Radiation Exposure Analysis in 3D Cancer Treatment

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Abstract: Dosimetry in the process of treatment of cancer tumour by ionising radiation. It is important and sometimes very challenging due to the fact that it is necessary to measure the radiation dose in vivo on small areas on the surface of the composite relief. Recently, in order to reduce the radiation dose to healthy tissues and concentration of the therapeutic effect of radiation directly on the tumour application method of three-dimensional (3D) irradiation started, in which radiation beams enter the body from different directions concentrating on the tumour. New methods of treatment correspondingly require more precise and sophisticated methods of dosimetry. Existing methods of 3D dose measurement are highly labor-intensive and generally suffer from low accuracy. In this paper, we propose the technical method of 3D measurement of the dose in real-time and approaches to build volume model of the dose distribution inside the patient's body using object recognition technique.

1 INTRODUCTION

For dosimetry of small areas in radiotherapy, common equipment used includes traditional micro ionisation chambers, semiconductor diode dosimeters, and increasingly in recent years the very useful MOSFET transistors. MOSFET transistors provide good accuracy and repeatability of results with dimensions of a few millimetres. In addition they are joined harmoniously with scanning and information processing systems (Soubra, M., Cygler, J. and Mackay, G.F.),(Thomson I., Reece M.H.). For 3D dosimetry, Gel Dosimeters (first proposed in the mid 80s) are the most widely used tools (Yves De Deene, Andrew Jirasek). These are models to replace the human body during irradiation (referred to as 'phantoms' by radiologists), composed of a gel-like material which changes its optical properties under the influence of ionising irradiation. Once irradiated, optical scanning reveals radiation focus through altered transparency of the gel. This method it allows the technician to customise parameters and 3D geometry of irradiation. However, due to the requirement of fabricating custom 'phantoms' for each use, gel dosimeters are very costly, time consuming, and inconvenient, while providing only moderately precise targeting and dosage information. (Yves De Deene, Andrew Jirasek). There are also methods of extrapolating 2D measurements to 3D models. The most modern methods (Karthikeyan Nithiyanantham, Ganesh K. Mani, Vikraman Subramani, Lutz Mueller, Karrthick K. Palaniappan, Tejinder Kataria) of measurement suggest to use of linear array diodes with 98 measurement points for scanning space inside 'water phantom' (essentially an aquarium of water which closely approximate the radiation absorption and scattering of the muscle and other parts of human body). The data is then linked to the patient CT image and the Monte Carlo method used to extrapolate dose distributions inside the patient's body. Measurements are controlled during irradiation by single point dosimiters (diodes), which allows monitoring and adjustment of treatment in vivo.

Impact of ionising irradiation at different MOS (metal oxide semiconductor) structure have been studied for quite a long time, at least since the mid 70-s due to the start using of electronics based on MOS technology in space systems (Ma T. P., Dressendorfer P. V.). The processes occurring in such structures under the influence of various types and intensity of radiation is very well studied and described in numerous articles associated with radiation hardness of MOS IS (Kohler, Ross A., Kushner, R.A.),(S. Kaschieva), (Claeys, C.,Simoen, Eddy), (G Meurant). For the purposes of measuring the accumulated radiation dose in medicine, such a structure, is still relatively new and as an indication of the accumulated dose is used the

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effect of degradation of MOS structure, particularly the under-gate dielectric (SiO2). Without going deep into the details of physical processes, we mention only the main effect that is used for dosimetry. Under irradiation, gate dielectric accumulates a positive charge which leads for example to the shift of threshold voltage in a MOSFET transistor or to the shift volt-farad characteristics of the MOS capacitor. If apply a positive voltage to the Gate of transistor (MOS capacitor) in the process of irradiation, the amount of accumulated charge increases. In the case if no voltage was applied, it makes possible to irradiate the passive MOS structure, and then measure the charge that is equivalent to the dose. Other effects occurring in the dielectric during irradiation can be ignored in this case. In the range of doses used in medicine, the charge accumulation is linear and proportional to the dose and only at high doses about 6-8 Gy (depends on technology of production) tends to saturation and loses linearity. In addition to all of this characteristics, dosimeters on MOS structures are small in size (around 1 sq. mm) and very simple in production.

The particular concern of this paper is the use of such sensors for creation of net bandage dosimetry system Figure 1, with a MOS capacitor sensor in every node of the grid. Such dosimetry net can be placed (dressed) around any part of the body (or fantom) and will allow to control the dose of radiation for the incoming and outgoing flow of irradiation and from any side. This will allow to build a 3D model of the absorbed dose inside the patient's body.

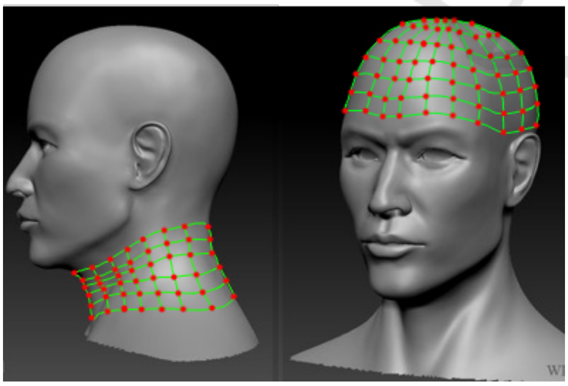

Figure 1: Net bandage.

2 STRUCTURAL SCHEME OF DOSIMETRY SYSTEM

The proposed dosimetric net, can be a convenient and inexpensive tool to verify the dose distribution inside the body as well as building three-dimensional models of absorbed dose. Since the MOSFET was well proven recently (A. Sathish Kumar, S. D. Sharma, and B. Paul Ravindran),(A. Gopidaj, Ramesh S. Billima GGA, Velayudham Ramasubramanian), (Bo-Young Choe), (Briere TM, et al.), (Scalchi P, Francescon P, Rajaguru P) as an in vivo dosimeter for absorbed dose, we have decided to focus our attention to even more simple structures such as the MOS capacitors since the effects of charge accumulation in under-gate dielectric of MOSFET (in fact under-gate MOS capacitor) determines its ability to function as a dosimeter. MOS sensors in our case have a number of benefits, MOS capacitors are extremely simple and inexpensive in production, we can select and vary any of the parameters of this structure (thickness and type of gate dielectric, the area of the structure) to improve its operation as a dosimeter, because it's a capacitor and in this structure there is no need to consider the parameters necessary for the operation of the transistor. The scheme of measurement of accumulated charge which corresponds to the absorbed dose requires less number of contacts (only 2 and one of them is common for all sensors) that facilitates the creation of matrix or grid with a large number of sensors.

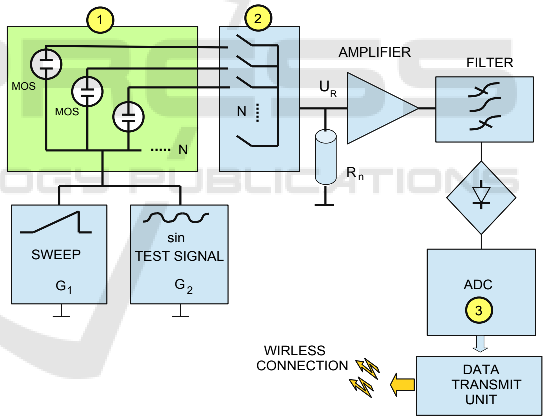

Figure 2: The measuring system for collecting data from sensors. 1- matrix of sensors, 2-multiplexer, 3-analog to digital converter.

The block diagram of such a system is shown in Figure 2. The accumulated charge in the oxide (equivalent dose) offered to determine by measuring voltage - farad characteristics. This method has long been known as a main and classical method for measurement of MOS structures properties (S. M. Sze), (E. H. Nicollian, J. R. Brews), (Jay N. Zemel) and well tested. A typical view of this characteristic for the silicon substrate n-type is shown on the Figure 3.

The figure shows the shift of C-V characteristics which occurs in the case of accumulating charge in the gate oxide, the measurement of this shift is our

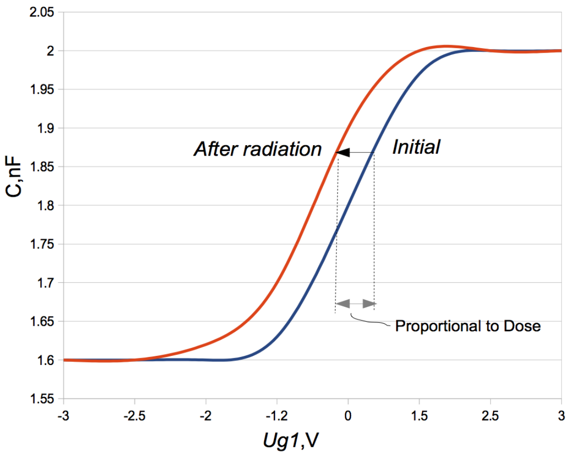

Figure 3: Volt-Farad characteristic of typical MOS condensator.

task in this case. Capacitive Sensors - dosimeters are connected in matrix (1). The reading of the sensors parameters is carried out consistently, analog multiplexer (2) switches from one structure to another. Sweep generator G1 provides a slow shift in a range of of a few volts on MOS and G2 provides a test signal with a frequency of 1 MHz and amplitude 10 mV. The amplitude of the alternate voltage on resistor Rn will be proportional to the capacity of MOS sensor, as can be seen from the formulas below.

$$Rc = 1/wC,\ \ i = Ug_2/Z = Ug_2/\sqrt{Rn^2 + 1/w^2C^2}$$

$$if\ \ R_c = 1/wC >> R_n,\ \ then\ \ i \approx wC(Ug_1)Ug_2$$

$$U_R = iR_n = Ug_2R_nwC(Ug_1)\ \ where\ \ w = 2\pi f$$

The measurement process for each sensor will take approximately no more than 5-10 ms. It means that the matrix of sensor with dimension 256 sensors will be read out in 1.5 - 2.5 seconds. These data are digitised by ADC (3) and sent to computer wirelessly, where data can be already processed further. The advantages of MOS as a absorbed dose dosimeters is also the fact that they kept the charge is quite stable and readings can be taken long time after exposure.

When a MOS capacitors is irradiated, positive charge trapped in the gate oxide (Hughes H. L., Benedetto J. M.), (Oldham T. R., McLean F. B.), (Adams J. R., Daves W. R., Sanders T. J.), it leads to shift of volt-farad characteristics, see Figure 3. The magnitude of the shift depends on the absorbed dose and is approximately 200 mV in the absence of gate voltage during irradiation. By applying a positive voltage on the gate , we can increase the sensitivity and shift can reach 400-500 mV per Gy.

To confirm behaviour of MOS structures under radiation by standard medical equipment the most common samples were taken, the gate oxide SiO_2 was grown in a dry environment at 1000C, thickness of oxide was 0.6 micrometres on Si wafer 4.5 Om /cm conductivity of n-type with F(fluorine) doping. Size of crystal was 1x1mm. Irradiation was carried out at Photon clinical linear accelerator 6MeV (Varian 2100 EX), doses were 0 to 10 Gy, at room temperature. As a control dosimeter, ionisation chamber ROOS was used. Results of the experiment are shown on Figure 4.

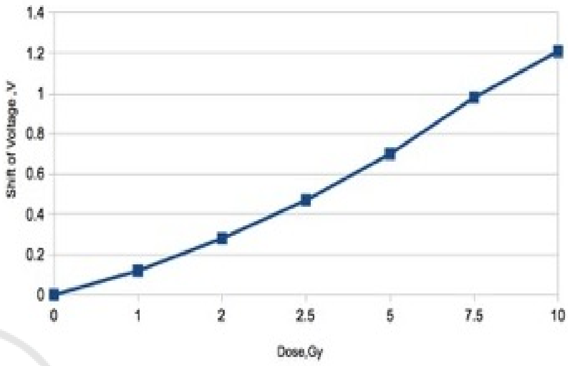

Figure 4: Characteristic of volt shift for the silicon substrate n-typer.

In our case we are going to use a successfully tested system of pattern recognition and bind our system of sensors on the skin of the patient. The image recognition system was used for skin cancer diagnostic and has been published in (Dubovitskiy and Blackledge, 2008), (Dubovitskiy and Blackledge, 2009), (Dubovitskiy and Blackledge, 2008) (Dubovitskiy and McBride, 2013), (Dubovitskiy D, Devyatkov V and Richer G) and (Dubovitskiy and Blackledge, 2008) this redundant system was working well and we expect it to be extremely effective.

3 SKIN PATTERN POSITIONING SYSTEM

The current medical practice includes several radiation exposure during the course of treatment with a number of days in between. The position of the net bandage on the patient's skin is very important to allow consistency for the next treatment of the same tumour. In order to address this, data from the CT scan could be used to adjust position for the next treatment. Computation of position is implemented by using Fractal Geometry theory to get the precise pattern of the skin. The precise pattern of the skin is corresponded to the calibration points on the net bandage. The real time computation system will allow a doctor to dynamically move the bandage and see the offset from the last treatment position. When offset approaches zero, the exact same position of the radiation sensors will be reached.

The skin has texture and a particular skin region could be characterised by Fractal features called Fractal parameters. An image of a skin sample has been taken by a specially designed dermatological image acquisition camera on Figure 5.

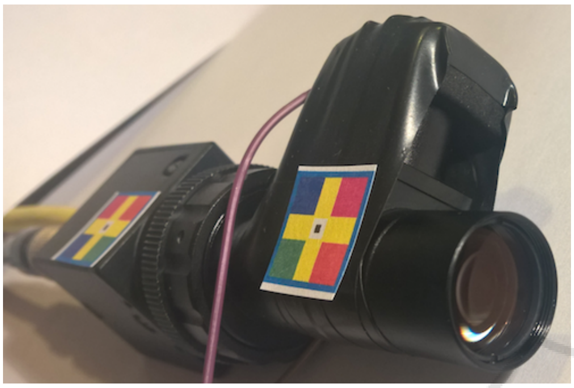

Figure 5: Dermatological image acquisition camera.

The correspondent points are calculated from Fractal parameters. If we consider the profile of a typical skin image, then the curve does not coincide with a sin-wave signal. To obtain adequate accuracy, it is necessary to magnify the resolution of the image, which in turn introduces distortion. For increased accuracy on low-resolution data, we consider a convolution function of a form more consistent with the profile of a video signal. For a signal I we consider the representation

$$F(k) = \sum_{n=1}^{N} I(n)$$

$$\arccos\left[\cos\left(\frac{2\pi(\mathrm{k}-1)(\mathrm{n}-1)}{N} - \frac{\pi}{2}\right)\right] - \frac{\pi}{2}$$

$$-i \arcsin\left[\cos\left(\frac{2\pi(\mathrm{k}-1)(\mathrm{n}-1)}{N}\right)\right]$$

and for an image I with resolution $m \times n$,

$$F(p,q) = \sum_{m=1}^{M} \sum_{n=1}^{N} I(m,n) \quad (1)$$

$$\left(\arccos\left[\cos\left(\frac{2\pi(p-1)(m-1)}{M} - \frac{\pi}{2}\right)\right] - \frac{\pi}{2}\right)$$

$$\times \left(\arccos\left[\cos\left(\frac{2\pi(k-1)(n-1)}{N} - \frac{\pi}{2}\right)\right] - \frac{\pi}{2}\right)$$

$$-i \arcsin\left[\arccos\left(\frac{2\pi(k-1)(p-1)}{M}\right)\right]$$

$$\times \arcsin\left[\cos\left(\frac{2\pi(k-1)(n-1)}{N}\right)\right] \quad (2)$$

In this work, application of the power spectrum method used to compute the fractal dimensions of a skin surface is based on the above representations for $F(k)$ and $F(p,q)$ respectively. We then consider the power spectrum of an ideal fractal signal given by $P = c|k|^{-\beta}$, where c is a constant and β is the spectral exponent. In two dimensions, the power spectrum is given by $P(k_x, k_y) = c|k|^{-\beta}$, where $|k| = \sqrt{k_x^2 + k_y^2}$. In both cases, application of the least squares method or Orthogonal Linear Regression yields a solution for β and c, the relationship between β and the Fractal Dimension D_F being given by

$$D_F = \frac{3D_T + 2 - \beta}{2}$$

for Topological Dimension D_T. This approach allows us to drop the limits on the recognition of small objects since application of the FFT (for computing the power spectrum) works well (in terms of computational accuracy) only for large data sets, i.e. array sizes larger than 256 and 256×256. Tests on the accuracy associated with computing the fractal dimension using equations (1) and (2) show an improvement of 5% over computations based on conventional Discrete Fourier Transform.

The setup calculates Fractal features dynamically from the centre of an image. The testing GUI software is presented on Figure 6:

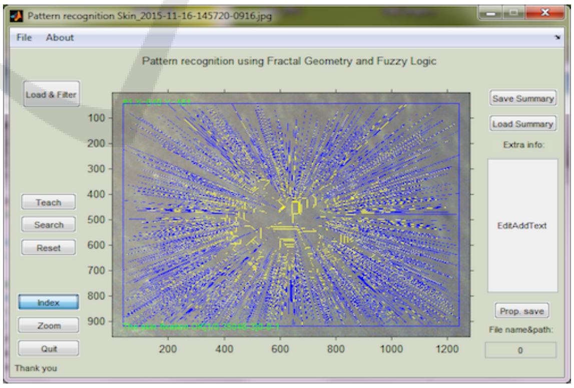

Figure 6: GUI software.

The original skin image from the camera is presented on Figure 7.

The current position of the net bandage and camera is given from optical calibration marks Figure 8.

The corespondent points of the current Fractal marks and optical position gives us the offset number which guide the doctor to the original position of the sensor net bandage.

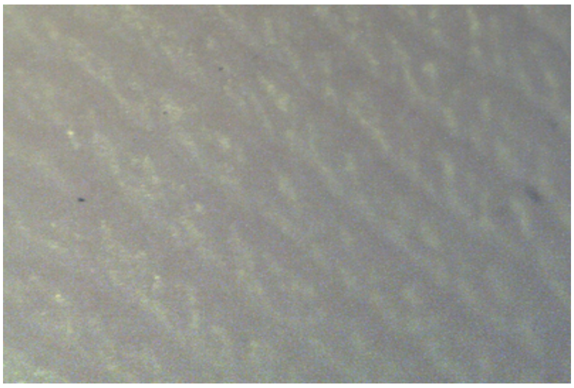

Figure 7: The original skin image.

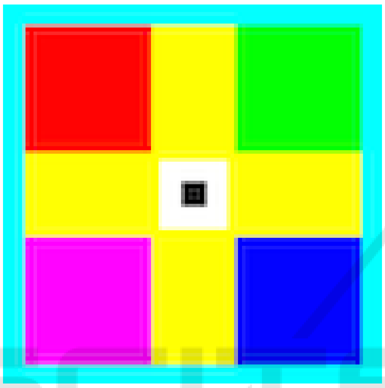

Figure 8: The optical calibration mark.

4 CONCLUSIONS

The focus of this paper is creation of the simple and convenient system which allows to control the spatial distribution of the accumulated dose inside body. The use of modern image recognition technique allows us to position the sensor net bandage in exact position like it has been used. The measurement of input beam radiation and output radiation (after passing the tissue) gives us unique possibilities to provide more accurate results. The calculation of exact accumulation dose and its confirmation by correct measurements is the key to the right healing. Simple and reliable system monitoring of 3D dose distribution will allow to provide treatment in the safest way. The safe way means that the healthy cells will not be the subject of unnecessary exposure (as much as possible) and will be be able maintain healthier life support. This work represents the new approach to accurate radiation exposure treatments. Industrial implementation will require further experiments and technological input in order to calibrate, coordinate and synchronise use of this technology in a clinical setting. However, we hope that our work will lay a foundation for the next step in safe cancer treatment, ultimately prolonging and improving the lives of many people.

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