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EDITORIAL

Can optical scanning technologies replace CT for 3D printed medical devices in radiation oncology?

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3D Printing in Radiation Oncology

Three dimensional (3D) printing is being increasingly adopted in radiation oncology for applications such as manufacturing bolus and brachytherapy treatment applicators, because of the accuracy and consistency of the prints that are achievable. The high conformity of these applicators compared with manual techniques, reduces air gaps above the surface of the patient, often resulting in improved dosimetric plan quality and reproducibility.

One common workflow utilised for 3D printing personalised devices in radiation oncology involves automatically contouring the external contour of the patient using a computer tomography (CT) scan based on a pre-defined Hounsfield unit (HU) threshold approach.[1–3] This external contour may then be used as a proxy for the patient's skin to design and 3D print a variety of beam modifying devices for radiotherapy treatments such as bolus. Before the bolus can be printed and used clinically, 3D modelling is used to refine the bolus to the correct thickness and add catheter tunnels for brachytherapy applications. This process enables a highly conformal, personalised applicator or bolus to be produced for each patient, which is potentially more efficient in terms of preparation time and cost of materials.

One disadvantage of this approach is the arbitrary definition of the skin surface on the CT, as a small increase or decrease in HU windowing can change the dimensions of the external contour, resulting in a change in shape of the 3D printed applicator, producing less than optimal conformity.[3] Another potential consideration is the requirement for multiple CT acquisitions as part of the planning process which increases the imaging dose to the patient.

While a clinical CT scanner has a typical resolution of approximately 0.5–1 mm, optical technologies such as structured light scanning (SLS) or photogrammetry have a much higher theoretical resolution, enabling more precise patient devices to be printed, resulting in improved conformity to the patient's skin and an enhancement in treatment accuracy and quality. We have already seen this technology applied in radiation oncology in the form of surface guided radiation therapy (SGRT) but could it replace CT scanners in a 3D printed bolus workflow?

As well as being significantly cheaper than CT imaging, in terms of initial hardware costs, optical scanning produces no ionising radiation, potentially enabling a reduction or elimination of imaging dose for some radiation oncology treatments. A unique feature of optical scanning is that it can also provide textural (colour) information about the surface of the patient (Fig. 1) potentially allowing for planning target volume (PTV) delineation on the virtual patient model by a radiation oncologist without radio-opaque markers.

3D Surface Scanning Technology

The two main 3D scanning technologies which have been investigated for 3D printing applications in radiation oncology are structured light scanning (SLS) and photogrammetry.

Structured Light Scanning

A SLS measures the shape of a 3D object by projecting known light patterns (often using a laser projection system) onto the surface and measuring the geometric distortion of the pattern using a camera system. The apparent distortion of this pattern can be used to reconstruct the topology of the object from the perspective of the camera.

This technology is often used in consumer hardware, such as facial recognition technologies on smartphones such as Apple© FaceID™. For metrology grade applications, the main disadvantages are the initial hardware cost and the use of high intensity lasers, which have been reported to cause some discomfort to patients if viewed directly.[4]

Photogrammetry

Another optical scanning technique, Photogrammetry, uses multiple photos from an ordinary camera (such as a digital single-lens reflex camera (DSLR) or smartphone) taken from as many angles around the target object as possible, which are then reconstructed in 3D space using a feature matching algorithm. Provided that there is enough overlap of "features" between the images, a structure-from-motion algorithm can calculate the shape of the target object in 3D space.

Photogrammetry has several disadvantages which have limited its adoption in healthcare. The main limitations are the computational processing power required for the complex reconstruction workflow and the lack of an absolute scale definition in the reconstructed models. Absolute scale is required to ensure the 3D printed model has the correct size, and is usually defined by placing a reference object in the reconstructed scene with known dimensions.

Limitations

Photogrammetry and SLS are both optical scanning techniques and consequently share many of the advantages and disadvantages compared with CT based surface delineation. Both approaches struggle to reconstruct optically reflective and transparent surfaces, both of which can be mitigated by applying matte powders or sprays on the affected surface during the acquisition process (demonstrated in Fig. 1 using Micropore tape).

While optical scanning technologies are useful for defining the surface of an object with a high resolution, they do not provide any information about the interior of the object. Since the 3D model is defined only in terms of the exterior surface of the target, the interior volume must be assigned a single density material, if used for planning, and therefore permits only homogeneous dose calculations to be performed.

Optical scanning techniques such as SLS and photogrammetry both require projections to be acquired from multiple directions to produce a complete 3D model of the patient, which can be time consuming and consequently, increases the possibility of motion artefacts in the models. The benefits of optical scanning techniques, namely the increased spatial resolution and textural information, paradoxically enable a patient to be more easily identified from their scan data, raising obvious privacy and data handling implications.

In addition to these technologies, the smartphone revolution has resulted in several cost effective, and convenient commercial alternatives to these systems such as light detection and ranging (LIDAR) devices (an example scan is shown in Fig. 1) which uses time-of-flight or phase-shift measurements to scan the surface of an object. Although these systems currently lack the spatial resolution of metrology grade SLS scanners or photogrammetry, they are generally easier to use, have fast scan times, are cost effective and convenient in the sense that they are built into some commercial smartphones.

Figure 1. CT (left) vs. LIDAR (center) vs. Photogrammetry (right) derived 3D models of a Rando anthropomorphic phantom. The CT scan was acquired on a Toshiba Aquillion scanner, Lidar scan was acquired with the Scaniverse© iPhone 13 Pro App. Photogrammetry reconstruction was performed using Metascan© iPhone app. Note the high level of detail on the photogrammetry scan (phantom slices and numbering are visible on the mesh).

Previous Work

The earliest study published on optical scanning techniques in radiation oncology appears to be by Renner et al.[5] who utilised the source light of a therapy unit to project a grid pattern onto the patient, in essence, an early structured light scanning approach. This projection was photographed together with calibration objects and then transferred to a computer terminal to reconstruct the topology of the patient as a 2D matrix.

Interest in the field was revived in 2018 by Sharma et al.[6] who used a low cost SLS to manufacture 3D printed bolus for radiation therapy, demonstrating the feasibility of this approach for routine clinical use.

Low cost, albeit less accurate alternatives to this approach, were published in 2019 utilising lower cost consumer smartphones. LeCompte et al.[7] used the TrueDepth™ sensor (a SLS sensor) on the Apple© iPhone X to produce a depth map from a single projection enabling a bolus of the nose region of a subject to be created. The same year, Douglass et al.[1] used photogrammetry to produce a superficial brachytherapy surface mould applicator using non-specialised smartphone camera technology. The dosimetric effects of this technique, compared with CT based applicators were investigated by Bridger et al.[2] in 2022. They found that although photogrammetry reconstruction resulted in slightly larger air gaps beneath the 3D printed applicator compared with the standard CT approach, similar brachytherapy treatment plans were achievable with comparable PTV and OAR doses.

Clinical Commissioning and Feasibility

In this issue of Journal of Medical Radiation Sciences, Crowe et al.[4] used a metrology grade structured light scanner to image patients for 3D printing radiotherapy medical devices. The high accuracy Artec Leo SLS system was commissioned and tested using typical radiotherapy phantoms for use in a clinical setting.

In this progressive study, the SLS was used to scan 26 participants producing 173 scans and assessed in terms of accuracy and practicality for manufacturing radiotherapy devices such as bolus. Using a metrology grade scanner enabled very high accuracy models to be produced compared to other optical scanning techniques.

Two millimetre boluses were fabricated for the participants using a 3D printer for sites of: glabella, nose, orbits and zygomatic bones which were chosen due to the high inter-participant variation in these areas. Participants were asked to self-assess the fit of the bolus, 87% of whom reported the fit felt good or comfortable. A visual inspection of the separations between bolus and skin showed excellent conformity as well.

The scanner was found to be intuitive, could be used without training and scans could be obtained with a single pass without the need for re-scans, except in anatomical locations which were occluded by other anatomy such as behind the ears. They reported difficulty with head and facial hair, which appeared as a single large geometric surface, and reconstruction of red wax was reported to be difficult.

One of the most important contributions from this study was the creation of pseudo CT water-equivalent datasets from the SLS scans which could be imported into the treatment planning system (TPS), enabling custom bolus and applicators to be designed and optimised prior to treatment planning. This enabled the use of the various tools already available in the TPS to design a bolus, reducing the specialist 3D modelling skills required by staff. It also provided a practical means for optical scans to be used in conjunction with other traditional imaging modalities such as CT, magnetic resonance imaging, bringing optical scanning modalities a step closer towards routine clinical use.

Conclusion

Optical surface reconstruction technologies have been shown to be useful for 3D printing applications in radiation oncology departments due to their higher spatial resolution, non-ionising radiation imaging, and the addition of textural information.

These technologies have already demonstrated their usefulness for applications such as SGRT, but can they replace existing imaging technologies in a 3D printing workflow? I believe the full benefits of this technology are yet to be realised, particularly, the usefulness of the textural information which is not provided by other radiographic modalities. As suggested by Crowe et al.[4] in the short term, optical scanning technologies will likely supplement existing radiographic imaging techniques and may be particularly useful for specialised techniques such as total skin electron therapy or total body irradiation which could utilise homogeneous volume or surface dose calculations. The synthetic water-equivalent computer tomography technique developed by Crowe et al.[4] is a promising next step towards this objective, irrespective of the type of 3D scanner used.

Other cost-effective 3D imaging technologies, such as LIDAR, built into consumer smartphones, enable real-time 3D reconstruction without specialised knowledge or training, could potentially enable patient scans to be acquired by oncologists during the patient's initial consultation.

Optical 3D scanning has several advantages compared to existing imaging technologies which may enable it to be used as the sole imaging modality for a limited number of specialised treatment techniques but further research is required before it could be used in a clinical setting. At the very least, I believe we will see optical scanning used routinely in the treatment planning workflow for the manufacturing of 3D printed bolus and supplement existing imaging modalities.

References

1. Douglass MJJ, Caraça Santos AM. Application of optical photogrammetry in radiation oncology: HDR surface mold brachytherapy. *Brachytherapy* 2019; **18**: 689–700. https://doi.org/10.1016/j.brachy.2019.05.006
2. Bridger CA, Reich PD, Caraça Santos AM, Douglass MJJ. A dosimetric comparison of CT- and photogrammetry-generated 3D printed HDR brachytherapy surface applicators. *Phys Eng Sci Med* 2022; **45**: 125–134. https://doi.org/10.1007/s13246-021-01092-1
3. Bellis R, Rembielak A, Barnes EA, Paudel M, Ravi A. Additive manufacturing (3D printing) in superficial brachytherapy. *J Contemp Brachytherapy* 2021; **13**: 468–82.
4. Crowe S, Luscombe J, Maxwell S, et al. Evaluation of optical 3D scanning system for radiotherapy use. *J Med Radiat Sci* 2022; **69**: 218–26. https://doi.org/10.1002/jmrs.562
5. Renner WD, O'Connor TP, Amtey SR, Reddi PR, Bahr GK, Kereiakes JG. The use of photogrammetry in tissue compensator design. Part II: experimental verification of compensator design. *Radiology* 1977; **125**: 511–6.
6. Sharma A, Sasaki D, Rickey DW, et al. Low-cost optical scanner and 3-dimensional printing technology to create lead shielding for radiation therapy of facial skin cancer: First clinical case series. *Adv Radiat Oncol* 2018; **3**: 288–96.
7. LeCompte, M.C., Chung, S.A., McKee, M.M., et al. Simple and rapid creation of customized 3-dimensional printed bolus using iPhone X true depth camera. *Pract Radiat Oncol* 2019; **9**: e417–21.

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