Advanced Camera Optimization

White Paper[1]

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[1] All data shown in this white paper are actual recorded results collected using phantoms under ideal testing conditions on production AlignRT installations at Vision RT offices (equivalent to clinical installations) and at an unaffiliated customer clinical site. The data presented are not endorsed by Vision RT and do not form any part of its claims. Rather, they simply represent actual data collected on Vision RT systems.

Abstract

AlignRT is a surface imaging system designed for initial patient setup and real time intrafraction patient position tracking during radiotherapy. With the goal of further enhancing the accuracy and stability of AlignRT, Vision RT have developed Advanced Camera Optimization (ACO), an innovative optical setup and calibration technique. As part of the ACO process, individual AlignRT camera pods are calibrated using data collected throughout a 3D volume that includes all clinically realistic surface locations. Additionally, the ACO optical setup tool (OST) is designed to optimize the optics of each pod and therefore provide enhanced tracking stability by minimizing inter-pod setup variability. The accuracy of AlignRT with ACO was assessed with a series of phantom studies. Scenarios for testing were chosen to provide the most challenging configurations for surface setup and tracking; large couch rotations, deep isocenters (up to 18 cm below the surface), clinically relevant regions of interest, and camera pod occlusions. Tracking stability during pod occlusions was assessed by rotating the gantry and measuring the change in AlignRT real time delta tracking information during occlusions. AlignRT with ACO was shown to provide sub-0.4 mm accuracy for all tested treatment scenarios, including sub-0.2 mm tracking accuracy for coplanar treatments. Changes in tracking accuracy during pod occlusions were shown to be < 0.1 mm.

1. Introduction

As radiotherapy equipment and treatment planning techniques continue to advance, techniques allowing for safer dose escalation strategies and reduction of dose to surrounding normal tissue have become more common. With these techniques it is important that the patient is correctly setup in the treatment position, and that their position is accurately and continuously monitored throughout treatment.

AlignRT has demonstrated clinical benefits for patient setup and intrafraction motion monitoring for a wide range of treatment indications, including cardiac sparing during DIBH left breast treatments [1] and cranial SRS procedures utilizing open-face masks [2] (Figure 1). As the accuracy of any SGRT system is related to the quality of the optical setup and calibration data, Vision RT has continued to research this area and has developed **Advanced Camera Optimization (ACO)**, an advanced optical setup and calibration technique.

Figure 1 – Surface guided SRS treatment procedure

ACO is a service performed procedure introduced to optimize the accuracy and stability of 6DOF tracking over a large field of view (FOV). Using a series of proprietary algorithms and techniques, the ACO procedure includes fine-tuning the optical setup and generating a 3D calibration model by acquiring multiple images of a precision manufactured ACO calibration plate as it is positioned throughout a 3D volume. The images are captured across a large FOV, resulting in 3D calibration data that is designed to encompass all typical clinical surface locations.

AlignRT can be used for initial treatment setup to position the patient both with respect to posture and to the treatment isocenter. In many instances the use of traditional surface marks (e.g. tattoos) and lasers have been replaced by SGRT for patient setup, and with the increased amount of information offered by SGRT in certain cases radiographic imaging frequency has been reduced [3].

In addition to providing accurate initial patient setup in radiotherapy, it is important to monitor the patient's position throughout the entire treatment process. The accuracy of patient tracking should ideally be independent of the treatment technique. Treatment techniques may range from coplanar treatments where there are no couch rotations or pod occlusions (i.e. static gantry positions that do not occlude a camera pod), to more complex treatment configurations which may include any combination of couch and gantry rotations (potentially resulting in one of the lateral camera pods becoming occluded). Additionally, it is important to maintain consistent tracking accuracy irrespective of the treatment isocenter and patient surface locations.

This white paper describes a series of tests and their respective results which were designed to measure the setup and surface tracking accuracy of AlignRT utilizing ACO. The goal of the tests was to provide AlignRT with the most challenging clinical configurations such that the accuracy of AlignRT with ACO is known for all clinical scenarios.

2. Materials and Methods

The accuracy of ACO was assessed on AlignRT via a series of phantom studies. Scenarios for testing were chosen to include the most challenging configurations for surface setup and tracking; large couch rotations, deep isocenters (up to 18 cm below the surface), clinically relevant regions of interest, and camera pod occlusions. The testing also looked at the coplanar tracking accuracy of AlignRT, and the ability for AlignRT to accurately position a phantom as part of an end-to-end test.

2.1. Measuring Absolute Setup Accuracy

The absolute setup accuracy is defined as the accuracy for which AlignRT can position a phantom in the planned treatment position in the treatment room. This study involved measuring the absolute setup accuracy of AlignRT with ACO, using DICOM CT surfaces from the treatment plan as the reference surface. End-to-end tests were performed using both a MAX-HD (IMT Inc., Troy NY) anthropomorphic cranial phantom, and the Vision RT MV Isocenter Calibration Cube rotated 45° from the calibration position. Treatment planning CT scans with a slice thickness of 1 mm were acquired for both phantoms, and treatment plans were created. The DICOM surface structures and treatment plans were imported into AlignRT and ROIs were chosen on the external CT reference surface (sample MAX-HD ROI shown in Figure 2).

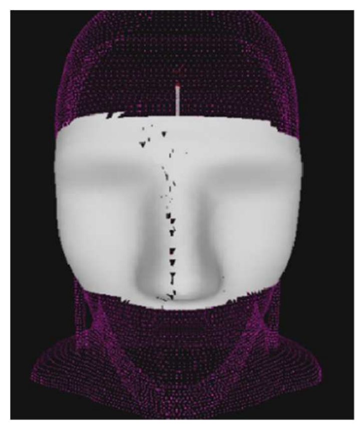

Figure 2 – Typical SRS ROI created on the MAX-HD surface.

Using the DICOM reference surface, the phantom was positioned on the treatment couch of a Varian TrueBeam® (Varian, Palo Alto CA) LINAC at HCA Healthcare UK at University College Hospital (London, UK) using 6DOF positional information from AlignRT. All real time delta (RTD) values were zeroed out, and a CBCT image was acquired. CBCT data was registered against the CT scan using the Auto and Manual Match functions on the TrueBeam® treatment console. The CBCT system had been calibrated using the Varian Imaging Isocenter Calibration System, IsoCal. The maximum error in absolute positioning of AlignRT was defined as the 6DOF match shifts between the CBCT and treatment planning CT.

2.2. Measuring Coplanar Tracking Accuracy

Tests to measure the accuracy of AlignRT with ACO under coplanar conditions were performed in the Vision RT Research Test Room (Basingstoke, UK) using the AlignRT MV Isocenter Calibration Cube phantom positioned at approximately 45° on a manual stage (Figure 3). Using a FaroArm® (Faro, Lake Mary FL) as the ground truth measurement against which to compare AlignRT RTDs, the stage was translated by ±1 cm and ±2 cm in each translational direction (VERT, LNG and LAT), and then by ±1° and ±2° rotations in YAW, PITCH and ROLL.

Relative to a reference surface captured at the zero position, a series of ten RTD measurements were captured at each position, with the experiment repeated four times. Measured RTD errors were defined as the difference between the offset phantom position (measured using the calibrated FaroArm®; accuracy = ± 0.034 mm, repeatability = 0.024 mm), and RTD values.

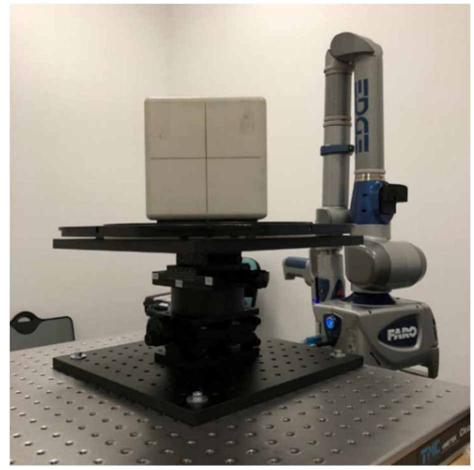

Figure 3 – Coplanar accuracy testing setup: SRS cube phantom on manual stage with FaroArm®.

2.3. Measuring Non-Coplanar Tracking Accuracy

Non-coplanar accuracy testing involved tracking a head phantom at various phantom and gantry rotations relative to a reference surface captured at the zero position. MAX-HD was positioned on a bespoke rotating platform (the platen; 0.1 mm / 0.1° manufacturing tolerances) (Figure 4). The position of the phantom was monitored using the AlignRT system at HCA Healthcare UK at University College Hospital, London, during various gantry and platen rotations, and RTD information was recorded for each configuration. At each platen rotation (0°, ± 45° and ± 90°), gantry positions of 0° and ± 30° were used to measure the impact of occluding each lateral camera pod.

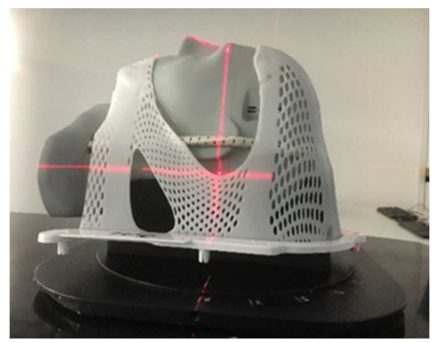

Figure 4 – Non-coplanar accuracy testing setup: MAX-HD phantom on the platen.

The influence of collecting volumetric data during ACO was assessed by repeating the above tests for a variety of different phantom positions (i.e. by changing the isocenter location of the phantom, with isocenters ranging from 3 to 18 cm below the surface). The stability and inter-pod optical setup consistency with ACO was explored using the RTD data collected with both no pod occlusions, and with one of the lateral pods occluded. To produce the most clinically relevant results, data where the gantry was rotated towards the rotated platen / treatment couch were excluded from the analysis as these configurations were deemed not clinically realistic (Figure 5).

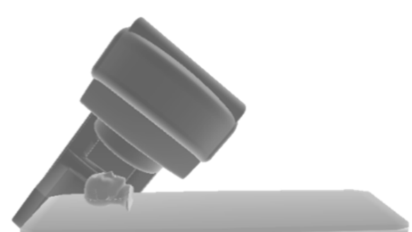

Figure 5 – Example "non-clinical" scenario where the data was excluded from the pod-occlusion analysis.

3. Results

3.1. Absolute Setup Accuracy

The maximum error in absolute positioning of AlignRT, defined as the 6DOF match shifts between the CBCT and treatment planning CT, was 0.2 mm / 0.4° for MAX-HD, and 0.2 mm / 0.2° for the cube phantom (Figure 6).

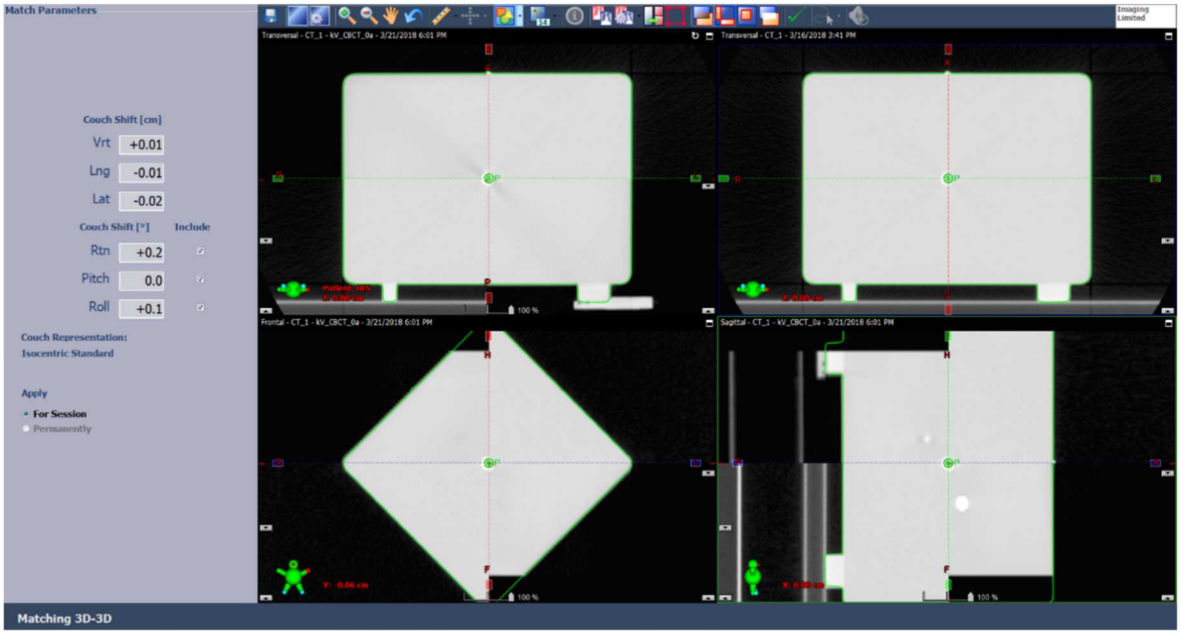

Figure 6 – Absolute setup accuracy cube phantom results.

3.2. Coplanar Tracking Accuracy

Under coplanar conditions, all measured RTD errors (difference between FaroArm® measured offset phantom position and RTD value) were below 0.16 mm and 0.05° (Average error = 0.00 mm / 0.01°, error range = -0.09 to 0.16 mm / -0.03 to 0.05°). Assuming a normal distribution, 98.8% of AlignRT RTDs accurately measured phantom translations with less than 0.2 mm / 0.1° error using ACO (2.5 standard deviations = 0.12 mm / 0.04°).

3.3. Non-Coplanar Tracking Accuracy

Across all couch and gantry angles (including pod occlusions), for a mid-depth isocenter (~12cm below the surface) it was demonstrated that AlignRT with ACO could track the Max-HD phantom with a maximum error of 0.32 mm (MAG RTD), and a maximum rotational error (YAW, ROLL and PITCH) of < 0.2° (Figure 7). Additional data (not shown) tracking the MV Isocenter Calibration Cube with the AlignRT system in the Vision RT Research Test Room, resulted in a measured non-coplanar tracking accuracy of ≤ 0.3 mm / 0.2° with ACO.

Isocenter Depth

Investigating the impact of isocenter location on RTD values, the difference in average MAG RTD value between shallow and deep isocenters was ~0.1 mm (Figure 8).

Pod Occlusions

The average change in RTD value with ACO caused by a pod occlusion was 0.06 ± 0.02 mm (maximum change = 0.07 mm) (Figure 9).

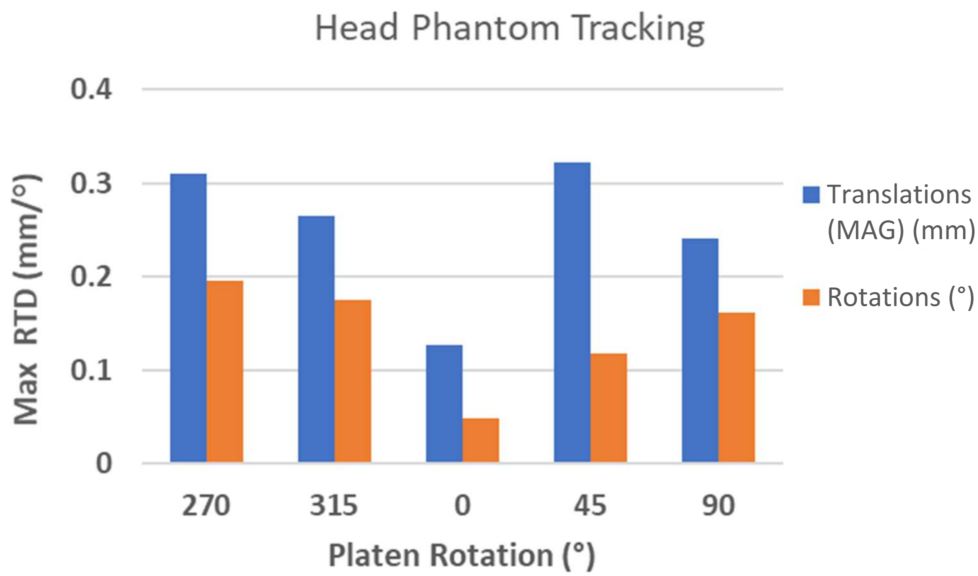

Figure 7 – Maximum magnitude and rotational RTD values recorded at different platen rotation angles, including all gantry angles, for a mid-depth isocenter.

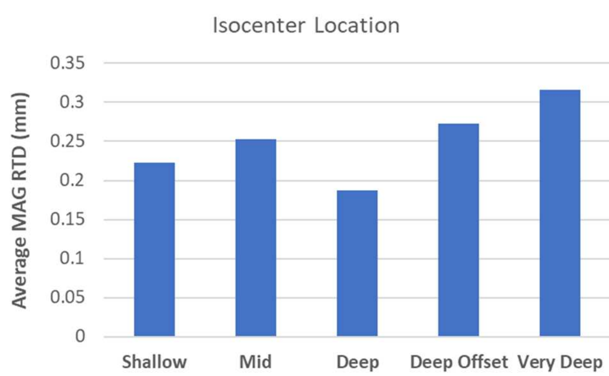

Figure 8 – Impact of isocenter location on non-coplanar tracking accuracy. Includes all gantry and phantom rotation angles.

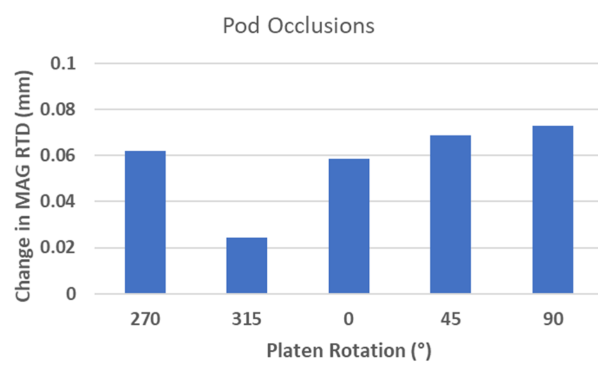

Figure 9 – Change in magnitude RTD when a lateral pod was occluded by the gantry, as a function of platen rotation.

4. Discussion

ACO was designed to provide a more accurate and stable optical setup and calibration across a 3D volume. The goal for ACO was to enable more accurate 6DOF patient setups and intrafraction monitoring, and more stable real time deltas throughout the entire patient treatment. Phantom study results from the absolute setup and known shift studies are summarized in Table 1. Data presented in this white paper suggests that AlignRT with ACO can provide sub-0.4 mm accuracy for all tested treatment scenarios in phantoms.

From this study, ACO has been shown to address three challenges inherent in any SGRT system; i) maintaining accuracy across a range of isocenter locations, ii) providing RTD stability when one of the camera pods is occluded, and iii) maintaining accuracy for all couch rotations. In the first two instances, changes in RTD values due to varying surface location or pod occlusions were shown to be on the order of 0.1 mm in phantoms. Regarding the third challenge, AlignRT with ACO was shown to provide sub-0.4 mm tracking accuracy including even the largest couch rotations.

The ACO accuracy measurements presented in this white paper have been independently replicated in phantom studies on several clinical and non-clinical AlignRT systems (data not shown). Additionally, in a study of over 450 cranial stereotactic treatment fractions, early clinical data from the University of Alabama at Birmingham supports this phantom data [4]. They conclude that ACO eliminates the dependence of isocenter location on tracking accuracy in patients.

Table 1 – Summary of measured accuracy data with ACO.

Accuracy Test	Measured Data
Absolute phantom setup error	≤ 0.2 mm / 0.4°
Coplanar tracking accuracy	< 0.2 mm / 0.1°
Non-coplanar tracking accuracy (MAX-HD)	< 0.4 mm / 0.2°
o Ave RTD change for varying isocenters	0.1 mm
o RTD change due to pod occlusions	< 0.1 mm
Non-coplanar tracking accuracy (Cube)	≤ 0.3 mm / 0.2°

5. Conclusions

Data contained within this white paper has shown that ACO, an advanced optical setup and calibration technique developed by Vision RT, provides highly stable and accurate surface monitoring across a full range of clinical treatment scenarios. The inter-pod optical setup consistency and volumetric calibration data offered by ACO has shown setup and tracking accuracy in phantoms of less than 0.4 mm for even the most challenging clinical configurations.

REFERENCES

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