Feasibility of using the linac real-time log data for VMAT treatment verification

N S Midi and Hafiz M Zin
Advanced Medical and Dental Institute, Universiti Sains Malaysia, Bertam, 13200, Kepala Batas, Penang, Malaysia.

E-mail: nshaheeramidi@yahoo.com

Abstract. This study investigates the feasibility of using the real-time log data from a linac to verify Volumetric Modulated Arc Therapy (VMAT) treatment. The treatment log data for an Elekta Synergy linac can be recorded at a sampling rate of 4 Hz using the service graphing tool on the linac control computer. A treatment plan that simulates a VMAT treatment was delivered from the linac and all the dynamic treatment parameters including monitor unit (MU), Multileaf Collimator (MLC) position, jaw position, gantry angle and collimator angle were recorded in real-time using the service graphing tool. The recorded raw data were extracted and analysed using algorithms written in Matlab (MathWorks, Natick, MA). The actual treatment parameters logged using the service graphing tool was compared to the prescription and the deviations were analysed. The MLC position errors travelling at the speed range from -3.25 to 5.92 cm/s were between -1.7 mm to 2.5 mm, well within the 3.5 mm tolerance value (AAPM TG-142). The discrepancies of other delivery parameters were also within the tolerance. The real-time linac parameters logged using the service graphing tool can be used as a supplementary data for patient specific VMAT pre-treatment quality assurance.

1. Introduction
Advanced radiotherapy treatment such as Intensity Modulated Radiation Therapy (IMRT) and Volumetric Modulated Arc Therapy (VMAT) allows conformity of radiation beam to the tumour using intensity modulated beams. The conformal beam is delivered using simultaneous movement of the dynamic multileaf collimator (MLC), the linac gantry and the collimator angle while the dose rate varied during irradiation [1]. The complexity of the MLC delivery makes IMRT and VMAT prone to delivery errors and requires patient specific treatment plan verification. Treatment verification using phantoms and clinical detectors requires difficult calibrations and is prone to errors if performed incorrectly. Alternatively, the MLC positions and other machine parameters are logged by the linac during treatment delivery may be used for verification. The adaptation of the advanced delivery technique is relatively new in Malaysia. Without appropriate training and quality assurance protocol, the quality of the treatment may be jeopardised. The study may provide an efficient safety net to detect any erroneous delivery of IMRT and VMAT for new centres implementing the advanced radiotherapy technique.

Varian linac (Varian Medical System, Palo Alto, CA), records the MLC positions based on the motor current feedback that provides the surrogate information at every 0.05 s in a text file. The file also contains delivery parameters such as the beam state, the gantry angle and the dose fraction that can be utilised for dose reconstruction [2–4] and mechanical error analysis [5]. However, the surrogate MLC
positions data is not able to detect error due to the MLC mechanical faults such as loose t-nut in the MLC system [6]. The study focuses on Elekta linac (Elekta, Crawley, UK) real-time MLC data measured by the propriety optical tracking system in the linac. The tracking system records the MLC position and other treatment parameters at every 0.25 s using the service graphing (SG) tool on the linac control computer. Our study investigates the feasibility of using the logged data for VMAT treatment verification.

2. Material and Methods

2.1. Treatment delivery

The study was performed on Elekta Synergy linac (Elekta, Crawley, UK) equipped with Agility multileaf collimator (MLC). Agility consists of 80 MLC pairs of 5 mm leaf width. The MLC positions are tracked by the propriety optical tracking system.

A dynamic motion of the MLC (dMLC) was first studied to investigate the structure of the data logged using the SG tool. All the MLCs in the right bank moves synchronously for 10 control points of different MLC positions. The MLC positions were 10.0 cm, 7.5 cm, 10.0 cm, 5 cm, 10.0 cm, 2.5 cm, 10.0 cm, 0 cm and 10.0 cm in the order of the control points. This back and forth of MLC motion produces opening and closing of a rectangular field. The other treatment parameters such as gantry angle and collimator angle remain constant.

A treatment prescription simulating a VMAT treatment delivery was delivered with 6 MV beam. The range of the prescribed treatment parameters are shown in Table 1. The MLC leaves move dynamically but asynchronously between 0.25 cm to 11.50 cm (the dynamic MLC shape will be explained in Section 3) and the pair of parallel collimator jaws position move from 5.0 cm to 11.5 cm. The gantry moves from 0° to 40° as the MLCs were moving. Total monitor unit (MU) was 50 MU.

| Parameters                   | Range of the prescription |
|------------------------------|---------------------------|
| MLC position                 | 0.25 to 11.50 cm          |
| Upper jaw                    | 5 to 11.5 cm              |
| Lower jaw                    | 5 to 11.5 cm              |
| Collimator rotation (°)      | 0 to 50                   |
| Gantry (°)                   | 0 to 40                   |
| Monitor unit                 | 50 MU                     |

The delivery parameters for the dMLC and the VMAT treatment were recorded using the SG tool on the linac control computer in the service mode. In this feasibility study, the prescribed MLC position logged during the delivery was only for the first MLC, i.e., MLC 1 and the middle MLC, i.e., MLC 40, while the MLC positions during treatment delivery were logged for all leaves. The limited number of the MLC positions recorded in the feasibility study is to minimise the complexity of the raw data recorded in the log file. Trigger function was set up to ensure the SG tool begins the data logging when the beam delivery started. The logged data were saved in an extensive mark-up language (XML) file after each treatment delivery.

2.2. Data analysis

The log file recorded by the SG tool was retrieved from the linac control system. It contains two-structured line in which the first line is the file header. The second line is the attributes containing the logged data recorded during delivery. Data extraction and analysis were performed using algorithm developed in Matlab R2013b (MathWorks, Natick, MA).

The MLC speed and gantry speed during treatment delivery were calculated using equation 1 and equation 2 respectively. The numerator calculates the difference between the two consecutive values recorded at every 0.25 s, i.e., the MLC positions in equation 1 and gantry angle in equation 2.
denominator describes the time between the two consecutive values. The delivered parameters were compared to the VMAT treatment prescription. Deviation between the prescribed and the delivered position for MLC 1 and 40 were also calculated. In addition to that, the influence of MLC speed, gantry angle and gantry speed to the MLC position errors of the middle leaf (MLC 40) were studied.

\[
\text{MLC Speed (cm/s)} = \frac{\text{MLC Position (i)} - \text{MLC Position (i+1)}}{(0.25)} \\
\text{Gantry speed (°/s)} = \frac{\text{Gantry angle (i)} - \text{Gantry angle (i+1)}}{(0.25)}
\]

3. Results

The range and the mean of deviation between the prescribed and the delivered value of MLC 1, MLC 40 and other delivery parameters are shown in Table 2. In the dMLC study, the range of the MLC error is between -1.7 mm to 2.5 mm. No deviation was seen in the delivered MU and jaw position. As the collimator and gantry were at a static position, no deviation was observed for these parameters. For the VMAT study, the range of MLC position error is between -0.6 mm to 1.6 mm. Figure 1 shows the actual MLC position during VMAT treatment from the logged data. Figure 1(a) shows the minimum field aperture at 0.25 s and Figure 1(b) shows the maximum field aperture at 9.25 s. Both sides of the jaws deviated to a maximum of 0.3 mm from prescription value. Collimator rotation and gantry angle position deviates to a maximum of 0.1° to 0.2° respectively.

| Parameters            | dMLC range (mean) | VMAT range (mean) |
|-----------------------|-------------------|-------------------|
| MLC Leaf 1 (mm)       | -1.7 to 2.5 (0.02)| -0.6 to 0.5 (0.003) |
| MLC Leaf 40 (mm)      | -1.7 to 2.5 (0.002) | -1.5 to 1.6 (0.003) |
| Monitor unit (MU)     | 0                 | 0                 |
| Upper jaw (mm)        | -                 | 0-0.3 (0.03)      |
| Lower jaw (mm)        | -                 | 0-0.3 (0.03)      |
| Collimator rotation (°)| -                 | 0-0.1 (0.03)      |

MLC speed was calculated to investigate whether it influences the MLC position error. MLC 40 in the dMLC study travels at a speed range from -3.24 cm/s to 2.64 cm/s. In VMAT the MLC travels at a higher speed from -5.88 cm/s to 5.92 cm/s. Figure 2 shows the position error for MLC 40 of the right MLC bank at different MLC speed for the dMLC study (Figure 2a) and the VMAT study (Figure 2b). Transient MLC position errors (spikes in the plot indicating higher error values) were seen when the leaves were changing its direction.

In the VMAT study, as the MLC speeds were modulating, gantry speed also varies throughout delivery. The range of the gantry speed during the treatment is between -10°/s to 8.8°/s as shown in Figure 3. Figure 4 shows the MLC position error as a function of gantry angle (Figure 4a) and gantry speed (Figure 4b). 97% of the MLC 40 position errors are between -0.5 mm to 0.5 mm at most gantry speed and gantry angle.
**Figure 1.** Plot of the MLC positions for the minimum (a) and the maximum (b) field size of VMAT study.

**Figure 2.** MLC position error and MLC speed for (a) dMLC and (b) VMAT for MLC 40.
4. Discussions
We have utilised the use of real-time log data of delivery parameters such as MLC position, monitor unit, jaw position, collimator rotation and gantry angle for VMAT treatment verification. Analysis of the deviation of the delivered MLC position from the prescribed MLC position shows errors ranges from -0.6 mm to 1.6 mm, well within the 3.5 mm tolerance value stipulated in AAPM TG-142 [7]. The dMLC study shows higher MLC position error than the VMAT although it records slower MLC speed. Leaf position error happened due to potential recoil when leaves changes direction [8] which explain why higher MLC position error happened at time where the MLC had to change its direction in the dMLC.
study. It also explains higher MLC position error at 0° and 40° gantry angles in VMAT. It is at the initial and final angle of each of the arc in which the MLC are required to reverse their movement direction. The errors were not affected by gravity. Clarke et al study the correlation of gravity effect on the stability of MLC using electronic portal device at different gantry angle and collimator rotation. Their results shows MLC position errors were consistent for all gantry angles except the initial and final showing that MLC error does not affected by gravity [9]. 97% of the MLC 40 error were within -0.05 cm to 0.05 cm at different gantry speed. Ga ntry angle and collimator rotation error in VMAT are within the machine tolerance value.

SG tool provide real-time data of treatment delivery parameters at sampling time of 0.25 s. The parameters are MLC position, beam MU, gantry angle, collimator angle and jaw position. The logged data includes prescribe and delivered value of parameters. Range of MLC position error in this study is between -1.7 mm to 2.5 mm. Pasler et al also reported that SG tool detect MLC position error as much as 6.5 mm when the dynamic parameter are pushed to maximum range [9].

5. Conclusion
The treatment parameters logged using the SG tool can be used as a supplementary verification method for IMRT and VMAT delivery. This study was performed on a simulated VMAT treatment fields. Verification of clinical treatment plans will be performed using the SG tool and the result will be compared to the measurements from clinical detectors.

6. References
[1] Masi L, Doro R, Favuzza V, Cipressi S and Livi L 2013 Impact of plan parameters on the dosimetric accuracy of volumetric modulated arc therapy Med.Phys. 40 071718.
[2] Dinesh Kumar M, Thirumavalavan N, Venugopal Krishna D, and Babaiah M 2006 QA of intensity-modulated beams using dynamic MLC log files. J Med Phys. J Med Phys. 31 36.
[3] Calvo-ortega JF, Teke T, Moragues S, and Pozo M 2014 A Varian DynaLog file-based procedure for patient dose-volume histogram – based IMRT QA Journal of Applied Clinical Medical Physics 15 5–7.
[4] Tae-Suk S, Jeong-Woo L, Jeong-Hoon P, Jin-Beom C, Ji-Yeon P, Bo-Young C, Doo-Hyun L, Semie H, Min-Young K and Kyoung-Sik C 2009 Inverse Verification of Dose Distribution for Intensity Modulated Radiation Therapy Patient-specific Quality Assurance Using dynamic MLC Log Files J Korean Phys Soc. 55 1649.
[5] Kerns JR, Childress N, and Kry SF 2014 A multi-institution evaluation of MLC log files and performance in IMRT delivery Radiat Oncol. 9 176.
[6] Agnew A, Agnew C, Grattan M, Hounsell A and McGarry C 2014 Monitoring daily MLC positional errors using trajectory log files and EPID measurements for IMRT and VMAT deliveries Phys. Med. Biol. 59 N49-N63.
[7] Klein EE, Hanley J, Bayouth J, Yin FF, Simon W, Dresser S, Serago C, Aguirre F, Ma L, Arjomandy B, Liu C, Sandin C and Holmes T 2009 Task Group 142 report: quality assurance of medical accelerators Med.Phys 36 4197–212.
[8] Mu G, and Xia P 2007 Impact of MLC leaf position errors on simple and complex IMRT plans for head and neck cancer Phys.Med. Biol. 53 77-88.
[9] Clarke M, and Budgell G 2007 Use of an amorphous silicon EPID for measuring MLC calibration at varying gantry angle Phys.Med.Biol. 53 473- 485.

Acknowledgement
This research is funded by Fundamental Research Grant Scheme, Ministry of Education Malaysia, 203/CIPPT/6771383. Thanks to the linac service engineer, Kho K.L. (ABEX Medical System) for the help with the service graphing tool in the initial stage of the work.