A Customized Data Acquisition Software for a Three-Dimensional Cubic Electronic Detector Array for Radiotherapy

Dante E. Roa[1,2], Miguel Risco-Castillo[3], Oliver Paucar[3], Enzo Aucca[4], Brayan B. Perez[3], Renzo Romero[3], Claudia Pauyac[4], William de Souza Santos[5], Mirko Alva-Sánchez[6], Alberto Gonzales[5,10], Renzo Ocampo[3], A. Bonatto[6], Andrés M. Gonzales[8,9], C. Sandra Guzman[7], Modesto Montoya[3], Erick Paniagua[11], and Jimmy Hernandez-Bello[1]

(1) HRS Oncology International, Las Vegas, NV
(2) Leonard Cancer Institute, Mission Viejo, CA
(3) Universidad Nacional de Ingeniería, Lima, Perú
(4) Pontificia Universidad Católica del Perú, Lima, Perú
(5) Federal University of Uberlandia, Uberlandia MG, Brazil
(6) University of Porto Alegre, Porto Alegre, Brazil
(7) Universidad Nacional Federico Villareal, Lima, Perú
(8) Clínica Aliada Centro Oncológico, Lima, Perú
(9) Universidad Tecnológica del Perú, Lima, Perú
(10) Universidad Nacional de San Agustín de Arequipa, Arequipa, Perú
(11) Universidad Nacional de San Antonio Abad del Cusco, Cusco, Perú

***Abstract*—A customized data acquisition software has been designed which allows to acquire data from a radiotherapy 3D cubic electronic detector array consisting of 23 x 23 active detector elements distributed in 5 matrixes. The software provides reliable data acquisition for different irradiation rates and beam energies available in radiotherapy linear accelerators (LINACs). The sensor array is connected to a specialized multichannel current input analog to digital converter managed by an FPGA which communicates with a PC via USB interface and a STM32 microprocessor to synchronize the data acquisition.**

***Keywords*— radiotherapy, 3D detector, active matrix**

I. Introduction

Advances in radiotherapy technology have transformed high-precision high-dose radiotherapy treatments into routine patient treatment modalities worldwide. Accessibility to these advanced treatments justify the need for more accurate 3D quality assurance (QA) and radiation dose verification prior to initiating the actual treatment on a patient.

Unavailability of a 3D electronic detection systems for this purpose, prompted us to develop a 3D cubic electronic detector array based on active matrixes. The active-matrix concept [1] [2] allows for fast data readout of many detector elements while sharing data channels (multiplexing).

This study describes a prototype 3D cubic electronic detector array and its specialized data acquisition system, including customized software tailored to the needs encountered in radiotherapy.

The software consists of three separate domains: Control software to manages the FPGA and STM32 signals; data acquisition software and the data analysis software.

II. Three-Dimensional Cubic Electronic Detector Array Prototype

A. The 3D Detector Array

The 3D cubic detector array consists of a 30 x 30 x 15 cm^3 PMMA phantom (Figure 1) with five active matrixes (AMs).

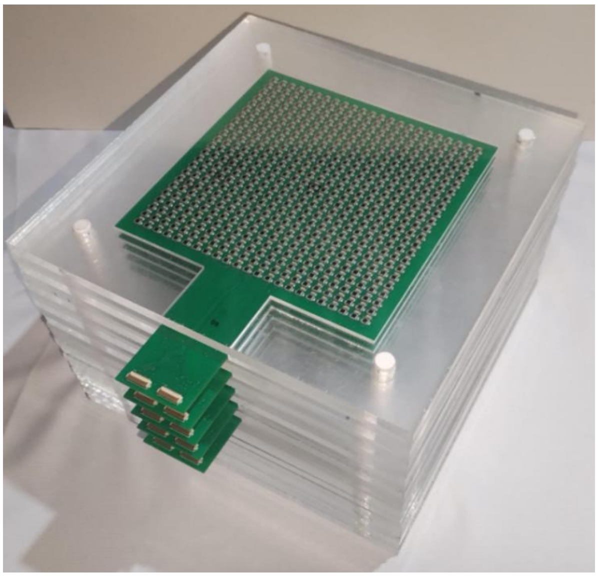

Figure 1- 3D detector array with the five active matrixes.

During operation, a radiotherapy beam percent depth doses curves (PDDs), profiles, and output factors can be acquired simultaneously with few monitor units (radiotherapy LINAC dose settings), and without beam scans, as performed in a water phantom. This is a significant time savings for the user.

Each AM has 529 detector elements (with a total of 2645 elements in the 3D detector array) distributed in 23 columns and 23 rows with 0.8 cm separation between elements and with a 20 x 20 cm^2 detection area (Figure 2).

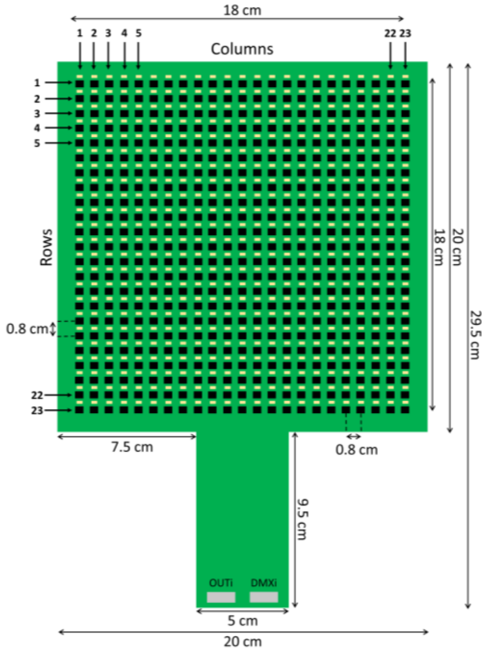

Figure 2 - Spatial disposition of the active elements in the matrix.

B. *Detector Element and Active Matrix*

A detector element, in an active matrix, consists of a photodiode, capacitor, and a MOSFET (Figure 3). When a radiation beam hits the photodiode, charges are released and then accumulate in the capacitor [3].

During data collection, the charge accumulated in the capacitor is read by a current input analog to digital converter where is digitalized and the raw value stored in a high-speed volatile memory. The charges accumulated are "hard reset" by control electronics before a next capture process.

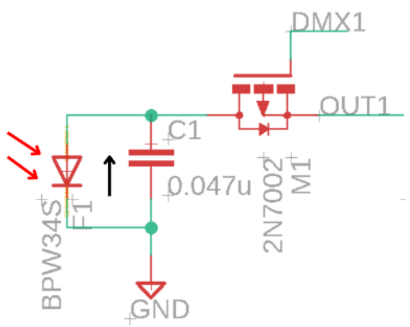

Figure 3- Active detector element.

C. *Acquisition hardware*

The acquisition hardware consists a DDC264EVM [4] (Figure 4), an evaluation module with four DDC264 [5], 64 channels current input, 20-bit analog-to-digital converter (ADC), controlled by a Xilinx Spartan FPGA which provides the glue logic, command signals needed and stores the data temporary in 16 MB of memory. For transfer the captured data to the PC, the board has a Cypress USB interface.

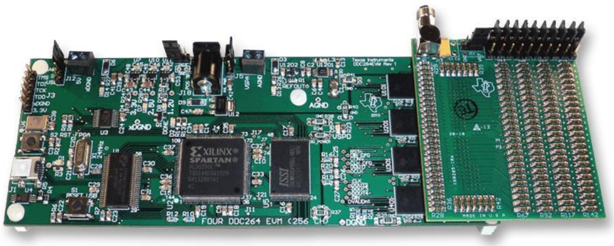

Figure 4 - DDC264EVM Main data acquisition board.

The active matrixes are connected to analog multiplexers controlled and synchronized by an STM32 board, Figure 5 shows an schematic representation of the connectivity between the active matrix and the PC.

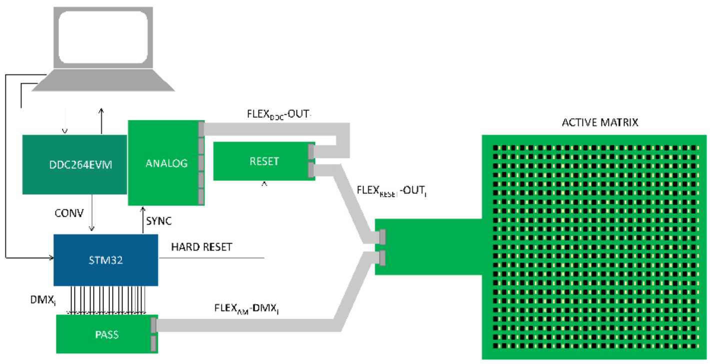

Figure 5 – Pictorial diagram of the connectivity between an active matrix and the PC.

Figure 6 shows how the active matrixes are currently connected to the acquisition system.

Figure 6 - Connectivity of the acquisition system.

III. The Software

The software consists of three components:

A. *Control Software*

Incorporates firmware and software that generates and controls command signals for capturing and move the data to a memory buffer. The FPGA configuration (Verilog) accepts several parameters that control timing and data acquisition made by DDC devices, critical for a proper data capture. These parameters can be read and set dynamically through the USB interface.

B. *Acquisition Software*

Allows for different data acquisition parameters to be entered by the user. As such, the software was written in C++ and consists of a custom-made library that serves as an interface for the hardware and a capture software that takes, organizes and stores the data on the PC.

The capture software (Figure 7) was programmed in C# and consists of a console application that accepts configuration parameters from the command line used to configure the FPGA and DDC in the main acquisition board.

```
DataCapture: Adquisition software for the DDC264EVM
Miguel Risco-Castillo (c) 2024 Version: 2.5

  --ccf n Sets CONV_CONFIG to n, default: 0
  --cfl n Sets CFGLOW to n, default: 0
  --cfh n Sets CFGHIGH to n, default: 7
  --cvl n Sets CONV_LOW_INT to n, default: 1600
  --cvh n Sets CONV_HIGH_INT to n, default: 1600
  --chc n Sets CHANNEL_COUNT to n, default: 256
  --nvi n Sets NDVALID_IGNORE to n, default: 0
  --nvr n Sets NDVALID_READ to n, default: 256
  --ro    Read only configuration registers
  --wcf   Write configuration registers
  --y     Do not request "press s" confirmation

Example: DataCapture --chc 128 --nvr 512
```

Figure 7- Screenshot example of the capture software.

C. *Graphic User Interface and Analysis Software*

The final component consists of a graphic user interface (GUI) and data analysis software, written in Matlab. This software takes the captured raw data and applies correction factors, stemming from AM detector element hardware differences, to produce the final data analysis.

Figure 8 shows a capture of the first stage of the data analysis, where the raw data is calibrated by using a previously acquired transfer functions for each detector element of the matrixes.

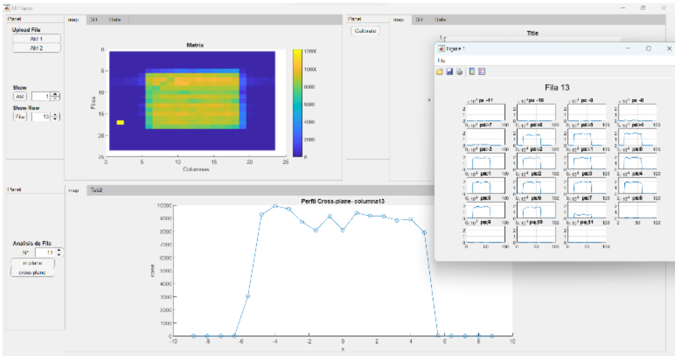

Figure 8- GUI and Analysis Software

Figure 9 shows the next stage of the analysis software with the data already processed and shows it in a 3-dimensional way.

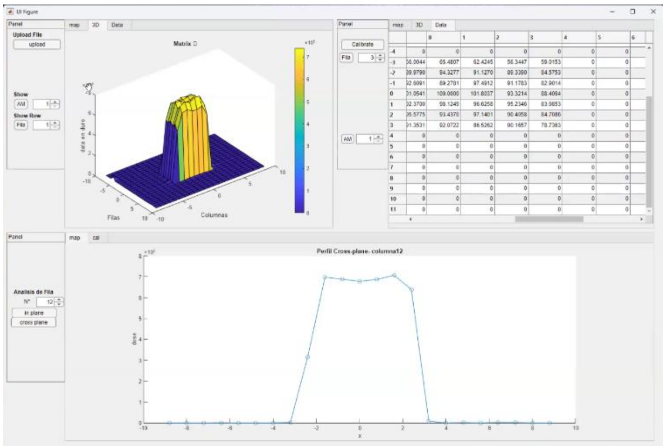

Figure 9 – 3-dimensional representation of the acquired data.

The data can be interpolated for a smoother representation. Figure 10 shows a reduced field of exposition of the first matrix.

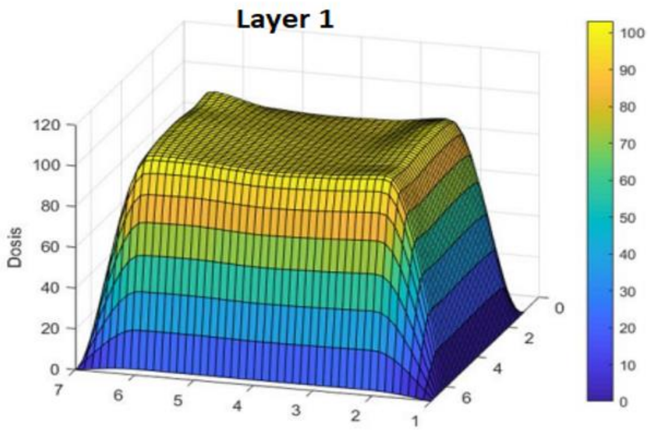

Figure 10 - Example of interpolated data from the first matrix.

Although the analysis software has not yet been completed, the current development has made it possible to verify the feasibility of data acquisition from a 3-dimensional detector [6].

IV. CONCLUSION

A fully software chain for data acquisition and analysis for a prototype of 3-dimensional electronic detector array for radiotherapy was implemented.

The control and acquisition software components successfully complete the configuration and data formatting/storing.

It was possible to build own libraries and tools to customize the appropriate timing and data capture and where was not possible with the previously available libraries and software provided by the DDC264EVM manufacturer.

The designed software allows to verify the feasibility of acquiring LINAC commissioning data with a three-dimensional electronic detector array.

Further research and implementation are needed to complete the GUI and analysis software. Figure 11 shows the typical setup where the 3D detector is placed under the LINAC.

Figure 11 - LINAC and the acquisition system setup.

V. REFERENCES

[1] Yu Chen, Jean M. Moran, Donald A. Roberts, Youcef El-Mohri, Larry E. Antonuk, and Benedick A. Fraass, “Performance of a direct-detection active matrix flat panel dosimeter (AMFPD) for IMRT Measurements”, Medical Physics 34, 4911 (2007); doi: 10.1118/1.2805993

[2] Jean M. Moran, Donald A. Roberts, Teamour S. Nurushev, Larry E. Antonuk, Youcef El-Mohri, Benedick A. Fraass, “An Active Matrix Flat Panel Dosimeter (AMFPD) for in-phantom dosimetric measurements”, Medical Physics 32, 2 (2005) doi: 10.1118/1.1855012

[3] R. Challco; D. Roa; Z. Arqque; O. Paucar; S. Guzman; A. Gonzales; A. Gonzales; M. Montoya; J. Hernandez-Bello, "A three-dimensional electronic detector array for radiotherapy based on active matrices", Proceedings of the XVI Mexican Symposium on Medical Physics 2348, 1, (2021), doi: 10.1063/5.0051241

[4] Texas Instrument, “DDC264EVM User's Guide”, 2011. [Online]. Available: http://www.ti.com/lit/ug/sbau186/sbau186.pdf

[5] Texas Instrument, “DDC264 64-Channel, Current-Input Analog-to-Digital Converter” Datasheet, 2016. [Online]. Available: https://www.ti.com/lit/ds/symlink/ddc264.pdf

[6] O. Paucar; Z. M. Arqque Meza; B. Perez Escobar; E. Paniagua Pancorbo; M. Risco-Castillo; R. Challco Chalco; C. S. Guzman Calcina; A. Gonzales Galvez; M. Montoya; A. E. Gonzales Ccoscco; J. Hernandez; D.E. Roa, "Feasibility of Acquiring Radiotherapy Linac Commissioning Data with a Three-Dimensional Cubic Electronic Detector Array", International Journal of Radiation Oncology, Biology, Physics 117, 25 (2023), doi: 10.1016/j.ijrobp.2023.06.2213