VNU Journal of Science, Mathematics - Physics 26 (2010) 61-70

Monte Carlo simulations and DSP application for optical parameter measurement

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Received 9 February 2010

Abstract. The Texas Instrument TMS320VC5510 DSK's calculation abilitiy with different program languages is investigated for minimum the DSP's measurement time. The steps of Monte Carlo simulations embedded into the DSK's flash through the DSK's JTAG interface for optical parameters measurement including absorption coefficient μ_a, scattering coefficient μ_s and anisotropy g are presented. The obtained results for diluted milk standard samples are also reported.

1. Introduction

Light propagation in turbid media can be described by the Radiance Transport Equation with three optical specified parameters: absorption coefficient μ_a, scattering coefficient μ_s, and anisotropy g [1]. The determination of these parameters can be taken by different methods: the approximate models such as Kubelka-Munk [2] or Monte Carlo simulations. The Kubelka-Munk model gives quick result as it bases on direct calculation of the backward scattering R_d, forward scattering T_d and the collimated light T_c [3]. However, it is not as exact as the result given by Monte Carlo simulations.

Monte Carlo simulations has developed since 1940s, even though, nowadays its application has been found in many fields due to it is a mathematic method that give exact results [4,5]. Nevertheless, Monte Carlo simulations require a great volume of calculation. In other words, it takes much time for calculation, thus, not suitable with on-line monitoring system. To cope with this, Monte Carlo simulations has been embedded into DSP environment - the Texas Instrument TMS320VC5510 DSK kit [6]. With a DSP's special structure such as parallel and pipe-line techniques, this method allows reducing the calculation time.

2. Theory

Monte Carlo simulations for photon propagation in turbid media containing absorption and scattering particles simulates random movement of photon, based on a set of rules that effect the movement. Fig. 1 illustrates the deflection of a photon caused by a scattering event.

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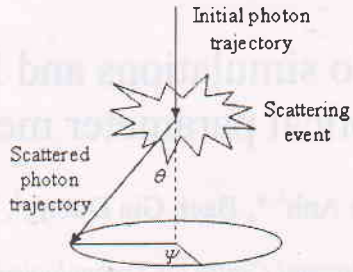

Fig. 1. Deflection of a photon with the deflection angle θ and azimuthal Ψ.

According to Monte Carlo simulations, photon moves step by step and the photon propagation is expressed by probability distribution functions of the step, deflection angle, azimuthal angle and the possibility of reflection, transmission at surfaces. Fig. 2 indicates the flowchart of photon movement in a biological sample.

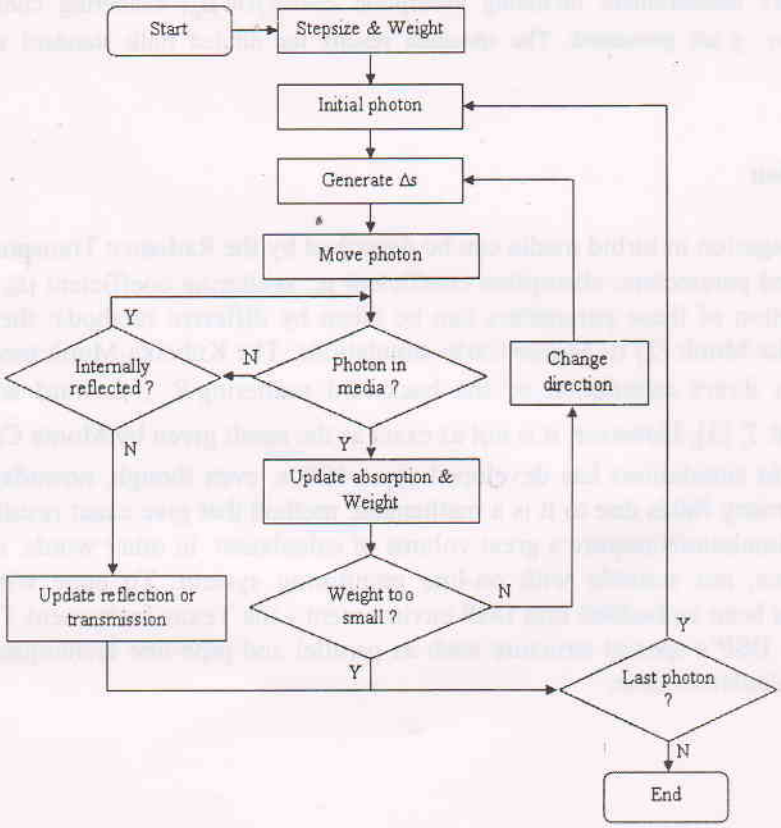

Fig. 2. Flowchart for Monte Carlo simulations.

Monte Carlo simulations for biological samples begin by photon stepsize and photon weighting. Photon position has been verified after each step. If the photon is internally reflected and still in the sample, it is possibly absorbed and then the absorption and photon's weight is updated. If the weight is

small but the photon is still considered, the next step is verified and the as-described process is repeated. If the photon's weight is neglected, the next photon is considered. The simulations finish when last photon is investigated.

- ***Photon stepsize s :***

The stepsize of the photon, s, is calculated based on a random sampling of the probability density function for s:

$$s = \frac{-\ln \xi}{\mu_t} \tag{1}$$

where ξ is a random variable with the value in the range (0, 1] generated by the computer; $\mu_t = \mu_a + \mu_s$ is attenuation coefficient.

- ***Photon weighting:***

Every photon is initialized with a weight of unity, $W = 1$. Once the photon has taken a step, some attenuation of the photon weight occurs. The new photon weight must be updated:

$$W \leftarrow W \frac{\mu_s}{\mu_t} \tag{2}$$

- ***Photon movement:***

After each step, photon has a new position (x', y', z') calculated from the current position (x, y, z) by:

$$\begin{cases} x' = x + \mu_x s \\ y' = y + \mu_y s \\ z' = z + \mu_z s \end{cases} \tag{3}$$

where (μ_x, μ_y, μ_z) are the direction cosines. It has a relation with a unit vector r specified the trajectory of the photon by:

$$\begin{cases} \mu_x = r\,x \\ \mu_y = r\,y \\ \mu_z = r\,z \end{cases} \tag{4}$$

Once the photon takes a step with deflection angle θ, azimuthal angle ψ, photon has a new position with the direction cosines (μ_x', μ_y', μ_z') calculated from current cosines (μ_x, μ_y, μ_z) by:

$$\begin{aligned} \mu_x' &= \frac{\sin\theta}{\sqrt{1-\mu_z^2}}\left(\mu_x\mu_z\cos\psi - \mu_y\sin\psi\right) + \mu_x\cos\theta \\ \mu_y' &= \frac{\sin\theta}{\sqrt{1-\mu_z^2}}\left(\mu_y\mu_z\cos\psi - \mu_x\sin\psi\right) + \mu_y\cos\theta \\ \mu_z' &= -\sin\theta\cos\psi\sqrt{1-\mu_z^2} + \mu_z\cos\theta \end{aligned} \tag{5}$$

3. Measurement setup

- ***The TMS320VC5510 DSK investigation:***

As the calculation of Monte Carlo simulations is time-consuming, the TMS320VC5510 DSK is investigated in order to minimize the calculation time. The multiplication of two matrixes sized n x n with differences of n is taken for investigating the DSP with different calculation volume. The obtained results are shown in table 1.

Table 1. Calculation time of the multiplication of two matrixes sized n x n with different program languages (C, Assembler with and without parallel structure)

Size of n	Assembler & Parallel structure (ms)	Assembler (ms)	C (ms)	Time ration between parallel and non-parallel structure (%)	Time ration between C and Assembler (times)
4	13	14	170	107.69	13.08
6	26	28	543	107.69	20.88
8	47	51	1209	108.51	25.72
10	79	87	2366	110.13	29.95
12	125	138	4029	110.40	32.23
14	187	207	6331	110.70	33.86
16	267	294	9608	110.11	35.99
18	368	405	14742	110.05	40.06
20	493	543	20135	110.14	40.84
22	643	708	27353	110.11	42.54
24	821	905	34570	110.23	42.11
26	1029	1135	44607	110.30	43.35
28	1270	1401	54644	110.31	43.03
30	1547	1695	67086	109.57	43.37
32	1862	2051	78772	110.15	42.31
34	2216	2435	97363	109.88	43.94
36	2613	2863	115431	109.57	44.18
38	3056	3334	138718	109.10	45.39
40	3405	3750	198005	110.13	58.15
42	3715	4112	271025	110.69	72.95
44	4005	4592	424101	114.66	105.89
46	4315	5105	555435	118.31	128.72
48	4507	5773	650253	128.09	144.28
50	4640	6400	724063	137.93	156.05
52	4755	7087	776405	149.04	163.28

Fig. 3 illustrates the dependence of calculation time on size n of the matrixes when the calculation programs is written in C language and in Assembler using parallel technique.

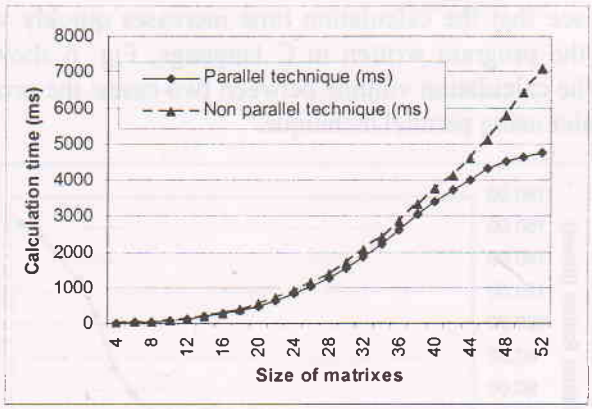

Fig. 3. Calculation time when the program are written in Assembler in two cases: with and without parallel techniques.

Fig. 3 shows that: normally, when using parallel technique, the calculation time is reduced by around 10% but when the volume getting higher, using parallel technique allows to reduce calculation time up to 50% (Fig. 4).

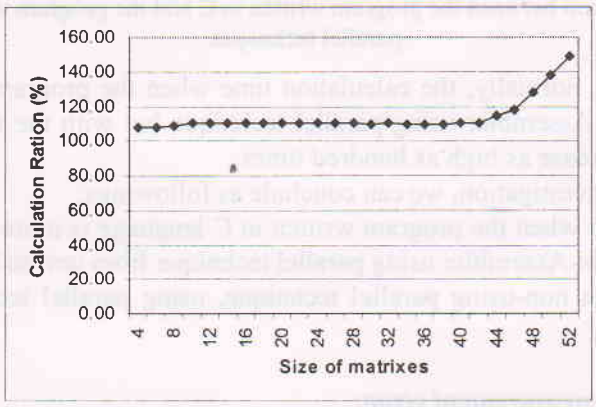

Fig. 4. Calculation time ration between Assembler with and without parallel techniques.

The differences of the calculation time when the program written in C and written in Assembler with parallel technique are shown in Fig. 5.

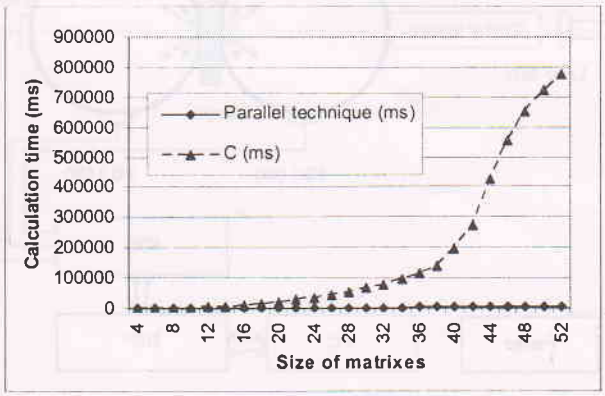

Fig. 5. Calculation time when the programs are written in C and in Assembler.

From Fig. 5, one can see that the calculation time increases quickly with the increasing of the calculation volume when the program written in C language. Fig. 6 shows the dependence of the calculation time ration on the calculation volume between two cases: the program written in C and the program written in Assembler using parallel technique.

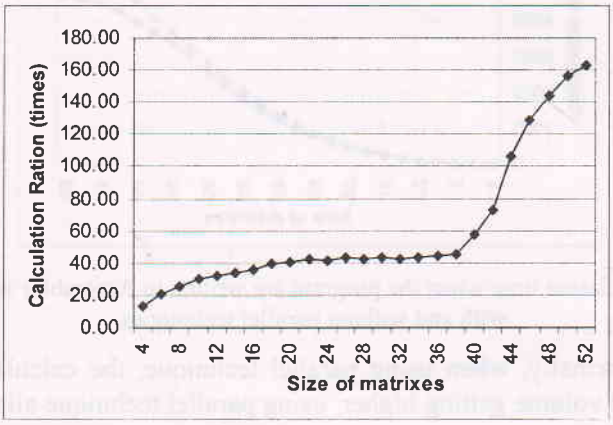

Fig. 6. Calculation time ration between the program written in C and the program written in Assembler using parallel technique.

As indicated in Fig. 6, normally, the calculation time when the program writen in C is 50 times higher than one writen in Assembler using parallel technique but with the increasing the calculation volume, the ration will increase as high as hundred times.

From the above DSP investigation, we can conclude as followings:

1) The calculation time when the program written in C language is more than the calculation time when the program written in Assembler using parallel technique from tens to hundred times;

2) In comparision with non-using parallel technique, using parallel technique allows to reduce calculation time up to 50%.

- ***Optical parameters measurement setup:***

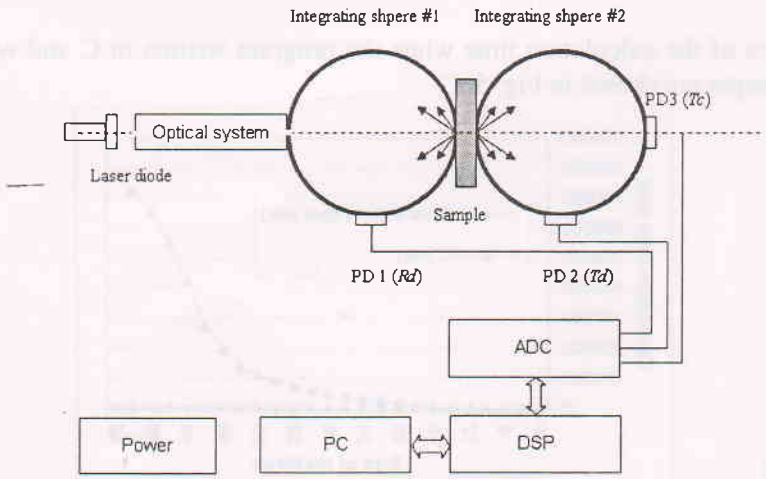

Fig. 7. Optical parameter measurement based on MC simulations and DSP.

The measurement to verify optical parameters based on Monte Carlo simulations and the Texas Instrument TMS320VC5510 DSK kit is shown in Fig. 7.

Algorithms for the Monte Carlo simulations are loaded into flash of the DSP board through the DSP's JTAG interface. The input signals: R_d, T_d, and T_c, after being converted into digital signals are sent to SDRAM of the DSP in parallel through the DSK's Memory Expansion Connector. The interfaces between the ADC board, the DSP board and the PC are illuminated in Fig. 8.

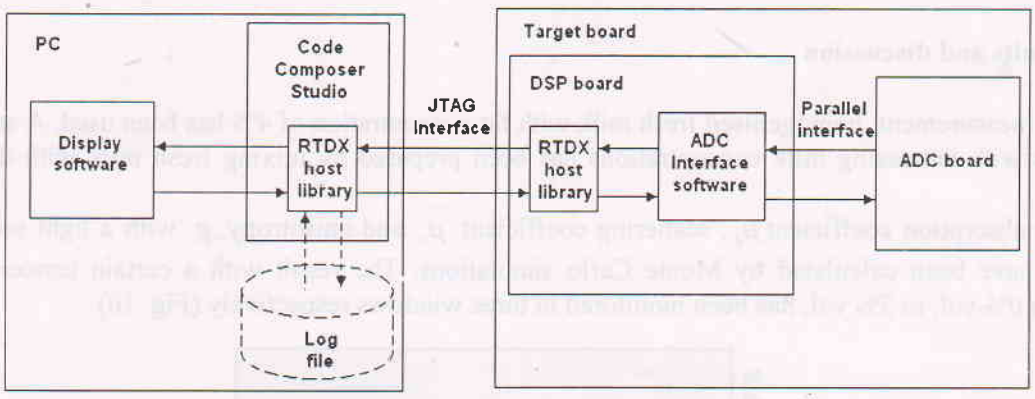

Fig. 8. Interfaces between the ADC, the DSP and the PC.

The flowchart for data access is shown in Fig. 9.

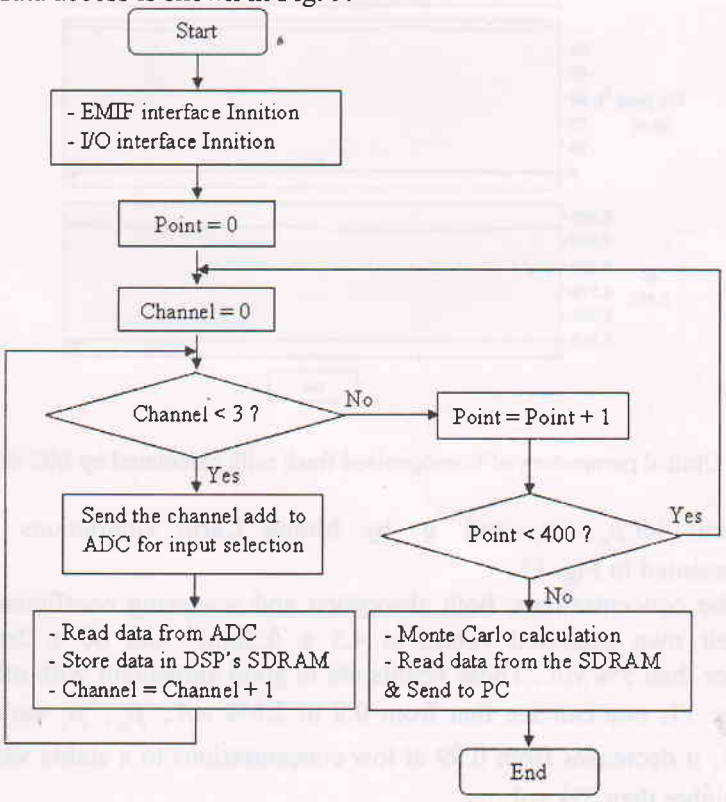

Fig. 9. Flowchart for data access.

It is needed to measure 3 parameters: μ_a, μ_s and g, thus, 3 windows are created with 400 sampling points for each one. 3 inputs corresponding to R_d, T_d, and T_c are selected one by one for each sampling point. In other words, all inputs are periodically scanned and each scan includes 3 sampling points corresponding to 3 inputs. After being converted into digital signals, these sampling points are stored and calculated in SDRAM of the DSP board before sending to the PC.

4. Results and discussion

For measurement, homogenised fresh milk with fat concentration of 4% has been used. A series of samples with increasing milk concentrations has been prepared by mixing fresh milk with distilled water.

The absorption coefficient μ_a, scattering coefficient μ_s and anisotropy g with a light source at 820nm have been calculated by Monte Carlo simulations. The result with a certain concentration between 0% vol. to 5% vol. has been monitored in three windows respectively (Fig. 10).

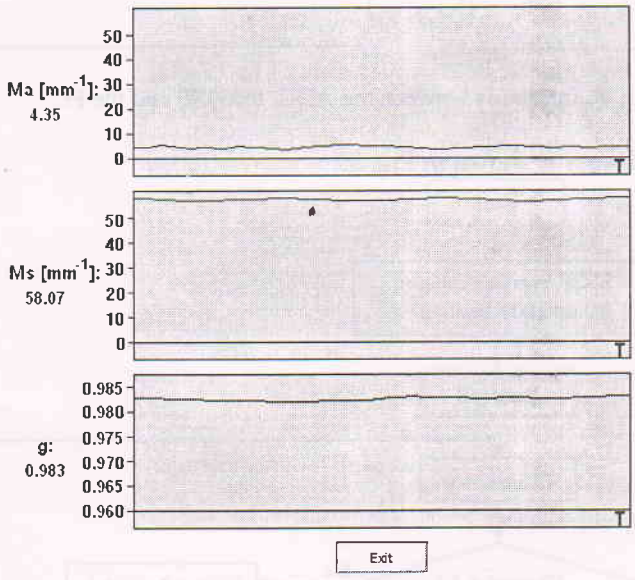

Fig. 10. Optical parameters of homogenised fresh milk calculated by MC simulations.

The measurement for μ_a, μ_s and g by Monte Carlo simulations with different milk concentrations is presented in Fig. 11.

By increasing the concentrations, both absorption and scattering coefficients increase gradually and then reach their own saturated values at 4.5 ± 0.2mm^{-1} and 60 ± 2mm^{-1} respectively for concentrations higher than 5% vol.. These results are in good agreement with other related works [7]. Moreover, from Fig. 11, one can see that from 0.8 to 2.0% vol., μ_a, μ_s vary linearly. As for the anisotropy factor g, it decreases from 0.99 at low concentrations to a stable value of 0.982 ± 0.005 for concentrations higher than 5% vol..

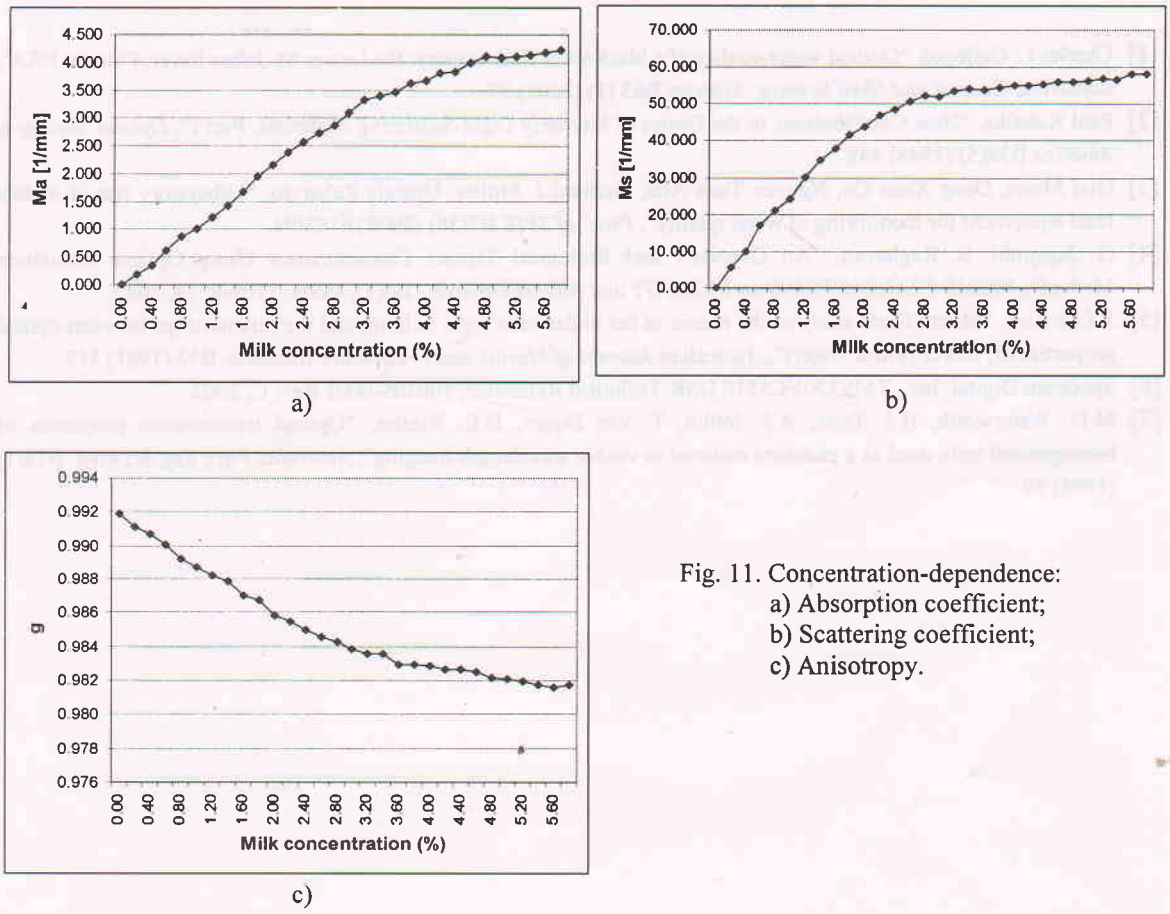

Fig. 11. Concentration-dependence:
a) Absorption coefficient;
b) Scattering coefficient;
c) Anisotropy.

5. Conclusion

The Texas Instrument TMS320VC5510 DSK is investigated for minimum the calculation time. The obtained results show that in the comparision with non-using parallel technique, using parallel technique allows to reduce the calculation time up to 50%. Moreover, the calculation time can be reduced to hundred times if the program is written in Assembler (using parallel technique) rather than in C language.

After the DSP's investigation, the optical parameters including absorption coefficient μ_a, scattering coefficient μ_s and anisotropy g of homogenised fresh milk with different concentrations have been measured. The measurement is taken by using Monte Carlo simulations embedded into the Texas Instrument TMS320VC5510 DSK kit through the DSP's JTAG interface. The obtained results show that for concentrations higher than 5% vol., μ_a, μ_s and g get their stable values at $4.5 \pm 0.2\text{mm}^{-1}$, $60 \pm 2\text{mm}^{-1}$ and 0.982 ± 0.005 respectively.

References

[1] Charles L. Gallegos, "Optical water quality of a blackwater river estuary: the Lower St. Johns River, Florida, USA", *Estuarine, Coastal and Shelf Science, Elsevier* B63 (1) (2005) 57.

[2] Paul Kubelka, "New Contributions to the Optics of Intensely Light-Scattering Materials. Part I", *Optical Society of America* B38(5) (1948) 448.

[3] Olaf Minet, Dang Xuan Cu, Nguyen Tuan Anh, Gerhard J. Muller, Urszula Zabarylo, "Laboratory test of mobile laser equipment for monitoring of water quality", *Proc. of SPIE* B7(36) (2006) 61630N.

[4] G. Jagajothi, S. Raghavan, "An Overview and Biological Tissues Characteristics Using Optical Simulation Method", *WSEAS TRANSACTIONS on BIOLOGY and BIOMEDICINE*, B4(1), ISSN: 1109-9518, 2007.

[5] J.T.O. Kirk, "Monte Carlo study of the nature of the underwater light field in, and the relationships between optical properties of, turbid yellow waters", *Australian Journal of Marine and Freshwater Resource* B32 (1981) 517.

[6] Spectrum Digital, Inc., TMS320VC5510 DSK Technical Reference, 506205-0001 Rev. C, 2002.

[7] M.D. Waterworth, B.J. Tarte, A.J. Joblin, T. van Doorn, H.E. Niesler, "Optical transmission properties of homogenised milk used as a phantom material in visible wavelength imaging", *Australas Phys Eng Sci Med.* B18(1) (1995) 39.