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Journal of Radiation Research and Applied Sciences
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A quality assurance technique for the static multileaf collimator mode based on intrinsic base lines

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ARTICLE INFO

Article history:
Received 19 February 2014
Received in revised form
18 March 2014
Accepted 19 March 2014
Available online 4 April 2014

Keywords:
Radiotherapy
Multileaf collimator
Quality assurance

ABSTRACT

The inspection of the static leaf positions of Multileaf Collimator (MLC) devices is essential for safe radiotherapy deliveries in both static and dynamic modes. The purpose of this study was to develop a robust, accurate and generic algorithm to measure the individual static MLC leaf positions. This was performed by extracting leaf tip locations from the radiographic film image and measuring their relative distance from a reference line on the film. The reference line was created with a selected set of MLC leaf sides. The film scaling was created and verified using the physical leaf width. The average measured distance corresponds to a leaf width of 10 mm was 9.95 ± 0.09 mm. The estimated reproducibility of the leaf tips location was ±0.26 mm. The code accuracy was checked by intentionally positioning set of leaves with small errors (1 mm), and the detected deviations from the expected positions ranged from −0.25 mm and +0.32 mm. The algorithm includes two self testing functions in order to detect failures of leaf positioning due to poor film quality and to avoid the potential systematic errors attributable to the improper collimator setting. The code is promising to be more efficient with Gafchromic and Electronic Portal Imaging Device (EPID).

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Peer review under responsibility of The Egyptian Society of Radiation Sciences and Applications

Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.jrras.2014.03.003

1. Introduction

Over the past two decades, the Multileaf Collimator (MLC) device has been widely implemented as a successful tool to achieve the desirable dose conformity to the target volume while sparing the normal tissues and the organs at risk in radiotherapy. This can be acquired for field-shaping in Static Mode (SMLC) or for dose modulation in Dynamic Mode (DMLC). The SMLC has been the fundamental option in conformal radiotherapy as the most popular radiotherapy techniques. On the other hand, with the development of the DMLC, the prescribed-dose lines can be dynamically conformed to the targets during beam on either with fixed gantry angle or with rotation. The leaf speed should be investigated for the safety of the DMLC delivery whereas the accuracy of the leaf position is essential for both of SMLC and DMLC modalities (Boyer et al., 2001 , 54 p.; Kung & Chen, 2000; LoSasso, 2008; Mohan et al., 2008).

The basic definition of the MLC leaf positions in the commercially available treatment distance between the leaf tips and the central line of the radiation systems is the radiation field. Accordingly, the MLC leaf positions inspection should ideally be performed by measuring these distances practically and comparing it with the MLC file coming from planning system. Besides, the central line of the radiation field should ideally intersect the mechanical isocentre of the linac at the radiation center point. However, ensuring this situation has been a challenge faced by various authors who dealt with linac isocentre position localization as an essential requirement for a successful Stereotactic radiosurgery/radiotherapy delivery Rowshanfarzad, Sabet, O'Connor, & Greer, 2011. Although there were many successful approaches and techniques mentioned in this publication, it is hard to extend one of them to fit for the purpose of MLC leaf positioning. This is because most of the hardware and software of those techniques were originally designed to identify the position of the point where the radiation center is, whereas the current purpose requires a robust, trustable and reproducible reference line passes through the radiation center point where all of the leaf positions can be measured from. Perhaps this was the reason why the earlier recommended approaches of MLC leaf positions calibrations were based on the accurate measurement of the central leaf pair positions relative to the radiation center, and apply a consistency approach to make sure that the rest are at the desirable positions (Hounsell & Jordan, 1997; Mubata, Childs, & Bidmead, 1997). These methods relies on the positions of the leaf sides of an arbitrary set of leaves to geometrically localize the radiation center point on a film, then employ this point as a reference point to calibrate the central leaf pair positions and subsequently localizes the rest of the leaf positions by consistent. Later on the MLC design and the corresponding QA have been reviewed extensively (Boyer et al., 2001) in which the optic field centerline is recommended as a reference for the MLC leaf position calibration with radiographic films. Therefore, it doesn't consider a radiographic identification method of the radiation center itself, but suggests a formula to work out the leaf tip positions from their light field projections instead. The subsequent publications have provided more direct measurement and calibration techniques while each of these techniques has their disadvantages. For instance some of them are specifically designed for certain machines (Sastre-Padro, van der Heide, & Welleweerd, 2004; Simon, 2009) beside the requirement of external reference object (graticule) for length calibration (Samant et al., 2002) while the other requires the setup of a scanning water tank along with ancillary equipment (Lopes, Chaves, & Capela, 2007) which is time and effort consuming. Recently, the implementation of Electronic Portal Imaging Device (EPID) to quantitatively analyze the garden fence (Sumida et al., 2012) and picket fence (Rowshanfarzad, Sabet, Barnes, O'Connor, & Greer, 2012) tests; the widely accepted tests for verification of the MLCs positions (Bhardwaj, Kehwar, Chakarvarti, Oinam, & Sharma, 2007; Boyer et al., 2001; Low et al., 2001; Sastre-Padro et al., 2007; Venencia & Besa, 2004). However, the methods were specially designed for these tests in addition to some radiation center determination issues; such as the use of a cross wire plate as an external reference to locate it in one of them (Sumida et al., 2012), and the lack of detailed information about its identification technique in the other (Rowshanfarzad et al., 2012).

Accordingly, we focused in this study on the quantitative inspection of the individual MLC leaf positions as a basic requirement for accurate MLC-implemented treatments. The SMLC test introduced in this study involves extracting leaf tip locations from an image and measuring their relative distance to a reference line on the image of well known distance from the radiation center. The reference line was created by means of selected set of MLC sides, so that no additional object was required at any stage of the experiment.

2. Materials and methods

A linear accelerator Clinac 23EX, (Varian Medical Systems Inc., Palo Alto, CA, USA), operated at 6 MV photon mode was used for all irradiations. The linac is equipped with an 80-leaf MLC Millennium, which includes two banks (A and B) each with 40 leaves mounted on a carriage. Each leaf is of 1.0 cm thick with maximum traveling distance of 15 cm at the isocentre level. Further leaf motions.require the movement of the carriage, but no carriage movement is allowed while beam is on. Films were placed on the treatment couch with 1.5 cm build up and reasonable backscatter thickness (5 cm) of a water-equivalent slabs (RW3- PTW-Freiburg, Germany) of 30 cm $\times$ 30 cm area and at source to film distance of 100 cm. Film scanning, alignment, cropping and saving in "tiff" format were achieved by using MEPHYSTO mcc software 1.8.0 (PTW-Freiburg, Germany), with Kodak extended dose range EDR2 Ready-Pack film (Eastman Kodak Company, Rochester, NY, USA) of size 25.4 cm $\times$ 30.5 cm and film scanner VIDAR VXR-16 (VIDAR Systems Corporation, Herndon, VA, USA) to provide 16-bit grayscale images at a spatial resolution of 71 dpi. The algorithm development for film analysis was carried out using the MATLAB 7.9.0 (R2009b) programming language and software where films were read and analyzed. The matrix size of the read image in MATLAB showed an image resolution of 0.083 mm in the x and y directions. The whole process of irradiating, processing, reading and analyzing films was around 100 min accumulatively.

Since the aim of this test was to determine the distance between the leaf tip positions and the radiation center, it was required to: (i) create an MLC pattern with different leaf locations that covers the range of clinical use, (ii) identify the position of the radiation center line or any line of a recognizable distance from it on the film so as to be taken as the reference of distance measurements, (iii) develop a calibration technique in order to convert distances in pixels to a unit of length (mm), and (iv) finding out the distance between the individual leaf tips and the reference line, and map them so it can be compared with the expected listed distances in the MLC files. The first two steps can be considered as test preparatory, while the others were the basis of the film-analysis approach in Matlab.

2.1. *Film preparation: MLC-test plans and base lines*

The MLC pattern was created using the commercial MLC Shaper software version 7 (Varian Medical Systems Inc., Palo Alto, CA, USA). Because of the film size limitation, it can cover only one quarter of the 40 cm × 40 cm linac field, Fig. 1(a). Subsequently, three other irradiations were required to cover the remaining of the linac field. The two MLC patterns M1 and M2, shown in Fig. 1(b), were over lapped to create the fields 1 and 2 on the film, shown in Fig. 1(a), and similarly for the rest of the fields. The leaves were initially delivered to create field 1, then each one was moved in the opposite direction of its bilateral ones to create field 2. Therefore, the potential of a mutual leaf driving as a result of an inter-leaf stickiness was eliminated. Moreover, the MLC gaps were designed to be narrow enough (1.0 cm wide) to provide flat profiles in the leaf motion direction regardless their off-axis distance, while the spacing between them was preferred to be consistent in order to compose a uniform vertical irradiation pattern as shown in Fig. 1(a).

To identify a point of known distance from the radiation center, two interleaf-leakage lines, the horizontal-line field (HL-field) and the vertical-line field (VL-field) were created, as shown in Fig. 1(a). The HL-field is generated due to the interleaf leakage between two neighbor leaves of the two fields HL1 and HL2, Fig. 1(c), with zero collimator rotation; one of the leaves was opened and the other was closed during a beam on in the first field and vice versa in the second one. The VL-field was shaped similarly, but with collimator rotation of 90° and wider jaw opening than that of the yellow rectangles, to show the edges of the leaves as it needed later on. The selection of these leave pairs was left arbitrary to the user, since it depends on the size of the film and the quarter of linac radiation field being covered as well as to avoid the interference with the other vertical fields. However, recognizing their numbers

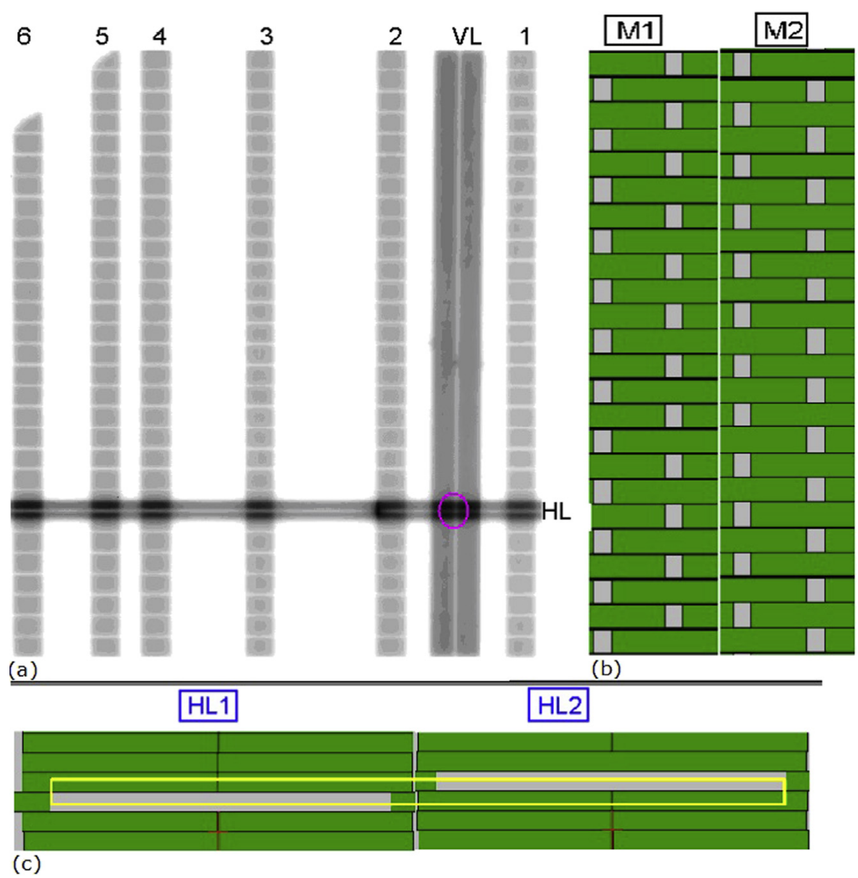

Fig. 1 – (a) The shape of the 6 MLC fields pattern appear on a film with the two perpendicular HL and VL base lines. (b) MLC patterns M1 and M2 as presented by Shaper. (c) The two MLC overlapping fields; HL1 followed by HL2 with jaws (shown as yellow rectangles); to create the HL. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

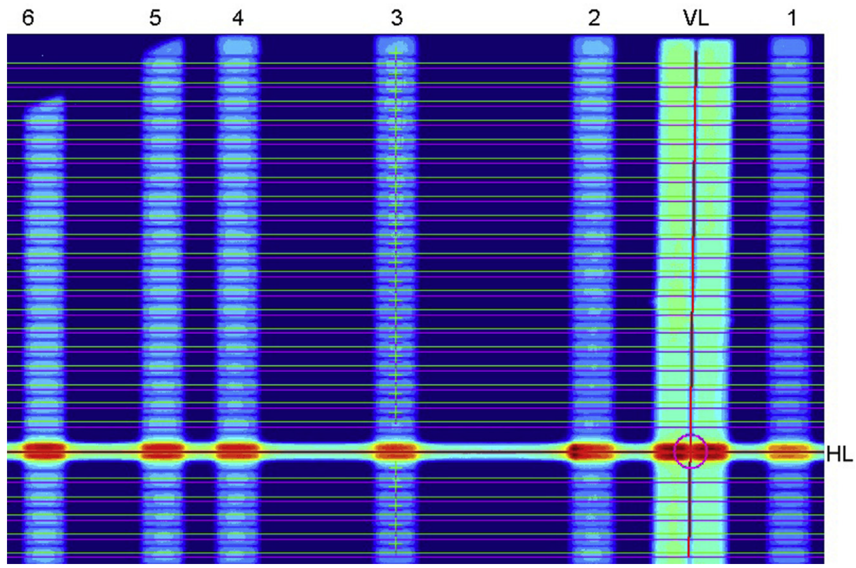

Fig. 2 – The (+) signs illustrate the edge function operated vertically. The strips horizontal lines are the positions of detecting leaf tips. The HL and VL appears in red lines in the middle of its fields, while their intersection (as a reference point) in a pink circle. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

was essential in order to identify their location relative to the isocentre. By this means a narrow sharp vertical line (VL) along VL-field was utilized as a reference line for the determination of the leaf tip locations, while the corresponding line (HL), in the HL field, was a guide to recognize the leaf numbers along the film. Furthermore, the two perpendicular lines HL and VL were used as the basic lines for film alignment. Consequently, to eliminate systematic errors in leaf positions and to preserve a sustainable film-alignment base line, it was necessary to make sure that the two lines are always at right angle. This was achieved by the regular check up of the accuracy of the collimator readout and by the calibration whenever it needed.

2.2. *Matlab code description*

Four images represent the four quarters of the linac radiation field were scanned, aligned, cropped and saved in tiff format with MEPHYSTO mcc software, and consequently imported to Matlab. Therefore, the user can find the pixel numbers (*X* and *Y*) of the approximate intersection pixel of the vertical and horizontal lines on each image individually, the center of the pink circle in Figs. 1(a) and 2. These were fed to the code as a guide to identify the positions of the VL and HL appear in red in Fig. 2. These lines were located by the fitting of the positions of minima in narrow horizontal and vertical strips of pixels (40 pixels wide) with central intersection area at the X and Y coordinates.

The approximate location of the mid-point of any of the vertical field pattern was required for the purposes of pixel spacing calibration and the identification of the best horizontal levels where each leaf tip can be detected. The reason for this mid-point selection criterion was to perform an efficient vertical scanning with a Matlab “edge” function to detect the neighbor leaf sides’ projection along the field of interest. The Laplacian of Gaussian method was found to be the most suitable one for this experiment with a zero THRESH value and a standard deviation SIGMA of 14.5. These values can be slightly changed depending on the film processing conditions and the MU values, given that values of 80 MU was delivered for all subfields created HL-field and VL-field, while it was 60 for the test patterns. The outcome of the vertical edge scanning along the center of field number 3, Fig. 2, was a set of colored (+) signs; where the distance between corresponding points in the consecutive pairs of points gave the leaf width in pixels. The position of theses colored (+) signs can vary depend on the MLC design. Given that the physical leaf width at the isocentre is known (depend on the MLC design), one can get the distances at the isocentre position directly regardless the source to film distance.

To identify the optimum levels, where each leaf tips can be detected, a vertical shift for each indivi-dual point equal to half width of the corresponding leaf (in pixels) was performed; the colored horizontal lines in Fig. 2. Since the spacing between each pair of lines is reasonably small compared with the leaf width, two appropriate groups of detection levels for the same set of leaf tip locations were defined. Therefore, the locations of the line pairs were split into two groups of row numbers where horizontal edge scans were performed to detect the leaf tips twice and average values were taken as final results.

Fig. 3 represents a screen shot of the Matlab figure version of the scanned films, shown in Fig. 1(a), after the whole process. The colored (+) signs, in Fig. 3, shows the detected positions of the leaf tips, except for that included in the VL-field. It is noticed in Figs. 2 and 3 that the fields of the HL superimposed with the vertical test fields producing an inconsistent high dose pattern at the HL-field and, consequently, this area

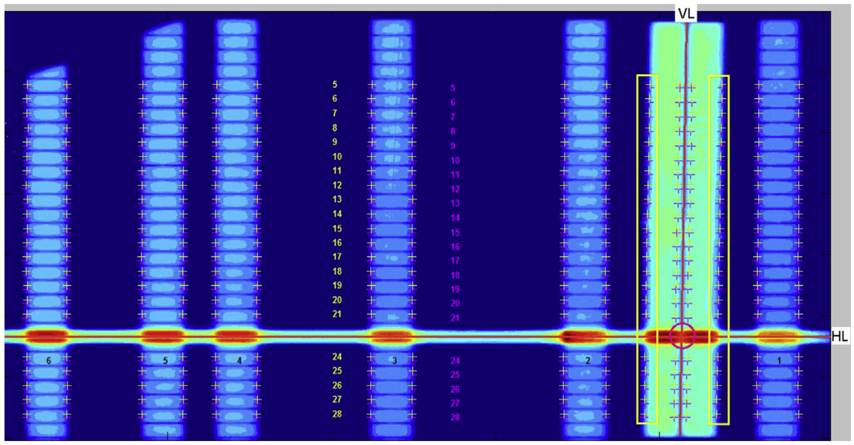

Fig. 3 – Film patterns as presented by MATLAB. The (+) signs on the MLC tips of field No. 3 appear with their numbers.

was excluded from the film. To overcome this, an overlapping film detection area of the upper and lower quarters of the linac field was allowed, so that the rejected leaf positions in one film can be incorporated in the other. This was achievable only when two different pairs of leaves were selected to create the HL with the different films. The other advantage of considering this overlapping film detection area was to have a set of an identically-projected leaf tip detected twice, once in each film, hence the reproducibility of the process can be assessed. Furthermore, the film pattern analysis shown in Fig. 3 was limited deliberately to start from the fifth leaf pair because the detection of the remaining four pairs of leaves with the fields numbers 5 and 6 was not possible, as they were covered by the collimators rounded corner, and similar condition take place with the other three films. In fact this example was satisfactory from the clinical point of view, since it covered the most practically used MLC leaves with their maximum traveling distance. However, less number of fields can be used to detect more MLC leaves, but with shorter detection range.

3. Results

3.1. *Localization precision*

Before finding the distances between the detected points and the VL, Fig. 3, it was vital to inspect the accuracy of the pixel-to-length conversion factor. As mentioned above; during the creation of the VL-field the normal jaws were opened wider so that the sides of the MLC leaves can be exposed, unlike in case of the HL-field. This was to allow measurements of distance between the red VL to the set of points located at the side edges of the VL-field; the set points are included in the two yellow rectangles in Fig. 3. The expected distance is equivalent to the leaf width (10 mm). The average measured distance between this set points and VL, obtained from ten films, was 9.95 $\pm$ 0.09 mm.

3.2. *Edge-detection sensitivity*

One of the most important issues concerned us was to ensure that the Matlab edge function produced sensible positions of the MLC tips that can fulfill the dosimetric field edge definition; 50% isodose curve at the depth of maximum dose (ICRU 1976). Since it is not possible to obtain this information from the film, we chose the criterion of maximum gradient of radiation intensity in the penumbra of the field, which was proved to be in a good agreement with the dosimetric definition (Bijhold, Gilhuijs, Herk, & van Meertens, 1991). To show the location of the detected points in the field's penumbrae, a set of profiles were drown at the different detection levels, an example is shown in Fig. 4. The detected points appeared to be in sensible positions in the penumbrae, since they are localized roughly at half the heights of the profiles. To evaluate the

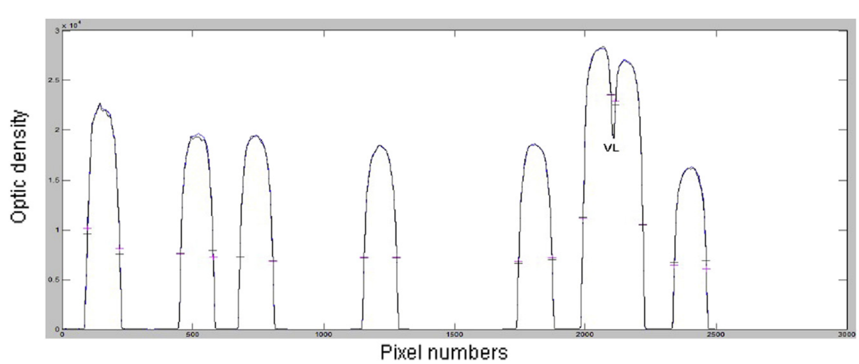

Fig. 4 – The location of the two groups of detected edge points, (+) color signs, appeared in the middle of maximum profile across any pair of leaves number.

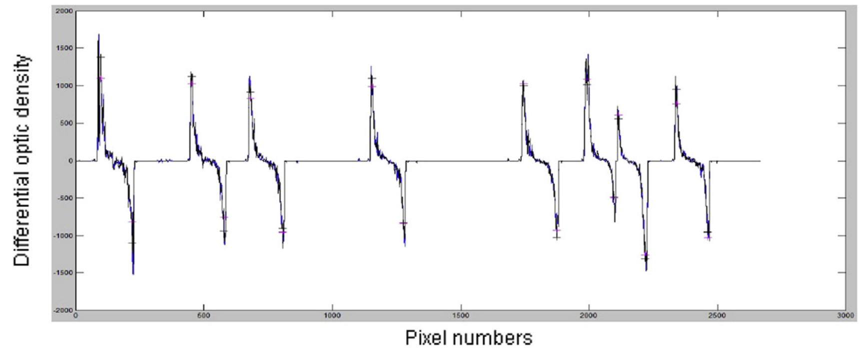

Fig. 5 – The detected edge points, (+) color signs, in a differential graph.

position of these points, another set of differential graphs were generated from the original profiles by applying the built in MATLAB function "diff", Kang, Deng, & Huang, 2009, which showed that these points were located right at the tips of the graph where the maximum dose gradient points were expected to be, as confirmed in Fig. 5. In fact, this is the way to check the performance of the algorithm and evaluate its efficiency in the first place, and became part of the routine work later on.

3.3. *Leaf-position error detection*

The overall outcome of the code was an array of individually detected locations (in mm) of selected leaves of the two MLC banks created from the four images collectively and assigned to the corresponding field's numbers. On the other hand, a special Matlab function was created to read the imported MLC files of all fields from the Shaper software, and subsequently an analogous array of the expected positions was created. Moreover, an additional function was written to evaluate and graphically represent the deviation between the predicted and measured leaf positions. Fig. 6 shows an example of the positional error between the measured and the expected leaf locations in bank A. The two upper and lower red horizontal lines in the figure represent the acceptable tolerance (±1.0 mm), which can be set by the user.

The green filled circles represent the mean value of error over the set of fields for each detected leaf tip, while the blue error bars border the maximum and minimum deviations. In case of any leaf position failed to be in the tolerance of the expected position, its mean positional error appear in red with two labels give the leave number and the field/fields number (s) where the failure occurred as shown in Fig. 6; A-12 was out of tolerance in field No. 5. This can prompt the user to perform a differential graph for the profile at the detection level of this leaf so as to exclude the probability of code error in this occasion.

3.4. *Reproducibility evaluation*

Before putting this version into practice it was necessary to check its reproducibility, as well as, its capability to detect slight leaf positional errors. As mentioned above, this experiment was originally designed to allow the reproducibility test as part of the routine application. Fig. 7 shows an example of

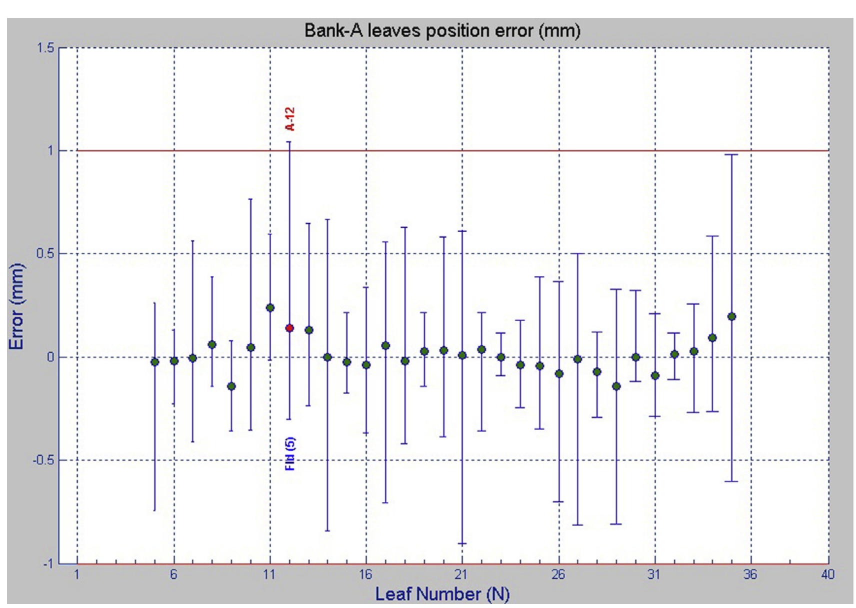

Fig. 6 – The leaf positional error (mm) between the expected and measured leaves positions in bank A.

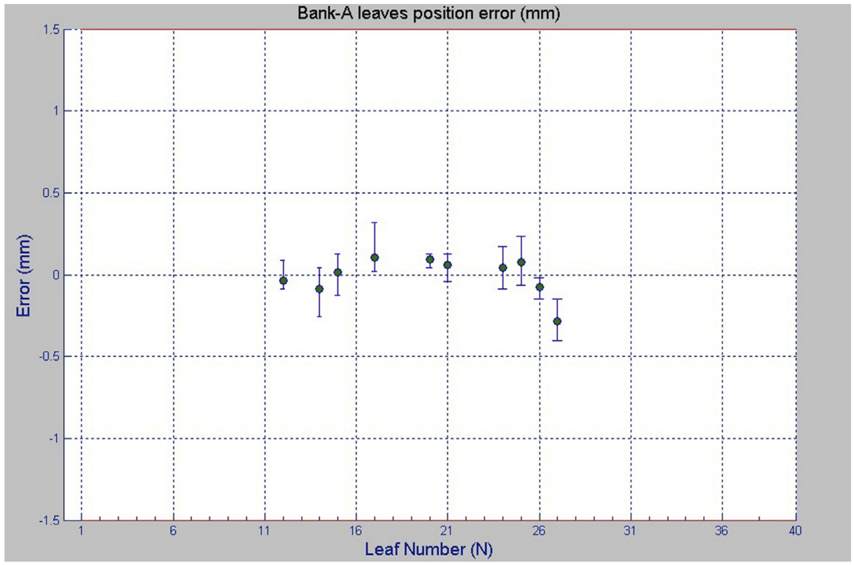

Fig. 7 – The reproducibility of measured leave positions (in bank A) between overlapping area of two films. The error bars represent the range of the errors over ten irradiations.

the difference between the measured positions of a set of central leaves with the upper and lower right films; the SD was ±0.26 mm over ten different irradiation sessions. On the other hand, the efficiency and accuracy of the code to detect intentional errors was checked by means of creating an MLC file where a set of randomly chosen leaves of one field were set up to be deviated 1.0 mm away from their positions in the original file as shown in Fig. 8. For this purpose a tighter tolerance of 0.5 mm was selected so it can pick up the erroneous positions. Furthermore, the presentation of the positional errors was restricted to the field No. 3, where the deliberate errors were expected only, which explains the nonexistence of the error bars in Fig. 9. This figure shows six out of the tolerance leaf positions in the field of interest (No. 3), as was anticipated, with deviations from the expected positions (1.0 mm away) ranged from −0.25 mm (A-23) and +0.32 mm (A-27). Besides, the numbers of the six misplaced leaves shown in Fig. 9 matched up with what can visually be seen inside the yellow marked area of their analyzed image shown in Fig. 8.

3.5. *Sensitivity to minor collimator rotation or carriage skews*

One more experiment was found interesting to find out the sensitivity of the code to a slight tilt of the VL line and, consequently, its capability to detect a potential skew of the MLC carriage. In this experiment, a deliberate drift in the zero

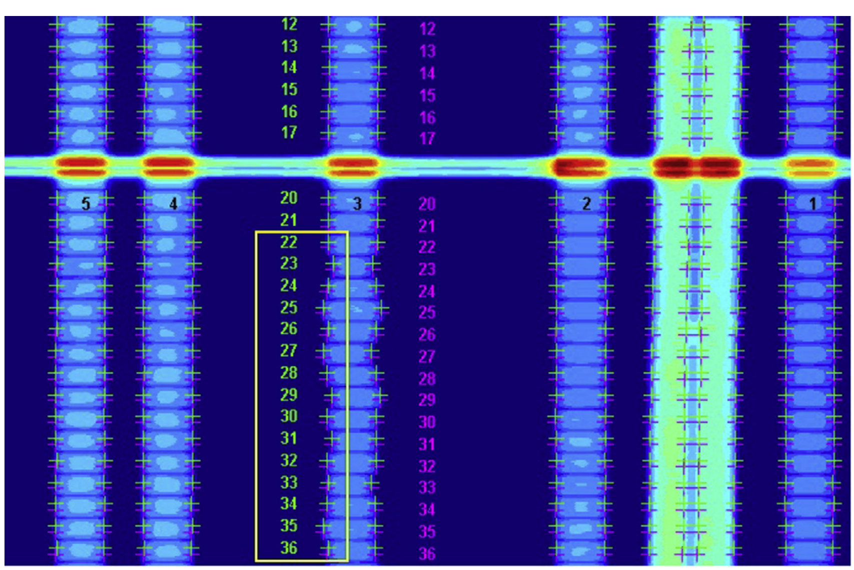

Fig. 8 – The erroneous of MLC in the field No. 3. The leaves in bank A, marked with yellow rectangular, were detected. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

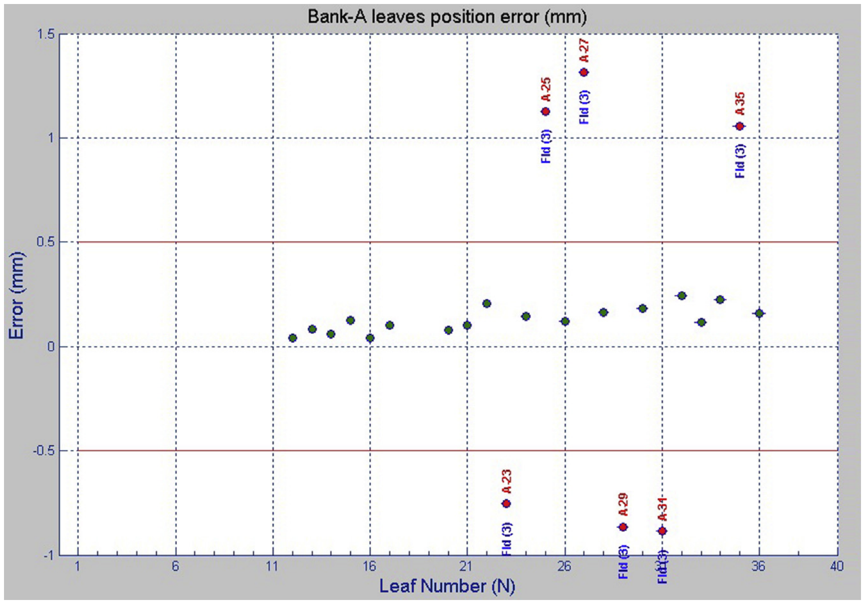

Fig. 9 – Accuracy of the code to detect the difference between the MLC files of the normal plan and the erroneous one in bank A. The failed leaves are colored in red and labeled with bank name and number as well as the field where these errors happen. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

collimator rotation of 0.3° was carried out, as shown in Fig. 10, which resulted in a typical angle of 90.3° between the VL and HL. This angle was measured with a special Matlab function as 90.23°. The tilt in VL produced remarkable trends of the A and B leaf positions error reached to 1.25 mm, Figs. 11 and 12. This behavior is the same as what would be expected if skew effects occurred with both of the carriages. So that, it was necessary to set a collimator readout accuracy tolerance of ±0.15° to avert false skew detection. In addition, this code was considered as a reasonable tool for the collimator readout check.

4. Discussion

The precise localizations of the MLC leaves is mandatory for safe SMLC and DMLC radio-therapy delivery (LoSasso, 2008; Mohan et al., 2008; Mubata et al., 1997). Accordingly, an application of an accurate and generic approach is presented in this work aiming for successfully computing individual leaf positions with Varian linacs MLC and EDR2 films. This approach relies on the accuracy of the leaf side positions to assess the leaf tip locations, and on the physical leaf width for

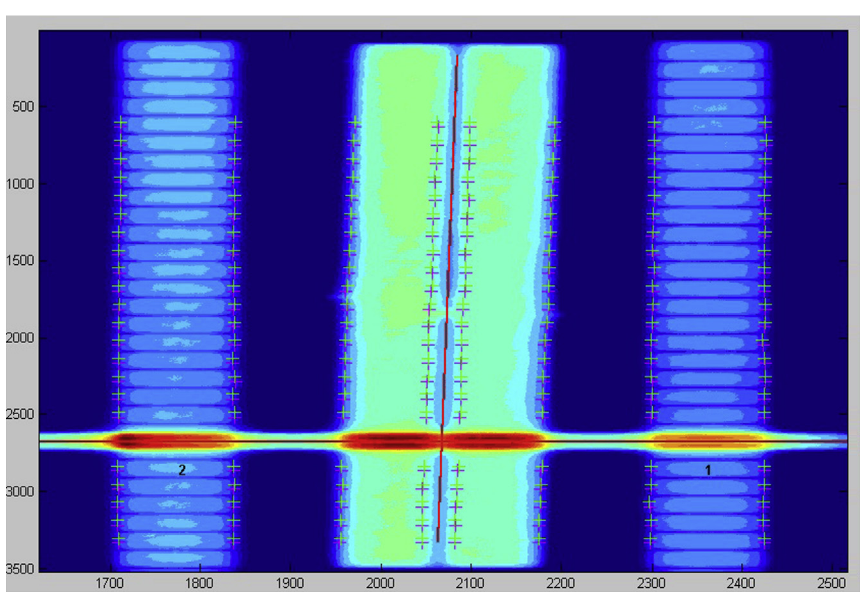

Fig. 10 – The non-orthogonal VL and HL when there is an inaccurate of the collimator readout of 0.3°.

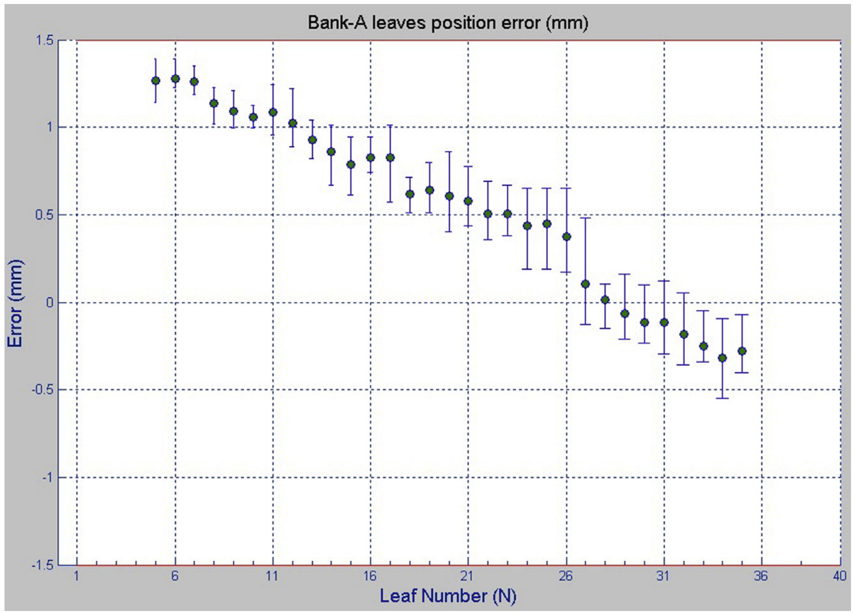

Fig. 11 – The trends of leaf positions error in bank-A as a result of the tilted VL.

pixel spacing measurement, which are both intrinsic characteristic of any MLC device regardless the vendor. On the other hand the analysis can be carried out across any 2D-matrix emerged from a uniform image providing that the image is of a reasonable spatial resolution which is the case of Gafchromic film and the electronic portal imaging device (EPID). Besides, the technique provides two self testing processes: the first is to check the performance of the Matlab edge scan function by the visual inspection of the detected point positions on the differential graphs, Fig. 5, while the second is to verify the collimator rotation angle in order to foil the chance of inappropriate carriage skew diagnosis. Furthermore, the reproducibility of the measurements can be checked out as part of the regular task, since a selected set of central leaf positions can be repeatedly measured in different films amongst the other sets of leaf positions.

The overall uncertainties of the measurements can be attributed to the following factors: (i) the usual drawbacks of the ERD2 film measurements, such as the quality of the film processing machine and conditions, which can defect the smoothness of the profiles and, in turn, disturb the edge function, and (ii) the accuracy of the manual alignment of the film with the MEPHYSTO mcc. These uncertainties have been collectively estimated as ±0.26 mm, the results of Fig. 7. However this uncertainty value can be slightly different with the various individuals and different film irradiation and

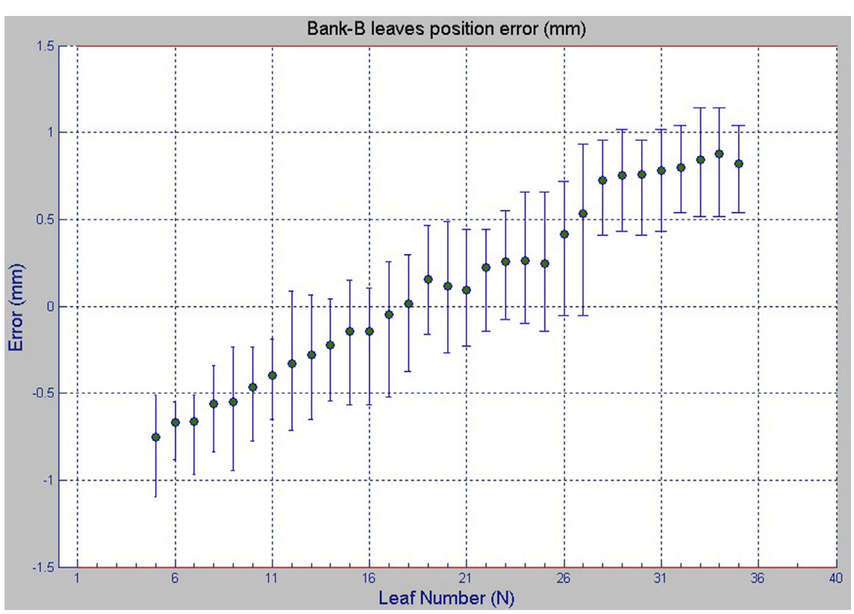

Fig. 12 – The trends of leaf positions error in bank-B as a result of the tilted VL.

processing conditions, while it can be reduced by means of automated film alignment with Gafchromic films or EPID. Furthermore, the system proved a high degree of accuracy in terms of measuring a know distance of 10 mm twice at every detection level, the average measured distance was 9.95 ± 0.09 mm, as well as the capability of easily detecting positional errors as small as 1 mm, as shown in Fig. 8.

The other important parameter that was found to be a potential source of uncertainty was the inaccuracy of the collimator readout, as 0.3° can produce noticeable positive trends of the errors reached to about 1.25 mm at the peripheral leaves of both carriages, as shown in Figs. 11 and 12. The figures also show an average error of 0.95 mm between the positions of leaves located at 19 cm apart (leaves numbers 6 and 26), which is in agreement with the pervious finding of 0.9 mm with the leaves 1 and 20, when similar collimator rotation (0.31) was deliberately applied (Rowshanfarzad et al., 2012) This has been overcome by the including collimator angle measurement as a part of the self testing procedure, as mentioned above. However, the uncertainty of the collimator angle measurements has not been investigated thoroughly in this work.

The current approach is originally designed to provide an independent measurement method of the individual MLC leaf tip distances from a well defined reference line created by using a set of recognized leaf sides. Therefore, it is an advanced expansion of the conception of the radiation center point localization by means of the robust positions of the leaf sides of the symmetrically opened MLC fields (Hounsell & Jordan, 1997; Mubata et al., 1997; Samant et al., 2002). However, it disagrees with the concept of relying on the positional calibration of the central leaf tips only in localizing the rest of the leaves consistently, Sastre-Padro et al., 2004, and consequently steers clear of the state of having significant systematic positional errors to the rest of the leaves that can be introduced by this means, Parent, Seco, Evans, Dance, & Fielding, 2006. Moreover, the use of leaf sides as reference for distance measurements has made the current method compatible with any of the commercially available MLC devices, unlike the use an auxiliary structure related to a specific MLC type such as the leading edge of the backup jaw with Elekta machines (Sastre-Padro et al., 2004; Simon et al., 2009). Furthermore, there is no external object, such a grid tray, Samant, et al. 2002, was required for pixel spacing determination, since the leaf thickness was used as the reference instead. In terms of time consumption an effort, the present application utilized EDR2 films, which requires time and effort to process however they are still less in comparison with that required to set up LA 48 (PTW-Freiburg, Germany) in water tank and the long procedure required for the same purpose (Lopes et al., 2007).

Finally, the suggested routine can inspire the quality assurance program designers to replace the commonly used picket fence (Bhardwaj et al., 2007; Boyer et al., 2001; Low et al., 2001; Rowshanfarzad et al., 2012; Venencia & Besa, 2004) and garden fence (Bhardwaj et al., 2007; Chui, Spirou, & LoSasso, 1996; Sastre-Padro et al., 2007; Sastre-Padro et al., 2004; Sumida et al., 2012; Venencia & Besa, 2004) patterns, since the current technique provide the absolute position of MLC leaves at any pattern, and can be applied for both initial leave calibration and regular consistency checks; with no external objects required for either radiation center determination or leaf position calibration.

5. Conclusions

The present work demonstrates an application of a suggested generic algorithm for MLC leaf positioning. The basic concept was to extend the usage of leaf side positions to be a guide for radiation center determination, so the central leaf positions can be calibrated, and define the reference line of the individual leaf tip positions measurement. The leaf width was found also a robust base line for film scaling and length measurements verification, which is anther intrinsic reference independent of the manufacturer. The algorithm has proved efficiency, reproducibility and suitability for clinical use. However there are some issues in terms of the traditional film processing problems and the manual alignment approach applied in the present application, which have been different with Gafchromic and/or EPID.

Acknowledgments

The authors wish to thank all members of radiation physics department, Oncology and Hematology Hospital, Maadi Armed Forces Medical Compound for their sincere cooperation and help.

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