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Medical Physics ICTP

Surface guided radiotherapy

Joint ICTP-IAEA Workshop on Radiation Protection in Image-Guided Radiotherapy (IGRT)

Outline

- Introduction
- SGRT technologies
- Clinical applications
- QA

Introduction

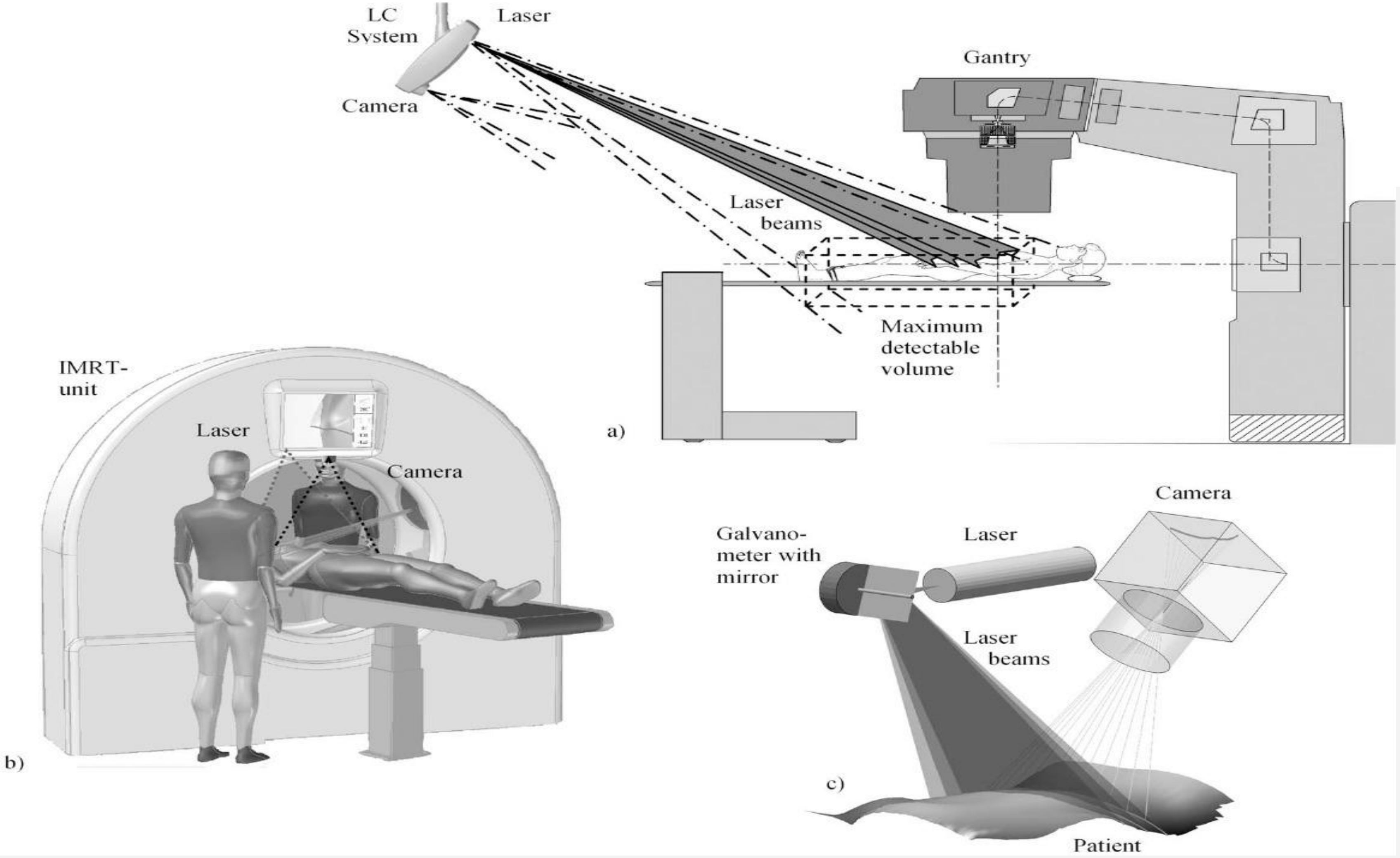
Surface imaging reconstructs the three-dimensional (3D) surface of the patients in real time using optical imaging without the need for external markers.

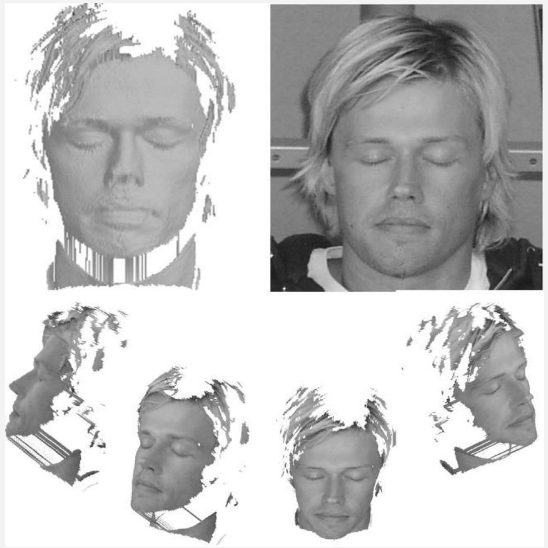
Its main advantage is that it is nonionizing.

It can, therefore, be used on a daily basis for

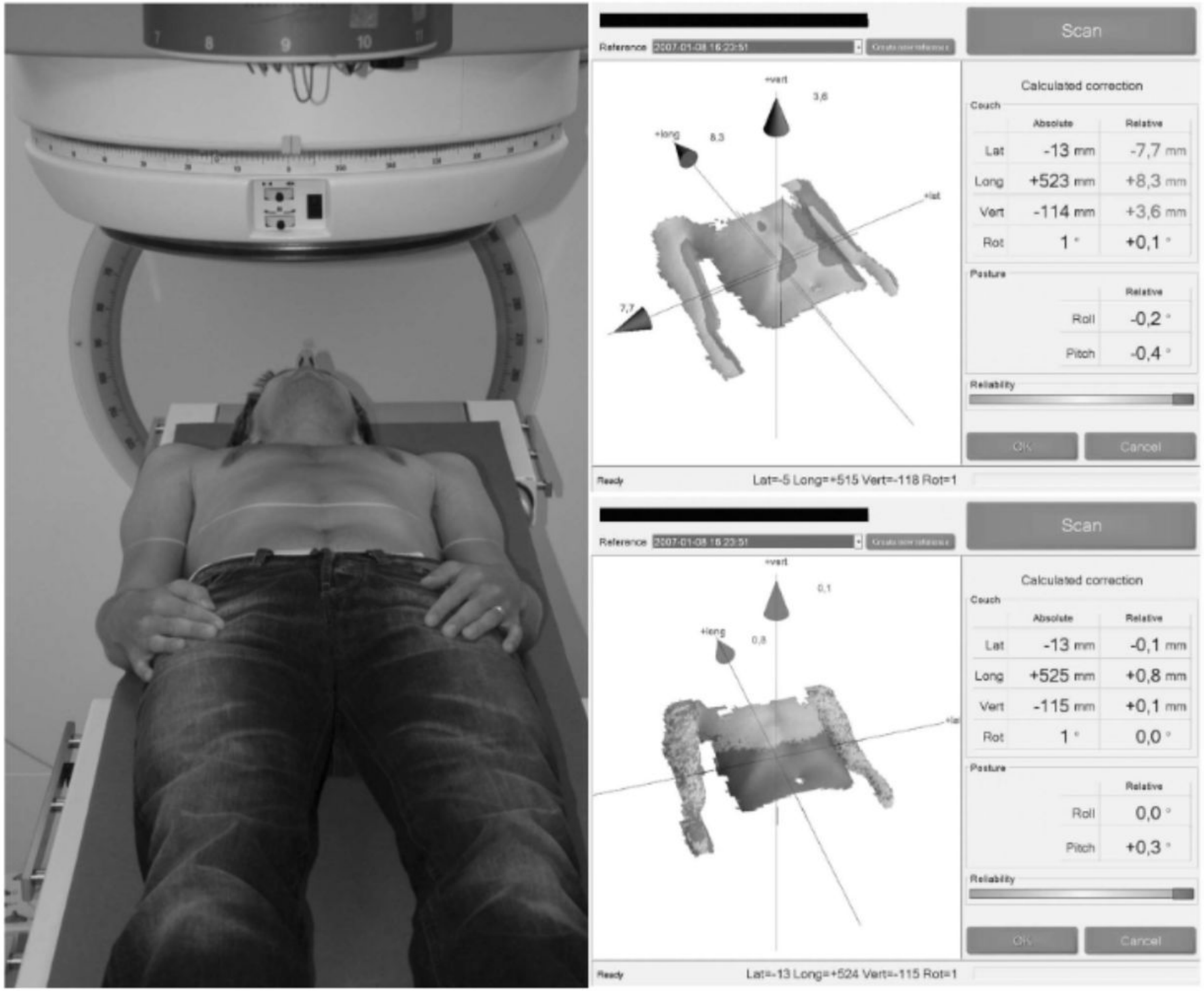
1. Initial positioning,
2. Continuous monitoring of intrafractional motion,
3. Interfacing with linac control systems to interrupt the radiation beam when thresholds of motion are exceeded

Laser camera system





1. Narrow line laser
2. Optical scanner: galvanometer mounted mirror to sweep the fan-shaped laser beam. The beam is swept alongthe patient with a step time of less than 300µs. The optical scanner, run by a servo and a scan control card connected tothe computer through a serial port, can step the laser line at 2500 Hz over an angle of 25° while the
3. CMOS camera captures the laser line on the patient at a frame rate of up to 50 fps.
4. The location of all patient contour data points in 3D space are then calculated by optical triangulation


[redacted]
Scan
Reference 2007-01-08 16:23:51
+vert
3,6
+long
8,3
+lat
7,7
Calculated correction
Couch
Absolute
Relative
Lat -13 mm -7,7 mm
Long +523 mm +8,3 mm
Vert -114 mm +3,6 mm
Rot 1 ° +0,1 °
Posture
Relative
Roll -0,2 °
Pitch -0,4 °
Reliability
OK
Cancel
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Scan
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+vert
0,1
+long
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Calculated correction
Couch
Absolute
Relative
Lat -13 mm -0,1 mm
Long +525 mm +0,8 mm
Vert -115 mm +0,1 mm
Rot 1 ° 0,0 °
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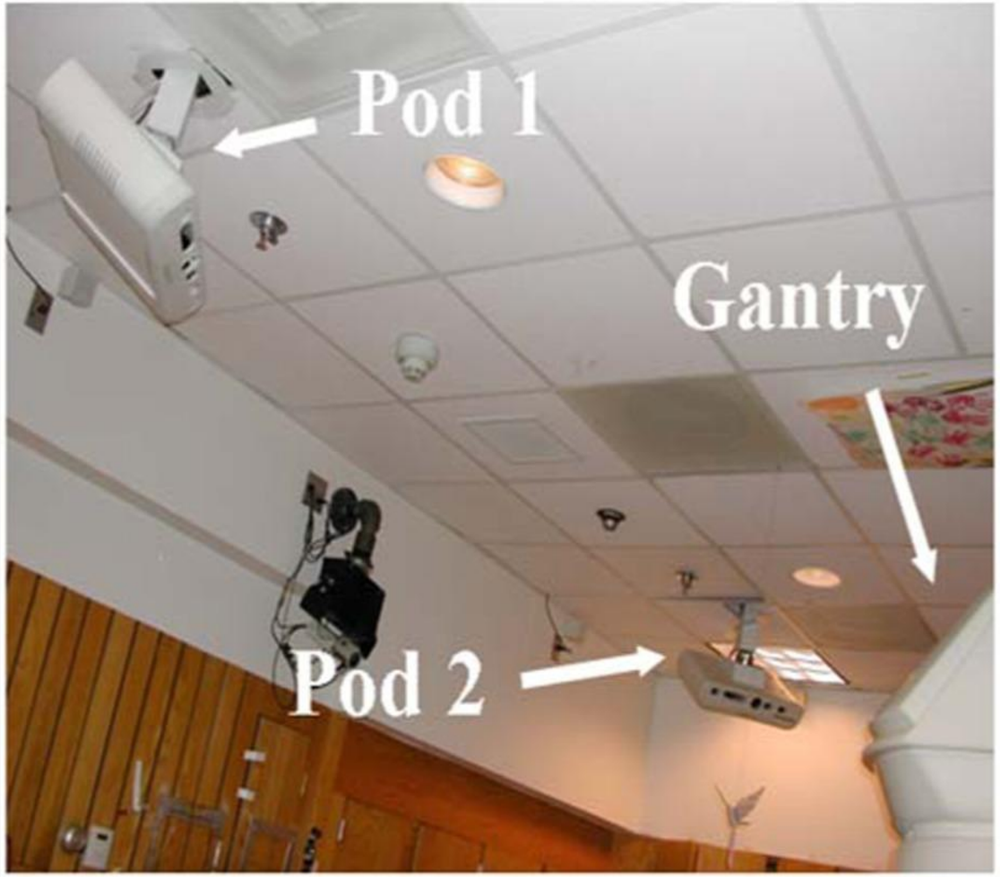
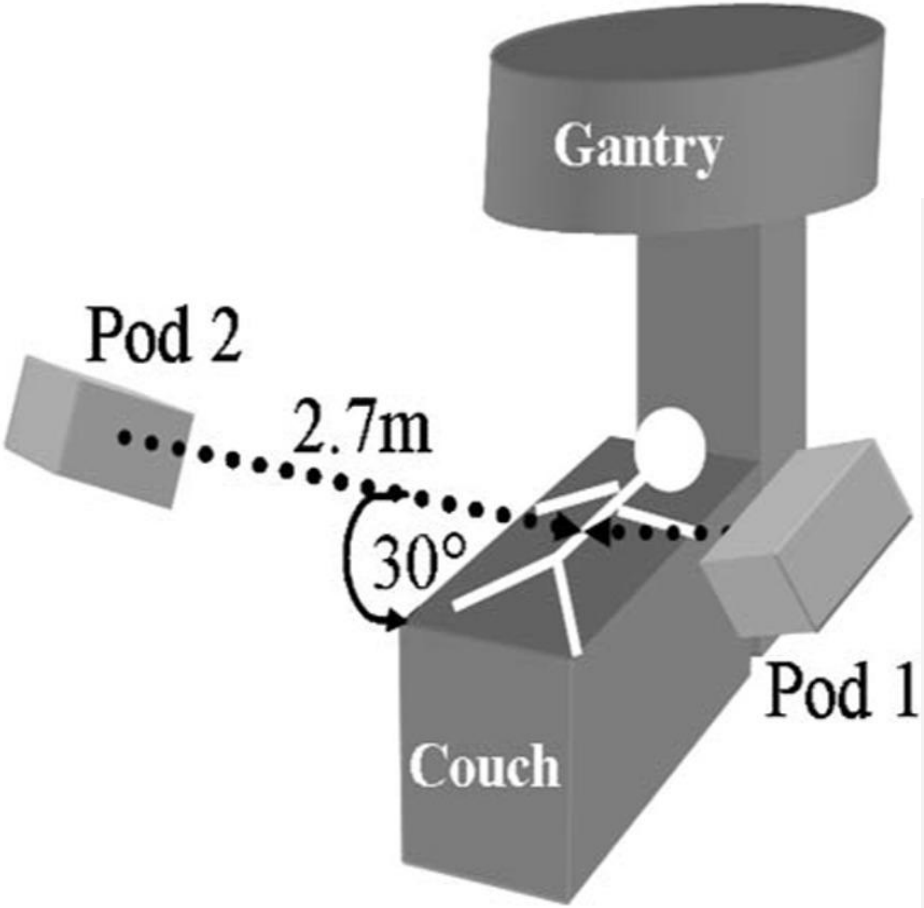
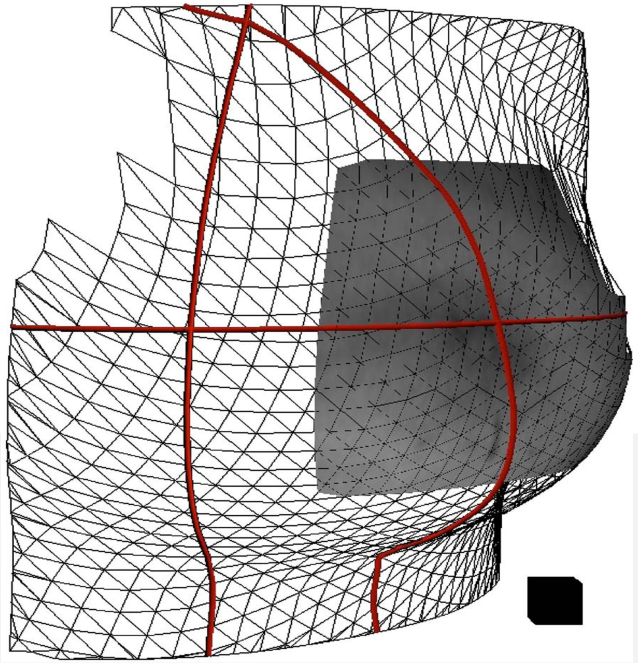
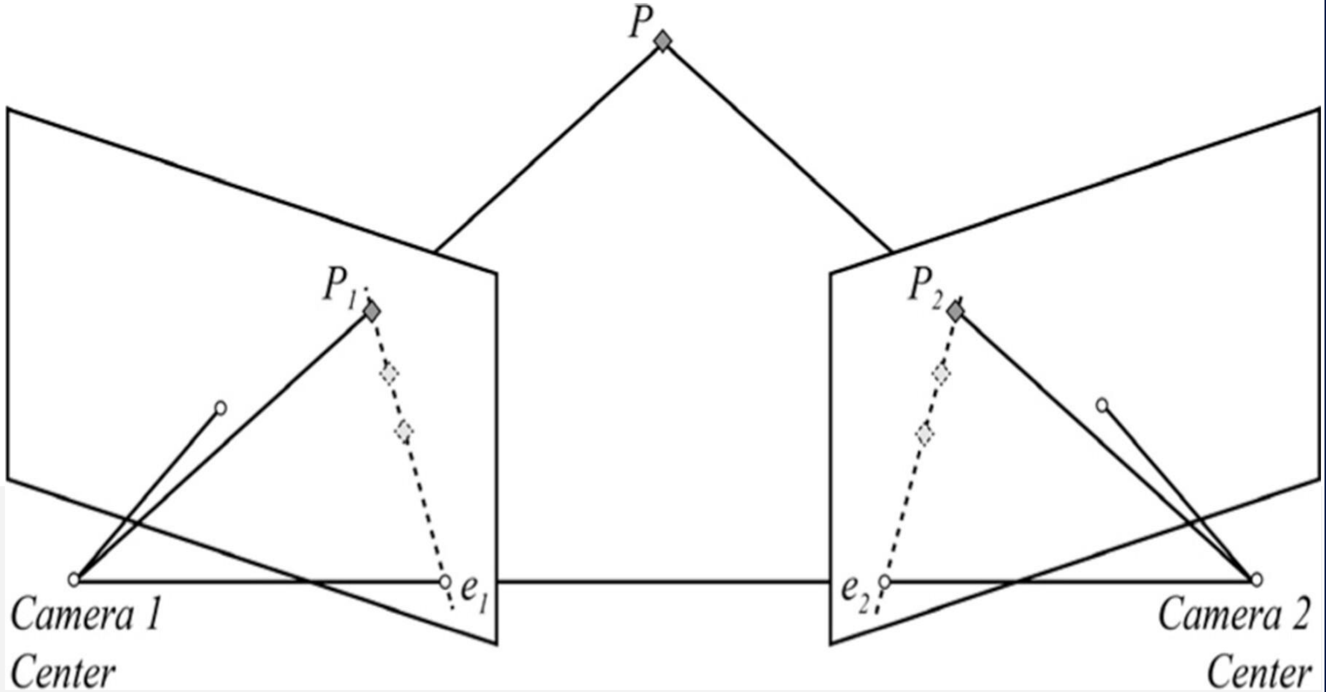
Stereo-vision surface imaging





Medical Physics, Volume: 32, Issue: 9, Pages: 2753-2762, First published: 17 August 2005, DOI: (10.1118/1.1984263)





(1) Identify the pixel coordinates of P in Camera 1 (P1),

(2) search the image of Camera 2 to find the corresponding pixel coordinate of P image 2 (P2)

(3) Project and compute the 3D location of P from the coordinates of P1, P2, and the known camera geometry.

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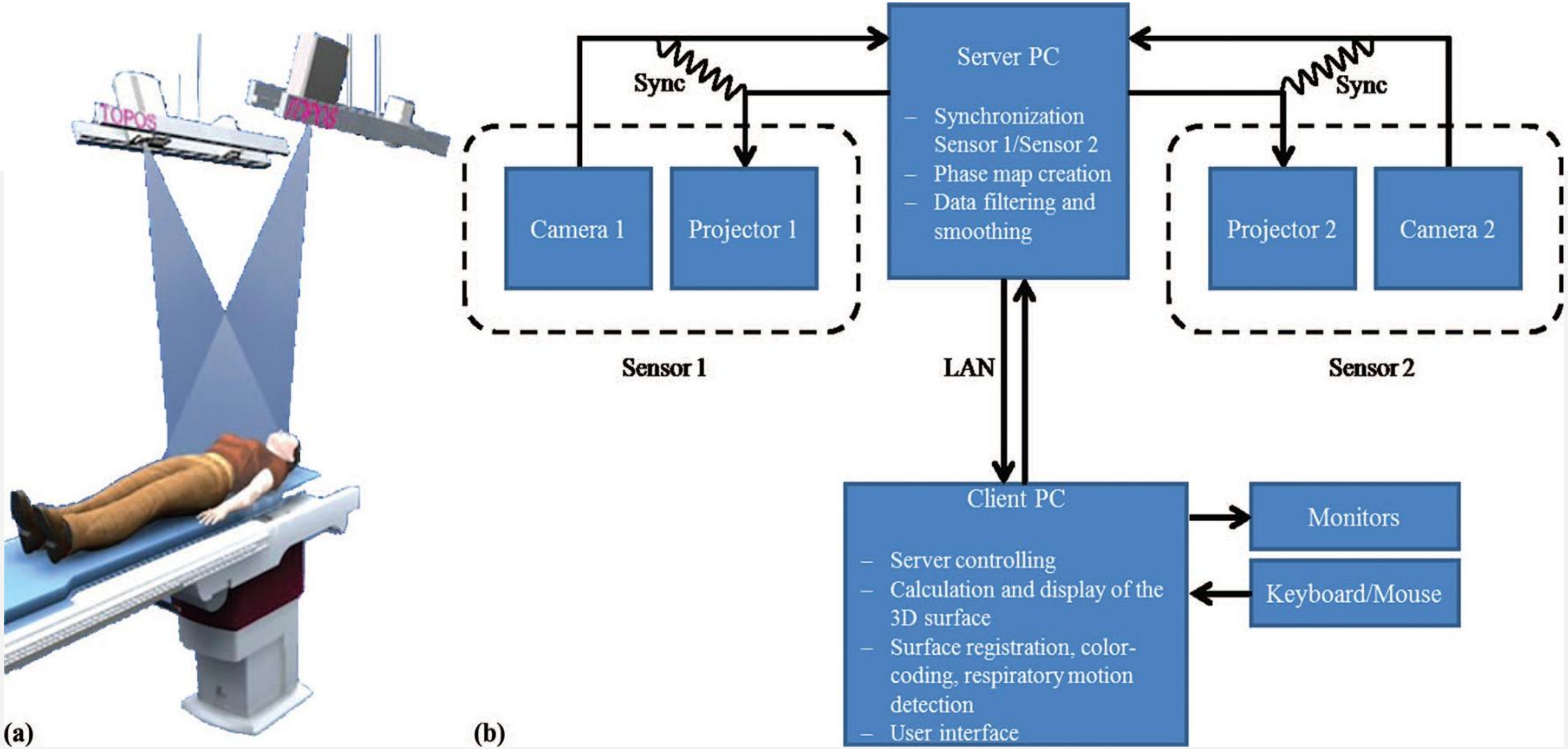
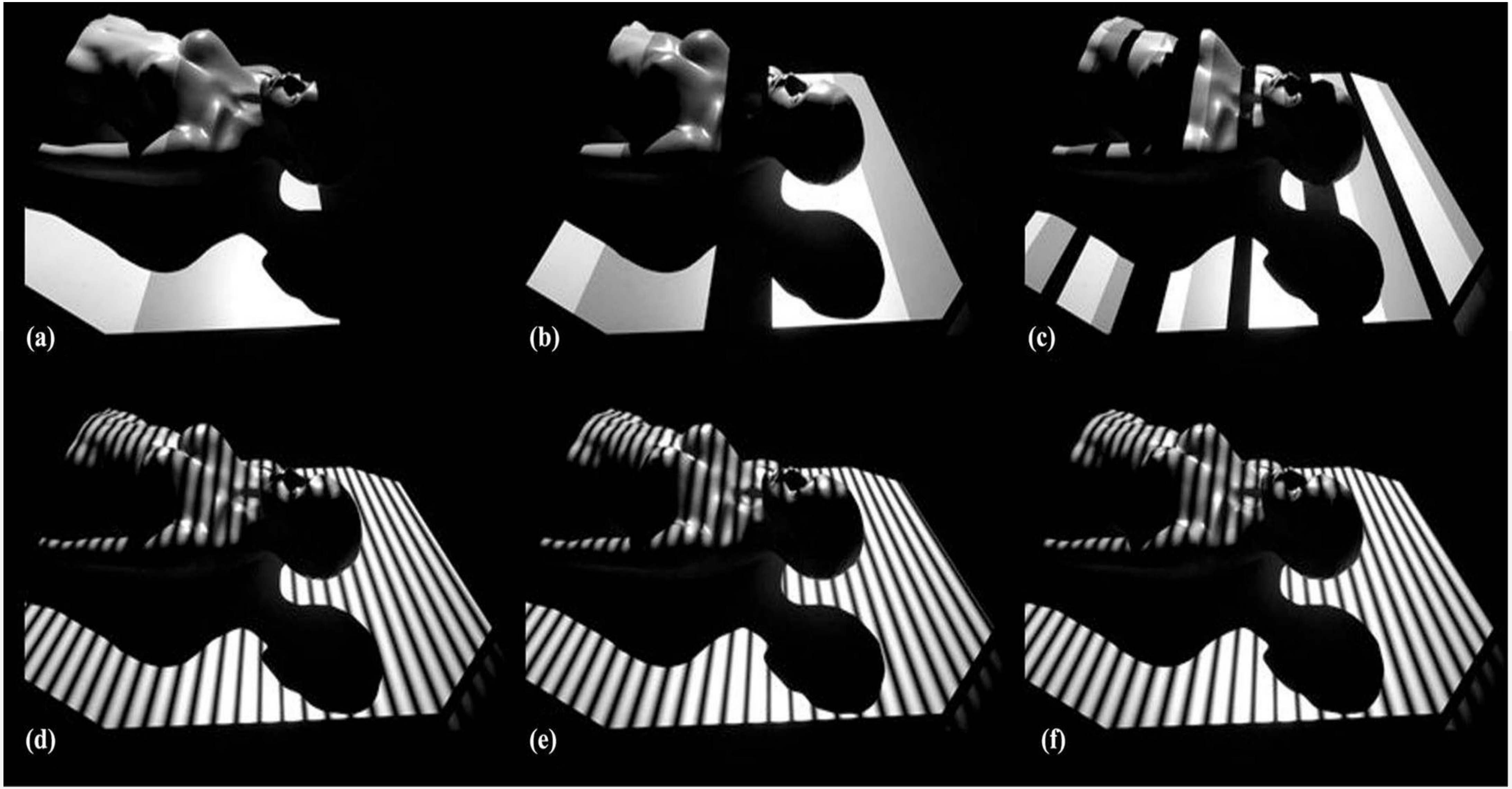
Strucured light imaging

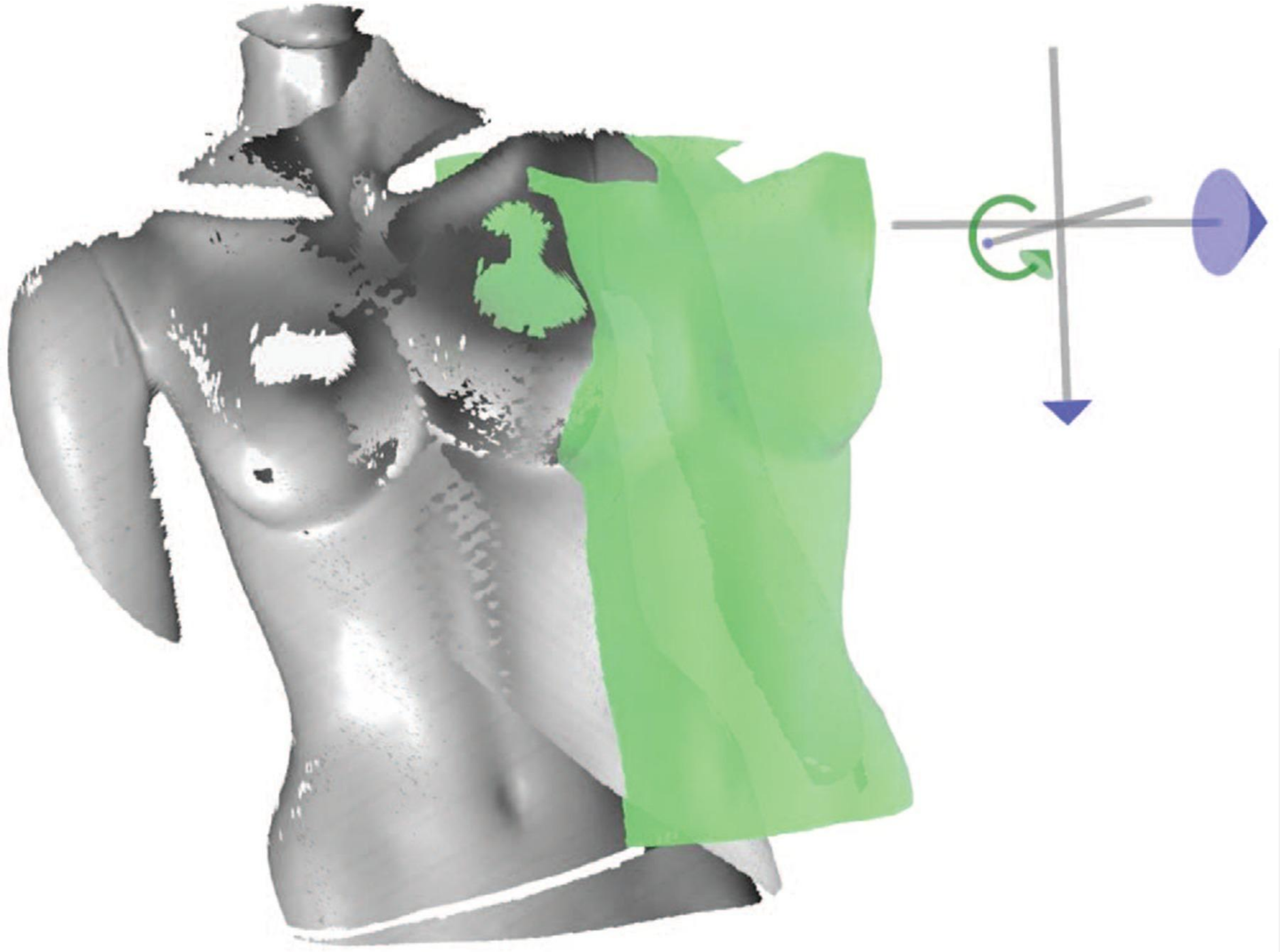


Medical Physics, Volume: 40, Issue: 4, First published: 29 March 2013, DOI: (10.1118/1.4794927)



(a)–(c) Gray-Code pattern to compensate for the 2π periodicity of the sine patterns. (d)–(f) Sine patterns, each shifted by 120° compared to the previous one.

Medical Physics, Volume: 40, Issue: 4, First published: 29 March 2013, DOI: (10.1118/1.4794927)



Time of flight camera

Provides the image of an object based on light travel time from the illuminator to the object and back to the sensor co-positioned with the illuminator.

1. The emitting light intensity is modulated with a high RF frequency, such as 30MHz, and the reflecting light from a surface reaches the detector with a relative phase difference.
2. Based on the phase shift and light speed, the distance of light traveling can be calculated and therefore the location of the spot.
3. Once an array of such spots is detected, the 3D surface image (such as 176×144 pixels) of the surface is then reconstructed

However, the TOF camera cannot be used for patient SGRT due to the following two major limitations: (1) the spatial resolution is limited to 2–5mm, and (2) the distance between the light source and the surface should cause a shift less than half of the period of the RF modulated light, usually less than 5 meters.

TABLE 1. General overview of commercially available SGRT systems as of October 2019

System (Vendor)	Treatment unit # hardware	CT Simulator system (vendor)	Patient identification	Patient biofeedback	Patient positioning Corrections
AlignRT (Vision RT)	1 to 3 cameras units (~90° apart)	GateCT (Vision RT)	Infrared facial recognition	Visual (Real-time coach)	6D
Catalyst (C-RAD)	1 to 3 cameras units (120° apart)	Sentinel * 4DCT (C-RAD)	Facial recognition	Audio & visual (Goggles)	6D
IDENTIFY (Varian)	3 cameras units (~90° apart)	IDENTIFY CT (Varian)	Palm reader	Visual coaching module	6D

Each unit may contain more than one camera.

* Uses laser scanning technology.

TABLE 2 Performance overview of commercially available SGRT monitoring systems as of October 2019

System (Vendor)	Optical technology	Camera size (W × H × D); Weight	Field-of-view* (Lat × Long × Vert)	Camera resolution	Frame rate	Positioning accuracy#	Registration algorithm
AlignRT (Vision RT)	Stereovision using a speckle pattern	430 × 66 × 186 mm; 4.5 kg	650 × 1000 × 350 mm^3	2048 × 2048 px (4MP)	4-24 fps	<1.0 mm <1.0°	Rigid
Catalyst (C-RAD)	Structured light imaging	620 × 390 × 280 mm; 16 kg	1100 × 1400 × 2400 mm^3	640 × 480 px (0.3 MP)	8-24 fps	<1.0 mm <1.0°	Deformable[27]
IDENTIFY (Varian)	Stereovision using a speckle pattern	500 × 80 × 182 mm; 3.3 kg	500 × 500 × 400 mm^3	1280 × 1024 px (1.3 MP)	10 fps	<1.0 mm <1.0°	Rigid

*FOV is specified for three-camera systems for SGRT tracking functionality only and defined relative to couch coordinates at the nominal position (Lat = Lateral, Long = Longitudinal, Vert = Vertical).
#Assessed in-phantom.
fps, frames per second; px, pixel.

TABLE 3 Overview of the interface capabilities with known vendors of commercially available SGRT monitoring systems as of October 2019

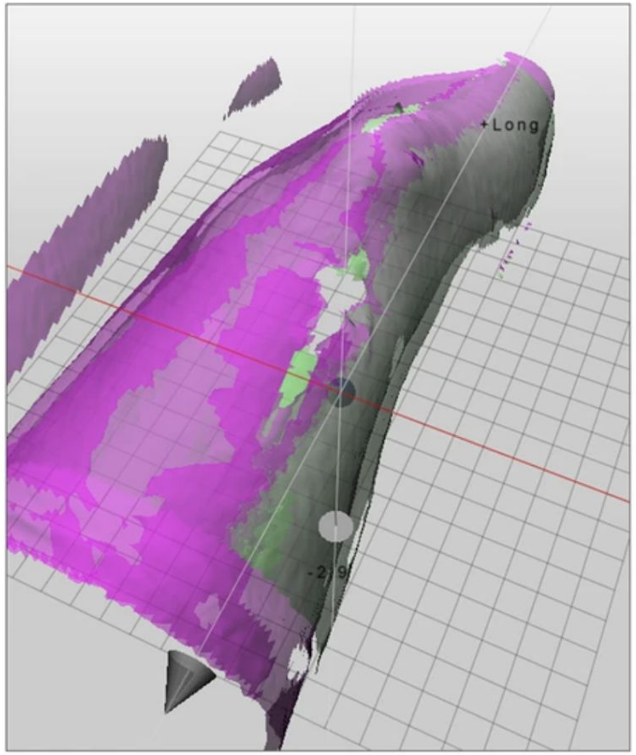
	CT Simulator interfaces		Photon treatment unit interfaces		Proton treatment unit interfaces	
System (Vendor)	Capability^	Vendor	Capability	Vendor	Capability	Vendor
AlignRT (Vision RT)	Prospective & retrospective acquisition	Philips Siemens GE Cannon	Automatic patient selection, beam-hold ability, couch shift ability	Varian (TrueBeam/C-series) Elekta Siemens#	Beam hold	IBA Hitachi
Catalyst (C-RAD)	Prospective & retrospective acquisition*	Philips Siemens GE Cannon	Automatic patient selection, beam-hold ability, couch shift ability	Varian (TrueBeam/C-Series) Elekta Siemens#	Beam hold	IBA Mevion
IDENTIFY (Varian)	Prospective & retrospective acquisition through marker-based tracking**	Philips Siemens GE	Automatic patient selection and record of treatment/simulation session from/to OIS	OIS-based: Varian (ARIA) Elekta (MOSAIQ)	Works in Progress	Works in Progress

^See Section 4.5 for more details.
#Couch shift not available.
*Supported by Sentinel SGRT system (C-RAD).
**Supported by Respiratory Gating for Scanners (RGSC).
OIS, Oncology Information System.

Clinical applications
patient positioning

Freislederer *et al. Radiation Oncology* (2020) 15:187

From: <u>Recent advances in Surface Guided Radiation Therapy</u>

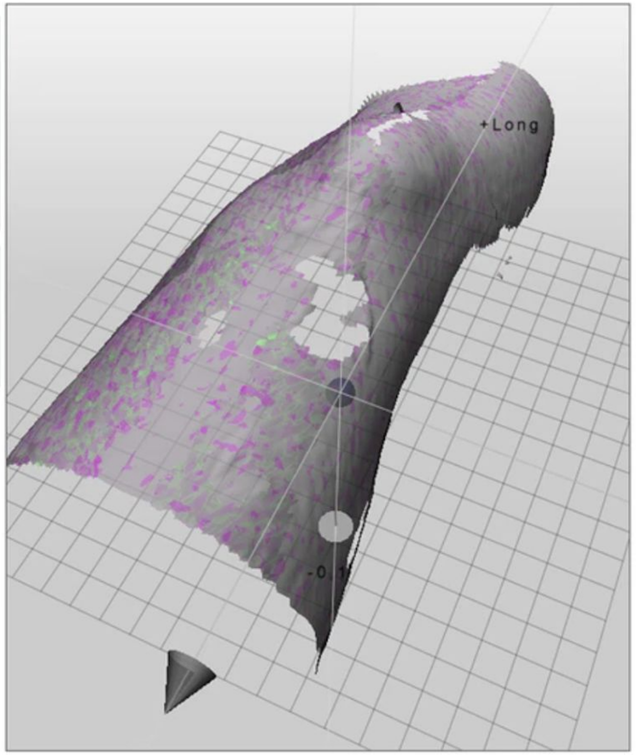


Couch

	Absolute	Relative
Lat	-86,5 mm	+8,5 mm
Long	+395,4 mm	-0,6 mm
Vert	-175,9 mm	-2,9 mm
Rot	+0,8 °	+0,8 °

Posture

	Relative
Roll	-2.5 °
Pitch	0.0 °



Couch

	Absolute	Relative
Lat	-91,0 mm	0,0 mm
Long	+468,0 mm	0,0 mm
Vert	-178,1 mm	-0,1 mm
Rot	+359,9 °	-0,1 °

Posture

	Relative
Roll	+0.1 °
Pitch	0.0 °

Example of patient positioning using SGRT. Left: The live surface data from a whole left leg (purple) deviates from the reference surface (green). Right: After correction, the surface data matches the reference image. Image courtesy of LMU University Hospital Munich, Germany

Breast positioning
clinical results

1) Reduction of positioning errors for skin and clip alignment by around 40% on average, with absolute errors (1SD) smaller than 4 mm
2) Surface-guided correction of the arm posture also improved the breast position
3) Factors affecting the accuracy in surface-guided patient setup:

i) patient motion,

ii) surface shadowing, selection of the region-of interest,

iii) absence of anatomical gradients in the patient (e.g. very flat surfaces)

iv) anatomical changes throughout the treatment

Positioning of internal targets (abdomen/pelvis/Head& Neck)

Poor correlation between patient surface and internal targets registrations.

However, surface imaging achieved at least the same precision as laser alignment and was considered a valuable tool for initial patient setup and as a complement to conventional imaging modalities.

Significantly reduced imaging times for patient positioning using surface imaging in head and neck patients by 5 min per fraction

Intracranial tumors: WBRT & SRS

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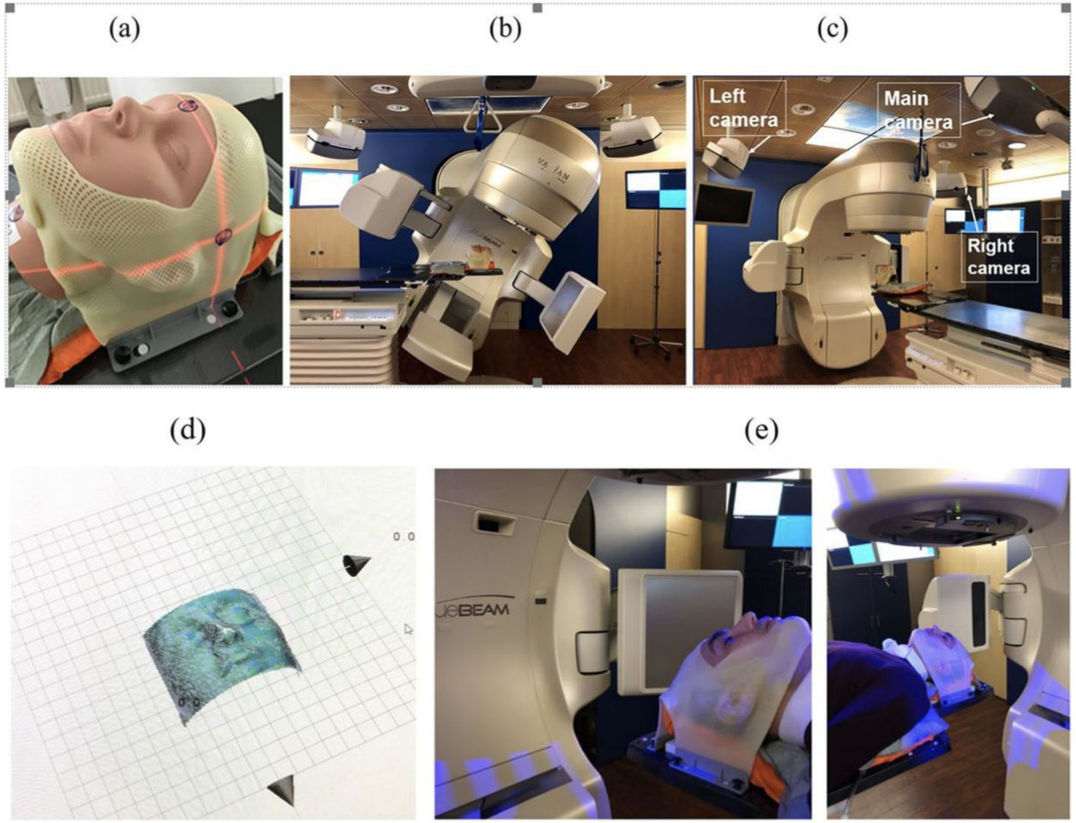

Fig. 2 a ORFIT open face mask together with a T-shaped vacuum bag, **b** Catalyst HDTM in kV-MV setup using the ExaFix-3 baseplate and **c** in setup at couch 0°(3 cameras are indicated with arrows). The cropped surface image (**d**) is extracted from the patient's open face mask (**e**). Image courtesy of MAASTRO Clinic, Maastricht, The Netherlands

1) Enables verification of patient position during non coplanar beam irradiation

2) Under guidance of a single camera system (C-RAD, Uppsala, Sweden), the isocenter motion was within 1.1 mm

3) Radiation therapy without a thermoplastic mask was clinically feasible

Dekker et al Phys Imaging Radiat Oncol. 2019 Jul 1;11:27–9.

Breath-hold

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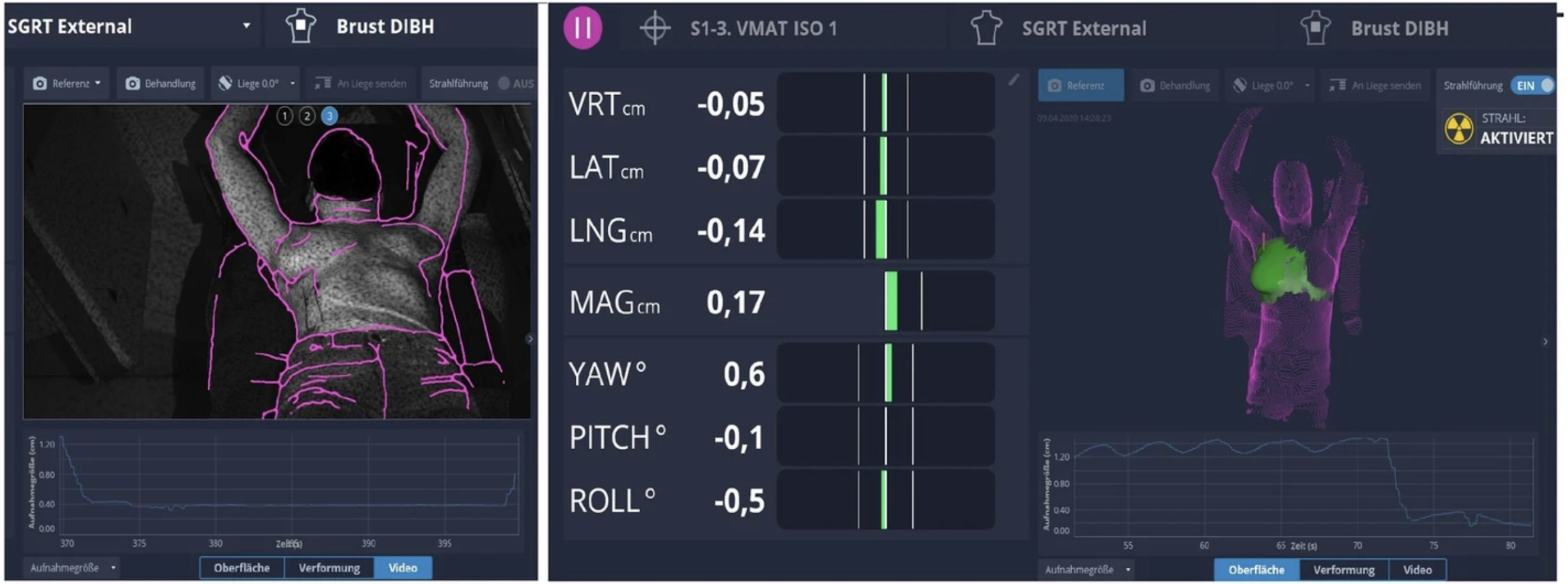

Positioning of a DIBH patient. Left: Positioning of the patient using the reference surface (purple) and the live surface data. Right: Monitoring of the DIBH during treatment on a highlighted (green) ROI. The breathing curve is depicted on the bottom. Image courtesy of Heidelberg University Hospital, Germany

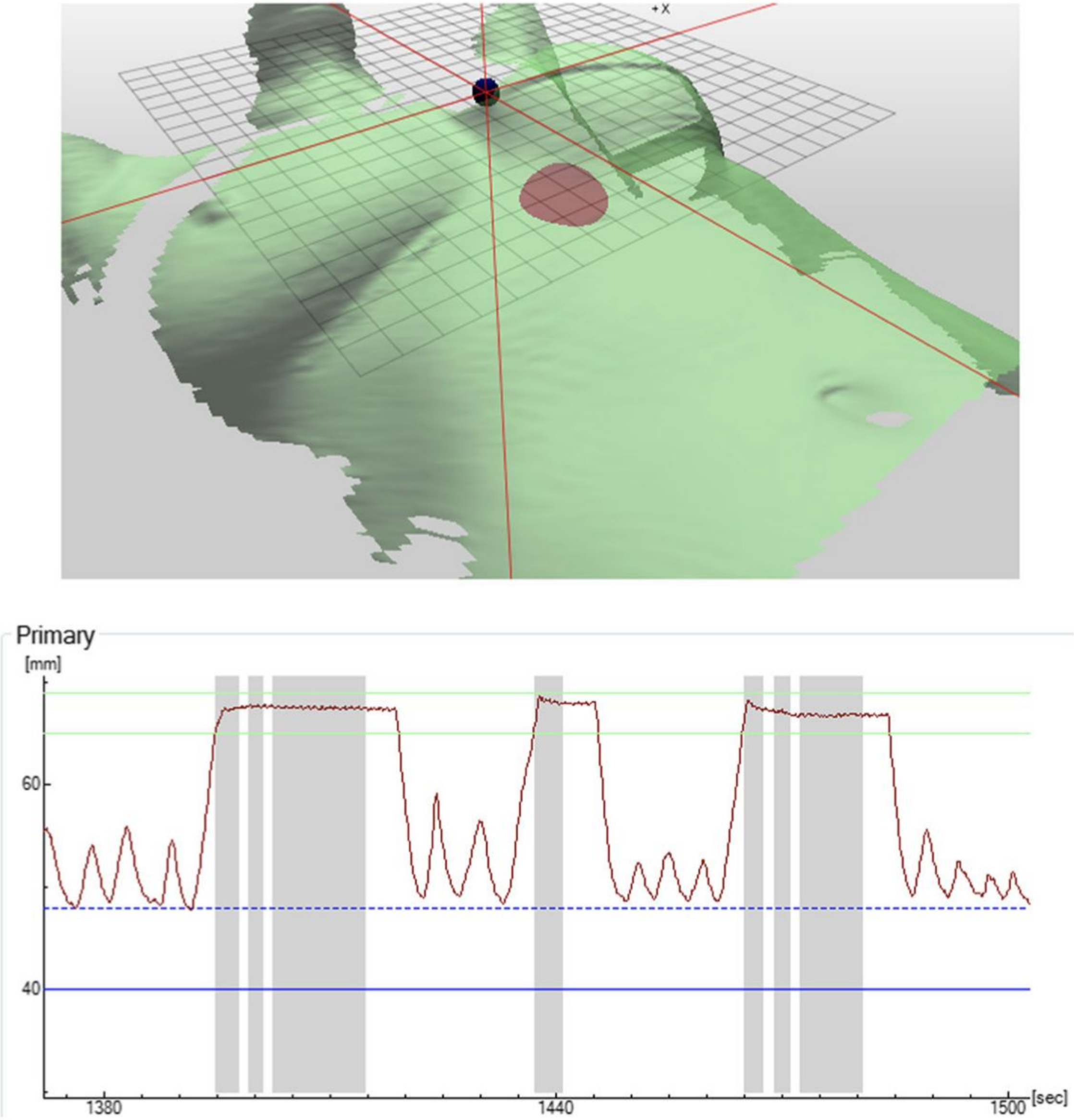

Fig. 4 DIBH monitoring. Top: A breathing spot (red) on the patient surface (green) is monitored. Bottom: The breathing curve with three breath-holds, covering 7 individual beams (indicated using the grey bars). Image courtesy of LMU University Hospital Munich, Germany

Screenshot

Breath-hold

Left breast cancer irradiation using DIBH using optical surface scanners is nowadays widely implemented at multiple institutions and the concept has also been adapted to right-sided breast irradiation for a reduction of lung and liver dose

For lung or liver treatments, the breath-hold level can be monitored using SGRT systems, although the system can only monitor the patient surface as a surrogate for tumor motion at most

The accuracy of SGRT systems have been reported within 5 mm for DIBH positioning and monitoring, and are similar to those reported in studies using spirometry-based positioning.

Kügele al J Appl Clin Med Phys. 2018;19(1):25–38.

Respiratory motion menagement

The potential of SGRT for respiratory motion monitoring and motion management is demonstrated by the strong correlation of SGRT monitoring with internal tumor position monitoring by x-ray imaging.

Respiratory motion signal and estimated volume variations are well correlated with spirometer measurements.

However, when implementing a SGRT-based tumor-tracking or gating-system, careful characterization of the beam-on and beam-off delays is advisable, as these might be non-negligible and vary between the SGRT and beam delivery systems

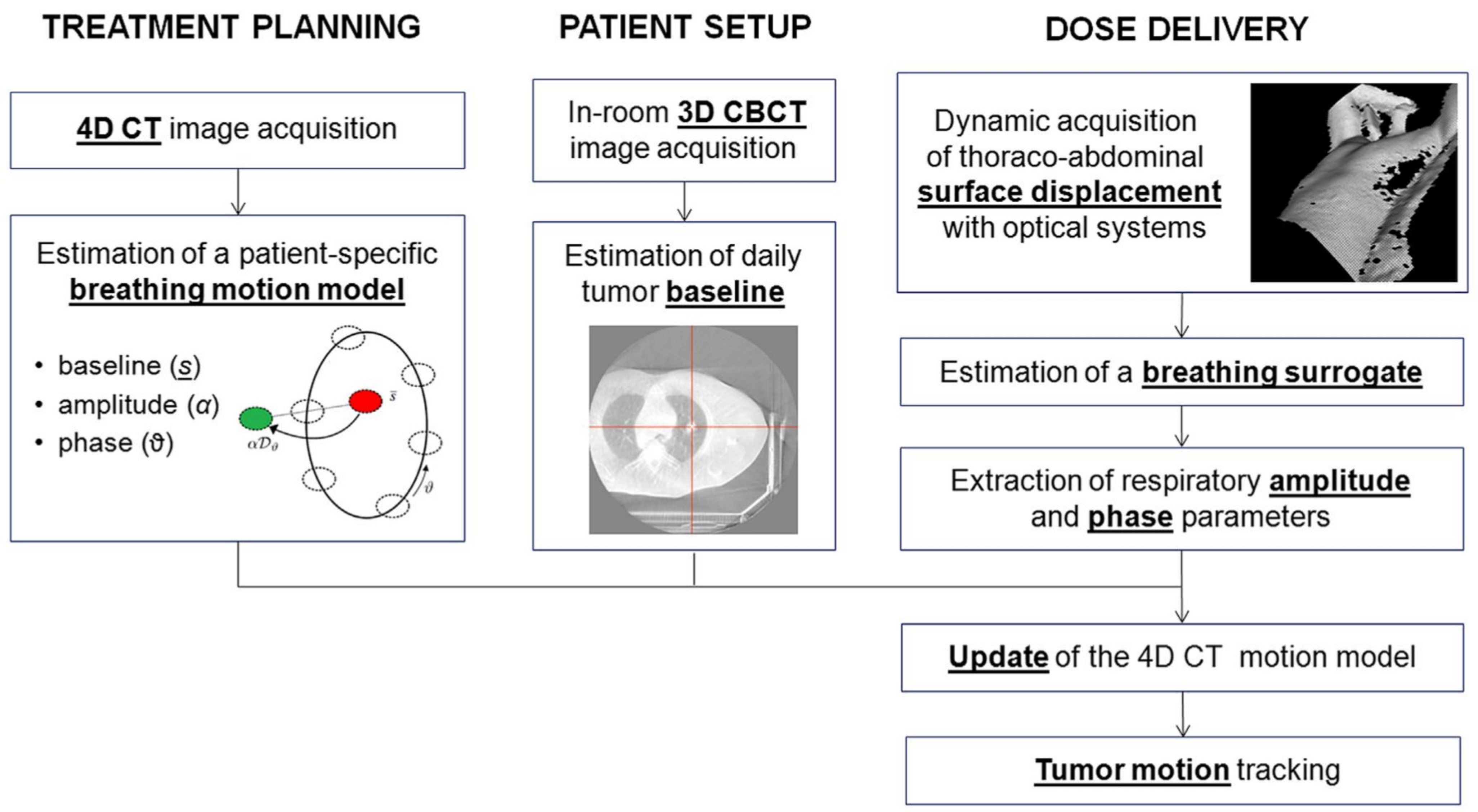

Fig. 1. Schematic representation of the proposed tumor tracking method (the representation of the motion model was extracted from previous work (19)). 3D = 3-dimensional; 4D = 4-dimensional; CT = computed tomography; CBCT = cone beam CT.

QA of SGRT (I) AAPM TG 147

TABLE 4 Summary of tests outlined in Section III.B. of AAPM's Task Group 147 for commissioning an SGRT system

Test category	Description	Tolerance
Interface with peripheral systems	• Integrity of data transferred from CT simulation, TPS, R&V systems for a variety of patient orientations to test coordinate systems • Confirm isocenter coordinate transfers accurately into SGRT system using a phantom • Beam delivery functionality (with/without gating) • CT triggering functionality for prospective/retrospective gating • Couch shift functionality	Passing/functional
Spatial drift and reproducibility	• Characterize warm-up period necessary prior to clinical use • Localization accuracy for a 90-min period or until stability is achieved[48]	• NA • $\leq$2 mm over 1 h; $\leq$1 mm after stabilizing
Static localization accuracy	• Localization accuracy of offset phantom over a reasonable clinical range (i.e., $\pm$100 mm range from isocenter)	$\leq$2 mm $\leq$1 mm for SRS/SBRT

QA of SGRT (II) AAPM TG 147

Dynamic localization accuracy	• 4D spatial localization accuracy • Frame rate characterization for clinically reasonable scenarios • Latency threshold (may depend on clinical workflow)	• per TG-142 • per spec. • within 100 ms of expected value
Camera system characteristics	• Camera exposure settings are appropriate for a variety of skin tones • Measure localization FOV • Characterization of camera occlusion for variety of clinical scenarios (e.g., couch/gantry angles)	• NA • per spec. • NA
Imaging	• Isocenter coincidence with all imaging modalities that will be used in complement with SGRT	$\leq$2 mm $\leq$1 mm for SRS/SBRT
End-to-end	• Characterization of localization and monitoring accuracy from CT to dose delivery including beam hold if available • Winston-Lutz including SGRT for SRS applications	• $\leq$1% dose change; $\leq$2% dose change for beam hold • <1 mm
Standard Operating Procedures	• Should include training guidelines for new personnel (either new to the department or new to the technology) • Should include intended use of the SGRT system, case-types, etc. • Should be updated as experience and technology evolves	Existing/Available

QA of SGRT (III) ESTRO-ACROP guidelines

Quality assurance			Frequency/Specification				
Parameter	Label	Specification	Recommended tolerance	CT simulator	C-arm linac	Closed-Bore linac	Particle Therapy
Static Accuracy	A1	Isocentre	1 mm/1° SRS: 0.5 mm/0.5°	D	D – Laser M-Radiographic	D	D
	A2	Translational shifts	2 mm	-	M	M	M
	A3	Rotational shifts	1°	-	M	M	M
	A4	Impact of camera occlusion	*1 mm/1°*		A\R	A\R	A/R
	A5	Couch rotation	1 mm/1° SRS: 0.5 mm/0.5°	-	M- Basic A – Radiographic	-	A/R
	A6	Setup/loading position	1 mm/1°	-	-	D	M
End to end positioning test	E1	End to end test	2 mm/1°	A/R	A/R	A/R	A/R
Dynamic Accuracy	D1	Beam hold performance	2% or 2 mm/2% γ = 95% (10% threshold)	-	A	A	A
	D2	Tracking performance – translations & Rotation & Couch-motion	1 mm	-	M/A	A	A
	D2	Tracking performance – rotations	1°	-	M/A	A	A
	D2	Tracking performance – with couch motion	1°, 1 mm	A	-	A	A
	D3	Respiratory trace	pass	D/M	D /M		D/M
	D4	Trigger performance	pass	A	-	-	-

QA of SGRT (III) ESTRO-ACROP guidelines

Quality assurance			Frequency/Specification				
Parameter	Label	Specification	Recommended tolerance	CT simulator	C-arm linac	Closed-Bore linac	Particle Therapy
System Performance	P1	Thermal Drift (clinical)	0.5 mm	A	A	A	A
	P3	Field of view – Basic/Advanced	pass*	A	A	A	A
	P4	Quality of acquired image	pass*	A\R	A\R	A\R	A\R
	P5	Integration – System interface with all peripheral systems	pass	-	-	-	-
	P6	Patient Interface	pass	D	D	D	D
Safety	S1	Interlocks	pass	M/A (If available)	M/A	M/A	M/A
	S3	Database backup & security	pass	A	A	A	A
	S4	System Configuration	pass	A	A	A	A
	S5	Mechanical Integrity	pass	D	D	D	D
Documentation	R3	QA-Documentation	pass	M/A	M/A	M/A	M/A

(*) when only visual inspection is possible, the comparison with the acceptance-reference should be done based on clinical criteria).