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Towards Using a Monolithic Active Pixel Sensor for In-Vivo Beam Monitoring of Intensity Modulated Radiotherapy

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Abstract

1 Introduction

The use of Intensity Modulated Radiotherapy (IMRT) for cancer treatments is entering wider use. These treatments involve using a complex configuration of field modifying components, known as Multileaf Collimators (MLC), to dynamically shape the beam. A treatment consists of a sequence of irregular shaped fields, which means real time monitoring and verification would be highly beneficial. In the current framework the treatment plans are verified before the patient is treated, but not during. The aim of our collaboration is to monitor the treatment being given to the patient. This is achieved by placing a camera system upstream of the patient. To monitor the beam during the treatment without attenuating the beam requires such a detector to be as thin as possible. To be able to provide information about the progress of the treatment the data acquisition from the sensor must also be fast. This will allow any errors in field shape to be detected at the time of the treatment. The system is also sensitive to the beam intensity and this can be used to ensure the correct dose is being delivered. The research that is funded by the National Institute for Health Research (NIHR) Invention for Innovation (i4i)programme1and presented here shows some of BEAMView's progress into achieving these goals.

1This abstract presents independent research commissioned by the National Institute for Health Research (NIHR) under the Invention for Innovation (i4i)programme. The views expressed in this abstract are those of the author(s) and not necessarily those of the NHS, the NIHR or the Department of Health

2 Beam Monitoring Camera Prototype

The camera system consists of a large area (6 x 6 cm2) Monolithic Active Pixel Sensor (MAPS) and a readout system [3]. The sensor has a total thickness of ~ 100 µm and contains 4096 x 4096 pixels, with a pitch of 14 µm. A sensor at this thickness attenuates the beam by ~ 0.1% and when the light shield is included this rises ~ 0.16%, based on 2 MeV photons [1]. The sensor was operated at 10 frames per second when collecting data. During the experiments the system was attached to the linac head via an accessory holder. In this configuration the sensor was 56.4 cm from the source.

3 MLC Leaf Position Reconstruction Methodology

In a raw image from the beam camera the edge of a MLC leaf is characterised by a rapid change in signal intensity. An algorithm was developed that exploits this to locate the edge position of the MLC leaves. The approach taken is to locate the edge positions of the MLCs using an image generated using the Sobel operators [2]. Prior to using the Sobel operators, a 2D gaussian smoothing filter is used to remove small pixel to pixel signal variations. The resulting image after both filters are applied shows the edges of collimators defining the beam aperture.
This was carried out for a field size of 5 x 5 cm2 with two MLC leaves, A and B protruding into the field. The frame was acquired when the linac was operating at 400 Monitor Units/Min with a pulse repetition frequency of 400 Hz. In this context a single frame was the integral of ~ 40 pulses.
This image can then be used to reconstruct the location of each of the MLC leaves, A and B. This is carried out in three steps. The first step makes a 1 pixel projection of the image onto the x-axis and locates the maximum point. A Gaussian probability distribution is then fitted around the maximum. The mean of this distribution is used to construct a contour of the MLC leaf. The edge position of the MLC leaf is modelled as a straight line. This model is then fitted to a region of ~ 30 pixels along the contour. The value determined from this fit is defined as the MLC leaf edge. A test was then carried out where the MLC leaf position was reconstructed for 100 individual frames to determine the resolution. The mean value of this distribution, which defines the leaf edge, has an uncertainty of 0.06 (~ 6 µm) pixels and a width of 0.5 (~ 50 µm) pixels, where the values in the parenthesis correspond to the value at 100 cm from the source (defined as the isocentre). The width of this distribution corresponds to the single frame resolution, which is improved upon with

10 seconds worth of data to 6 μm.
To study the performance of the edge reconstruction described in 3 a test was carried out using Gafchromic film. This method is standard in radiotherapy and has a precision of ~ 0.5 mm. The film was placed on the patient couch under build up and exposed to 300 Monitor Units. The edge position was then reconstructed using the film, with the edge positioned defined as 50% of the maximum dose. This was carried out for different MLC leaf configurations. In the first configuration both MLC leaves are side by side. Then MLC leaf A was moved away from MLC leaf B. The result of this experiment showed a linear relationship between the two sets of measurements. The result of a linear fit to the data gave a value of 0.1±0.5 for the intercept and 1.00±0.05 for the gradient. This agreement shows that within the resolution of the film the reconstructed MLC leaf positions are consistent.

4 Current Status and Outlook

The results presented here show that this system in nominal operation using a thin MAPS sensor can determine a MLC leaf position to within 6 μm for 10 seconds worth of data and 50 μm for a single frame. The resulting reconstructed MLC leaf positions agree with the photon field edge determined using film to the limit of the film accuracy. Work is continuing to test and validate dose models. This combined with high resolution MLC leaf positioning will allow the system to be used as an online monitoring system.

References

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