Improvement and Evaluation of a Time-of-Flight-based Patient Positioning System

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Abstract. In this paper we improve a surface-based patient positioning method. The method describes a system for automatic positioning of patients using time-of-flight cameras in radiotherapy. To improve the registration result three new preprocessing steps (bilateral filtering, temporal averaging, variance filtering) are introduced to the processing pipeline. Furthermore, the accuracy of the surface matching algorithm (ICP) is improved by changing the distance measurement from point-to-point to point-to-surface. The mean registration error is improved by 2.14 mm to 0.74 mm, whereby the working distance could also be increased from 0.8 m to 1.5 m.

1 Introduction

The precise delivery of irradiation to the target volume within radiotherapy and particle therapy depends heavily on the correct positioning of the patient. In the worst case dose delivery to a false location can harm healthy tissue [1]. Therefore, accurate patient positioning in radiotherapy and particle therapy is an important issue for high precision treatment.

Both the treatment plan coordinate system and the patient coordinate system have to be aligned properly before each treatment session. A pre-treatment CT is acquired and used as a basis for the treatment plan. Within this CT dataset the shape and position of the tumor can be verified and a dose delivery plan can be created. Right before the treatment session starts, the tumor position has to be aligned with the isocenter of the linear accelerator. Automatic patient positioning also increases the patient throughput [2]. Surface-based patient positioning is a convenient way to position patients without radiation.

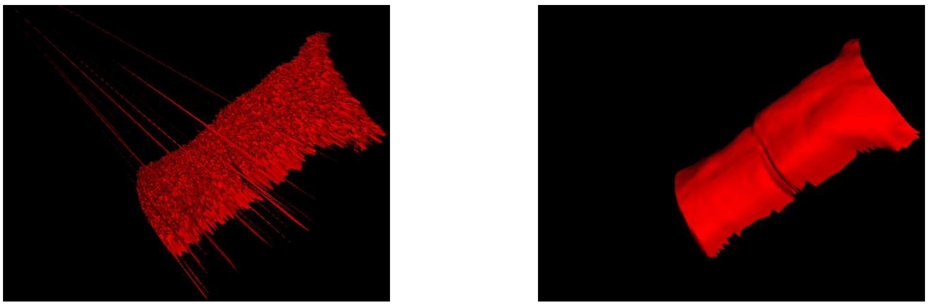
A commercial available surface based system for patient positioning is the VisionRT system (www.visionrt.com). Schoeffel et al. [3] investigated this system and obtained an accuracy of 0.40 mm $\pm$ 0.26 mm for rigid phantoms. In this paper we use a similar evaluation setup.

Schaller et al. [4] proposed an approach where a time-of-flight (TOF) camera is used to acquire the 3-D shape of a patient in order to position it with respect to a priorly acquired reference surface. Compared to the VisionRT system, such a system uses only one camera and is much more cost-effective. They could achieve a mean registration error of 2.88 mm for rigid body phantoms at a camera distance of 80 cm.

2 Materials and Methods

For testing and evaluation we used a rigid plaster cast body phantom, which is described in detail in [5]. Utilizing this phantom, a simulation close to clinical conditions can be achieved. Furthermore, a recent TOF camera, the CamCube from PMD Technologies is used. Details about TOF cameras can be found in [6].

Due to the measuring principle of TOF cameras the data provided by this modality is suffering from various problems (Fig. 1). The most prominent problems regarding surface registration are the high noise level of the data and so called flying pixels. These occur whenever a distance discontinuity between two objects in the field of view of the TOF camera is given. Both problems make it difficult to register two surfaces acquired by a TOF camera in a robust and absolut manner. Due to the ToF sensor matrix, which is 204 × 204 pixels, the computed 3D coordinates exactly match a grid structure in x and y direction. A standard iterative closest points (ICP) algorithm [7] using an Euclidean point-to-point distance measurement prones to suffer from a "snap-to-grid" effect. For



(a) Phantom shape without filtering (b) Phantom shape with filtering

Fig. 1. Comparision of preprocessing steps.

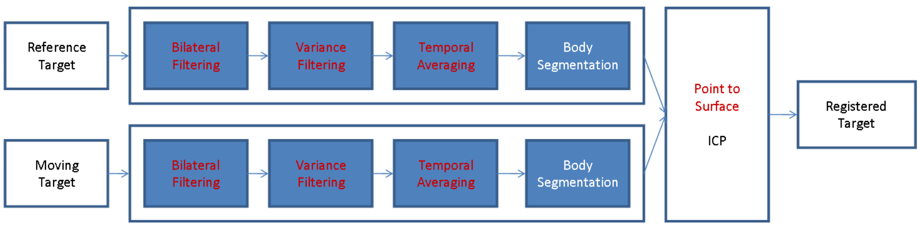


Fig. 2. Processing pipeline, showing the standard components used by Schaller et al. [4] and improved/new components (in red) to obtain much more stable results.

a distance of 1.0 m the grid spacing is already about 3.5 mm. To improve the registration result all crucial components of the registration pipeline are modified (Fig. 2).

First of all, the noisy raw data need to be preprocessed. A set of filters is applied to reduce the temporal as well as the spatial noise artifacts. In order to cope with spatial noise, bilateral filtering [8, 9] is applied to the distance matrix. Since bilateral filtering is an edge preserving smoothing technique, object structures can be preserved much better than with the Gaussian filter utilized in [4]. Temporal noise is suppressed by averaging the 3D information of the camera over a certain amount of frames. Furthermore, we introduce a variance filter to eliminate bad pixels. For each pixel, we compute the variance based on the last frames. By applying a threshold to these values, "flying pixels" can be eliminated.

As a further modification to improve the registration accuracy, we changed the strategy to find point correspondencies in the ICP algorithm from point-to-point to point-to-surface.

Figure 3 shows the test setup, which is similar to [3]. The movement of a Siemens ONCOR patient table was observed with three gauges – one for each axis. The gauges used for this evaluation had a total measurement range of 1 cm and an accuracy of 10 μm The TOF camera was perpendicularly aligned to the table in a distance of about 1.5 m, which is a suitable distance for a practical setup. Instead of a treatment couch the authors of [4] use a robot arm with a precision of 0.1 mm to position a phantom. For the evaluation the patient table was moved arbitrarily in one direction with the other two directions locked. The evaluated relative table translations were in a range between 0.5 mm and 9.5 mm, which is very similar to the experiments described in [3]. In contrast to [3] and [4], rotations as well as translations in three dimensions at the same time were not considered within these experiments. The translation provided as output of the ICP algorithm was compared to the real translation given by the gauges.

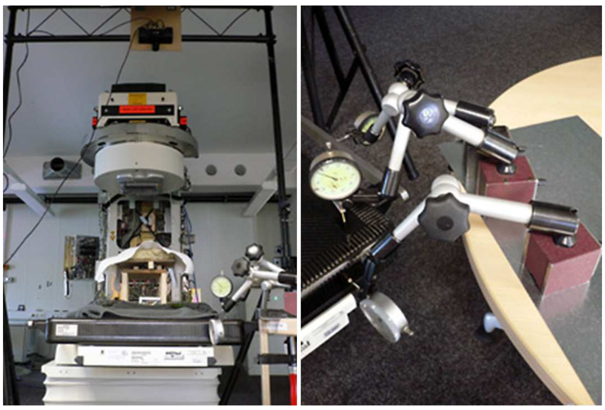


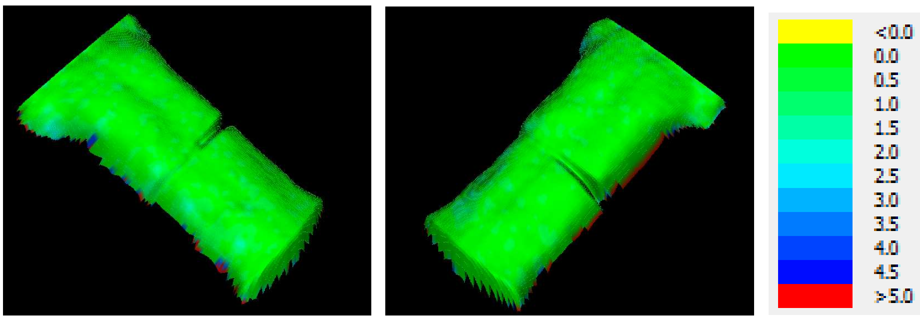
Fig. 3. Test setup: left side: Siemens ONCOR system with ToF camera viewing the body plaster cast phantom; right side: three measurement gauges to measure patient table displacement with an accuracy of 1/100 mm.

Table 1. RMS of the Euclidean error of the computed translation with respect to the ground truth for lateral (x), longitudinal (y) and vertical (z) displacements.

ground truth	min [mm]	max [mm]	mean [mm]	median [mm]	std [mm]
0.50 mm translation in x	0.17	0.39	0.30	0.30	0.17
0.95 mm translation in x	0.28	0.56	0.42	0.40	0.24
2.50 mm translation in x	0.26	0.41	0.35	0.36	0.14
5.35 mm translation in x	0.20	0.63	0.47	0.49	0.32
6.45 mm translation in x	0.37	1.20	0.77	0.62	0.66
7.15 mm translation in x	0.30	0.67	0.51	0.51	0.30
9.50 mm translation in x	1.64	1.88	1.75	1.75	0.49
0.50 mm translation in y	0.00	0.42	0.22	0.17	0.24
5.15 mm translation in y	1.03	1.43	1.26	1.20	0.56
7.15 mm translation in y	0.30	0.93	0.54	0.42	0.49
9.15 mm translation in y	0.81	1.46	1.20	1.17	0.66
0.95 mm translation in z	0.10	0.55	0.39	0.42	0.32
2.95 mm translation in z	0.45	0.66	0.54	0.53	0.24
6.35 mm translation in z	1.08	1.24	1.16	1.16	0.32
7.60 mm translation in z	1.14	1.37	1.23	1.22	0.37
average	0.54	0.92	0.74	0.71	0.37

3 Results

Table 1 shows the RMS error of the Euclidean distance between ground truth and computed result. The statistical indicators mean, median and standard deviation are thereby determined upon a sequence of 50 consecutive frames of the non-moving phantom. Figure 4 illustrates the surface distance between the reference and the transformed source dataset.



(a) left-side-view (b) right-side-view (c) color-scale

Fig. 4. Exemplary registration result: Color coded distance between transformed source and target dataset (range: 0 mm – 5 mm).

In comparison to [4], we could decrease the mean positioning error from 2.88 mm ± 1.84 mm to 0.74 mm ± 0.37 mm, although the distance between camera and treatment couch was incremented from 0.80 m to 1.50 m. The proposed modified algorithm is capable to process with 1 fps on a standard dual-core 2.0 GHz CPU at the moment.

4 Discussion

In the future, the algorithm has to be improved regarding runtime and robustness for displacements higher than 1 cm. Currently, a feature-based pre-registration algorithm is investigated, which can provide a good initial translation and rotation of the body shape. This can be used as initialization for the ICP algorithm to refine the registration result.

References

1. Moore CJ, Graham PA. 3D dynamic body surface sensing and CT body matching: a tool for patient set-up and monitoring in radiotherapy. Comput Aided Surg. 2000;5(4):234–45.
2. Sweeney R, Vogele M, Wegmayr A, et al. The patient positioning concept for the planned MedAustron centre. Radiother Oncol. 2004 12;73(2):64–7.
3. Schoffel PJ, Harms W, Sroka-Perez G, et al. Accuracy of a commercial optical 3D surface imaging system for realignment of patients for radiotherapy of the thorax. Phys Med Biol. 2007;52:3949–63(15).
4. Schaller C, Adelt A, Penne J, et al. Time-of-flight sensor for patient positioning. In: Proc SPIE. vol. 7258; 2009.
5. Ulrich C, Schaller C, Penne J, et al. Evaluation of a time-of-flight based respiratory motion management system. In: Proc BVM; 2010. p. to appear.
6. Xu Z, Schwarte R, Heinol H, et al. Smart pixel: photometric mixer device (PMD): new system concept of a 3D-imaging-on-a- chip. In: Proc Int Conf Mechatronics and Machine Vision in Practice; 1998. p. 259–64.
7. Rusinkiewicz S, Levoy M. Efficient variants of the ICP algorithm. In: Proc 3DIM; 2001. p. 145–52.
8. Tomasi C, Manduchi R. Bilateral filtering for gray and color images. In: Proc ICCV; 1998. p. 839.
9. Paris S, Durand F. A fast approximation of the bilateral filter using a signal processing approach. Int J Comput Vision. 2009;81(1):24–52.