I_1/O_3 is decentralized into three I_1/O_1 processes and reached the 3 degree of freedom. The design of this system is followed the real-time cooperation constraints (RTCC) of synchronous sampling time, bounded jitter and constant measurement delays. The software based clock synchronization is used, if it replaced by the hardware based, the system consistency will be improved. This tool can be extended by adding additional sensor nodes to measure for other bio-chemical parameters like, Glucose, Cholesterol, Urea etc., and increase the maximum load values, if does so the overall performance of this apparatus will be increased. 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 distributed blood analyzer can be viewed as an eco-friendly system.

Table. 2. Performance of the Distributed blood analyzer.

Performance Measured	Value Attained
Speedup	2.1
Efficiency	0.833
Throughput	0.0174

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- SEMOSN: Security and monitoring of sensor networks
- SECSED: Sensor circuits and sensor devices
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- SAPSN: Software, applications and programming of sensor networks
- DAIPSN: Data allocation and information in sensor networks
- DISN: Deployments and implementations of sensor networks
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Sensors & Transducers Journal (ISSN 1726-5479) provides an advanced forum for the science and technology of physical, chemical sensors and biosensors. It publishes state-of-the-art reviews, regular research and application specific papers, short notes, letters to Editor and sensors related books reviews as well as academic, practical and commercial information of interest to its readership. Because it is an open access, peer review international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per annual by International Frequency Association (IFSA). In additional, some special sponsored and conference issues published annually. *Sensors & Transducers Journal* is indexed and abstracted very quickly by Chemical Abstracts, IndexCopernicus Journals Master List, Open J-Gate, Google Scholar, etc.

Topics Covered

Contributions are invited on all aspects of research, development and application of the science and technology of sensors, transducers and sensor instrumentations. Topics include, but are not restricted to:

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- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
- Sensors interfaces, buses and networks;
- Signal processing;
- Frequency (period, duty-cycle)-to-digital converters, ADC;
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