Université Lumière Lyon 2

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THÈSE

pour obtenir le grade de

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présentée par

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Prise en compte du mouvement respiratoire pour la reconstruction d'images tomodensitométriques

Obtention d'images TDM 4D en salle de traitement pour la radiothérapie du cancer du poumon

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Bibliographie

X. Allen Li, C. Stepaniak et E. Gore : Technical and dosimetric aspects of respiratory gating using a pressure-sensor motion monitoring system. *Med Phys*, 33(1):145–154, Jan 2006. Cité page 63.

A.H. Andersen : Algebraic reconstruction in CT from limited views. *IEEE Trans Med Imag*, 8(1):50–55, Mar 1989. Cité pages 40 et 84.

A.H. Andersen et A.C. Kak : Simultaneous algebraic reconstruction technique (SART) : a superior implementation of the ART algorithm. *Ultrason Imaging*, 6(1):81–94, Jan 1984. Cité pages 40, 96 et 123.

M.R. Ay, S. Sarkar, M. Shahriari, D. Sardari et H. Zaidi : Assessment of different computational models for generation of x-ray spectra in diagnostic radiology and mammography. *Med Phys*, 32(6):1660–1675, Jun 2005. Cité page 52.

M.R. Ay et H. Zaidi : Development and validation of MCNP4C-based Monte Carlo simulator for fan- and cone-beam x-ray CT. *Phys Med Biol*, 50(20):4863–4885, Oct 2005. Cité page 52.

C. Blondel : *Modélisation 3D et 3D+t des artères coronaires à partir de séquences rotationnelles de projections rayons X*. Thèse de doctorat, Université de Nice-Sophia Antipolis, 2004. URL `http://www.inria.fr/rrrt/tu-0820.html`. Cité pages 23, 96, 98, 99, 105, 108, 110 et 112.

C. Blondel, G. Malandain, R. Vaillant et N. Ayache : Reconstruction of coronary arteries from a single rotational X-ray projection sequence. *IEEE Trans Med Imag*, 25 (5):653–663, May 2006. Cité page 96.

C. Blondel, R. Vaillant, G. Malandain et N. Ayache : 3D tomographic reconstruction of coronary arteries using a precomputed 4D motion field. *Phys Med Biol*, 49 (11):2197–2208, Jun 2004. Cité page 96.

V. Boldea : *Intégration de la respiration en radiothérapie : apport du recalage déformable d'images*. Thèse de doctorat, Université Lumière Lyon 2, 2006. URL `http://liris.cnrs.fr/publis/?id=2959`. Cité pages 53 et 97.

V. Boldea, D. Sarrut et C. Carrie : Comparison of 3D dense deformable registration methods for breath-hold reproducibility study in radiotherapy. *In SPIE Medical Imaging*, volume 5747, pages 222–230, San Diego, California, USA, 2005. Cité page 53.

V. Boldea, D. Sarrut et S. Clippe : Lung deformation estimation with non-rigid registration for radiotherapy treatment. *In* Springer Verlag Lecture Notes in Computer Science, éditeur : *Medical Image Computing and Computer-Assisted Intervention (MICCAI)*, volume 2878, pages 770–777, Montréal, Canada, 2003. Cité page 53.

Y. Boykov et V. Kolmogorov : An experimental comparison of min-cut/max- flow algorithms for energy minimization in vision. *IEEE Trans Pattern Anal Mach Intell*, 26 (9):1124–1137, 2004. Cité page 59.

Y. Boykov, O. Veksler et R. Zabih : Fast approximate energy minimization via graph cuts. *IEEE Trans Pattern Anal Mach Intell*, 23(11):1222–1239, 2001. Cité page 59.

I. Buvat, V. Chameroy, F. Aubry, M. Pélégrini, G. El Fakhri, C. Huguenin, H. Benali, A. Todd-Pokropek et R. Di Paola : The need to develop guidelines for evaluations of medical image processing procedures. *In SPIE Medical Imaging*, volume 3661, pages 1466–1477, San Diego, California, USA, February 1999. Cité page 48.

P. Cachier, X. Pennec et N. Ayache : Fast non rigid matching by gradient descent : study and improvements of the "Demons" algorithm. Rapport technique RR-3706, INRIA, 1999. URL http://www.inria.fr/rrrt/rr-3706.html. Cité page 53.

G.T.Y. Chen, J.H. Kung et K.P. Beaudette : Artifacts in computed tomography scanning of moving objects. *Seminars in Radiation Oncology*, 14(1):19–26, 2004. Cité pages 18 et 27.

W. Chlewicki, C. Badea et N. Pallikarakis : Cone based 3D reconstruction : a FDK-SART comparison for limited number of projections. *In Mediterranean Conference on Medical and Biological Engineering and Computing (MEDICON)*, Pula, Croatia, 2001. Cité pages 73 et 84.

P.S. Cho, R.H. Johnson et T.W. Griffin : Cone-beam CT for radiotherapy applications. *Phys Med Biol*, 40(11):1863–1883, 1995. Cité page 23.

P.E. Chow, S. Tenn et N.M. Wink : Evaluation of a C-arm cone beam device for use in image guided radiotherapy. *In International Conference on the Use of Computers in Radiation Therapy (ICCR)*, Seoul, Korea, 2004. Cité page 24.

R. Clackdoyle, F. Noo, J. Guo et J.A. Roberts : Quantitative reconstruction from truncated projections in classical tomography. *IEEE Trans Nucl Sci*, 51(5):2570–2578, Oct. 2004. Cité page 38.

C.R. Crawford, K.F. King, C.J. Ritchie et J.D. Godwin : Respiratory compensation in projection imaging using a magnification and displacement model. *IEEE Trans Med Imag*, 15(3):327–332, 1996. Cité page 98.

B. De Man et S. Basu : Distance-driven projection and backprojection in three dimensions. *Phys Med Biol*, 49(11):2463–2475, 2004. Cité pages 41 et 108.

B. Delhay : *Estimation spatio-temporelle de mouvement et suivi de structures déformables. Application à l'imagerie dynamique du coeur et du thorax.* Thèse de doctorat, Institut National des Sciences Appliquées de Lyon, 2006. Cité page 97.

L. Desbat, S. Roux et P. Grangeat : Compensation of some time dependent deformations in tomography. *IEEE Trans Med Imag*, 26(2):261–269, 2007. Cité pages 97, 98 et 99.

A.C. Dhanantwari, S. Stergiopoulos et I. Iakovidis : Correcting organ motion artifacts in X-ray CT medical imaging systems by adaptive processing. I. Theory. *Med Phys*, 28(8):1562–1576, 2001a. Cité page 28.

A.C. Dhanantwari, S. Stergiopoulos, N. Zamboglou, D. Baltas, H.-G. Vogt et G. Karangelis : Correcting organ motion artifacts in X-ray CT systems based on tracking of motion phase by the spatial overlap correlator. II. Experimental study. *Med Phys*, 28(8):1577–1596, 2001b. Cité page 28.

L. Dietrich, S. Jetter, T. Tücking, S. Nill et U. Oelfke : Linac-integrated 4D cone beam CT : first experimental results. *Phys Med Biol*, 51(11):2939–2952, 2006. Cité pages 63, 73 et 74.

G.X. Ding, D.M. Duggan et C.W. Coffey : Characteristics of kilovoltage x-ray beams used for cone-beam computed tomography in radiation therapy. *Phys Med Biol*, 52 (6):1595–1615, Mar 2007. Cité page 52.

M. Endo, S. Mori, T. Tsunoo, S. Kandatsu, S. Tanada, H. Aradate, Y. Saito, H. Miyazaki, K. Satoh, S. Matsusita et M. Kusakabe : Development and performance evaluation of the first model of 4-D CT-scanner. *IEEE Trans Nucl Sci*, 50 (5):1667–1671, Oct. 2003a. Cité page 22.

M. Endo, T. Tsunoo, S. Kandatsu, S. Tanada, H. Aradate et Y. Saito : Four-dimensional computed tomography (4D CT)–concepts and preliminary development. *Radiation Medicine*, 21(1):17–22, 2003b. Cité page 22.

J.D. Escolar et A. Escolar : Lung histeresis : a morphological view. *Histology and Histopathology*, 19(1):159–166, 2004. Cité page 68.

R. Fahrig, A.J. Fox, S. Lownie et D.W. Holdsworth : Use of a C-arm system to generate true three-dimensional computed rotational angiograms : preliminary in vitro and in vivo results. *AJNR Am J Neuroradiol*, 18(8):1507–1514, Sep 1997. Cité page 23.

L.A. Feldkamp, L.C. Davis et J.W. Kress : Practical cone-beam algorithm. *J Opt Soc Am A*, 1(6):612–619, 1984. Cité pages 36, 96 et 123.

B. Feng, H.C. Gifford, R.D. Beach, G. Boening, M.A. Gennert et M.A. King : Use of three-dimensional Gaussian interpolation in the projector/backprojector pair of iterative reconstruction for compensation of known rigid-body motion in SPECT. *IEEE Trans Med Imag*, 25(7):838–844, Jul 2006. Cité pages 97 et 98.

E.C. Ford, G.S. Mageras, E. Yorke et C.C. Ling : Respiration-correlated spiral CT : a method of measuring respiratory-induced anatomic motion for radiation treatment planning. *Med Phys*, 30(1):88–97, 2003. Cité page 63.

D.G. Fryback et J.R. Thornbury : The efficacy of diagnostic imaging. *Medical Decision Making*, 11(2):88–94, 1991. Cité page 48.

R.R. Fulton, B.F. Hutton, M. Braun, B. Ardekani et R. Larkin : Use of 3D reconstruction to correct for patient motion in SPECT. *Phys Med Biol*, 39(3):563–574, Mar 1994. Cité pages 97 et 98.

A.Y.C. Fung, K.M. Ayyangar, D. Djajaputra, R.M. Nehru et C.A.. Enke : Ultrasound-based guidance of intensity-modulated radiation therapy. *Medical Dosimetry*, 31(1):20–29, 2006. Cité page 23.

O. Gayou, D.S. Parda, M. Johnson et M. Miften : Patient dose and image quality from mega-voltage cone beam computed tomography imaging. *Med Phys*, 34(2):499–506, 2007. Cité page 24.

R. George, S.S. Vedam, T.D. Chung, V. Ramakrishnan et P.J. Keall : The application of the sinusoidal model to lung cancer patient respiratory motion. *Med Phys*, 32 (9):2850–2861, 2005. Cité pages 27 et 57.

D.P. Gierga, J. Brewer, G.C. Sharp, M. Betke, C.G. Willett et G.T.Y. Chen : The correlation between internal and external markers for abdominal tumors : implications for respiratory gating. *Int J Radial Oncol Biol Phys*, 61(5):1551–1558, 2005. Cité page 63.

A.S. Glassner, éditeur. *An Introduction to ray tracing*. Academic Press, London, 1989. Cité page 41.

A.L. Goertzen, F.J. Beekman et S.R. Cherry : Effect of phantom voxelization in CT simulations. *Med Phys*, 29(4):492–498, Apr 2002. Cité page 52.

R. Gordon, R. Bender et G.T. Herman : Algebraic reconstruction techniques (ART) for three-dimensional electron microscopy and x-ray photography. *Journal of Theroretical Biology*, 29(3):471–481, Dec 1970. Cité page 39.

P. Grangeat : *La tomographie*. Hermes Science, 2002. Cité pages 32 et 39.

P. Grangeat, A. Koenig, T. Rodet et S. Bonnet : Theoretical framework for a dynamic cone-beam reconstruction algorithm based on a dynamic particle model. *Phys Med Biol*, 47(15):2611–2625, 2002. Cité pages 64, 98 et 99.

B.A. Groh, J.H. Siewerdsen, D.G. Drake, J.W. Wong et D.A. Jaffray : A performance comparison of flat-panel imager-gased MV and kV cone-beam CT. *Med Phys*, 29(6):967–975, 2002. Cité page 24.

E. Hansis, D. Schäfer, M. Grass et O. Dössel : An iterative method for the reconstruction of the coronary arteries from rotational X-ray angiography. *In SPIE Medical Imaging*, San Diego, California, USA, 2007. Cité page 84.

M. Heiland, D. Schulze, G. Adam et R. Schmelzle : 3D-imaging of the facial skeleton with an isocentric mobile C-arm system (Siremobil Iso-C3D). *Dentomaxillofacial Radiology*, 32(1):21–25, Jan 2003. Cité page 23.

O. Helenon, D.S. Chanin, M. Laval-Jeantet et J. Frija : Artifacts on lung CT scans : removal with Fourier filtration. *Radiology*, 171:572–574, 1989. Cité page 28.

B.K.P. Horn et B.G. Schunck : Determining optical flow. *Artificial Intelligence*, 17:185–203, 1981. Cité page 53.

J.S. Hott, V.R. Deshmukh, J.D. Klopfenstein, V.K.H. Sonntag, C.A. Dickman, R.F. Spetzler et S.M. Papadopoulos : Intraoperative Iso-C C-arm navigation in craniospinal surgery : the first 60 cases. *Neurosurgery*, 54(5):1131–1137, May 2004a. Cité page 23.

J.S. Hott, S.M. Papadopoulos, N. Theodore, C.A. Dickman et V.K.H. Sonntag : Intraoperative Iso-C C-arm navigation in cervical spinal surgery : review of the first 52 cases. *Spine*, 29(24):2856–2860, Dec 2004b. Cité page 23.

G.N. Hounsfield : Computerized transverse axial scanning (tomography). 1. Description of system. *The British Journal of Radiology*, 46(552):1016–1022, Dec 1973. Cité pages 20 et 39.

B.F. Hutton, A.Z. Kyme, Y.H. Lau, D.W. Skerrett et R.R. Fulton : A hybrid 3-D reconstruction/registration algorithm for correction of head motion in emission tomography. *IEEE Trans Nucl Sci*, 49(1):188–194, Feb. 2002. Cité pages 97 et 98.

ICRU : Prescribing, recording and reporting photon beam therapy (supplement to ICRU report 50), report 62. Rapport technique, ICRU, 1999. Cité page 18.

C. Jacobson : *Fourier methods in 3D-reconstruction from cone-beam data*. Thèse de doctorat, Linköping University, 1996. Cité page 44.

D.A. Jaffray : Emergent technologies for 3-dimensional image-guided radiation delivery. *Seminars in Radiation Oncology*, 15(3):208–216, Jul 2005. Cité page 18.

D.A. Jaffray, D.G. Drake, M. Moreau, A.A. Martinez et J.W. Wong : A radiographic and tomographic imaging system integrated into a medical linear accelerator for localization of bone and soft-tissue targets. *Int J Radial Oncol Biol Phys*, 45(3):773–789, Oct 1999. Cité page 25.

D.A. Jaffray et J.H. Siewerdsen : Cone-beam computed tomography with a flat-panel imager : initial performance characterization. *Med Phys*, 27(6):1209–1343, 2000. Cité page 25.

D.A. Jaffray, J.H. Siewerdsen, J.W. Wong et A.A. Martinez : Flat-panel cone-beam computed tomography for image-guided radiation therapy. *Int J Radial Oncol Biol Phys*, 53(5):1337–1349, 2002. Cité pages 18 et 25.

P. Jannin, J.M. Fitzpatrick, D.J. Hawkes, X. Pennec, R. Shahidl et M.W. Vannier : Validation of medical image processing in image-guided therapy. *IEEE Trans Med Imag*, 21(12):1445–1449, Dec. 2002. Cité page 48.

P. Jannin, C. Grova et C.R. Maurer : Model for defining and reporting reference-based validation protocols in medical image processing. *International Journal of Computer Assisted Radiology and Surgery*, 1:63–73, 2006. Cité page 48.

M. Jiang et G. Wang : Convergence of the simultaneous algebraic reconstruction technique (SART). *IEEE Trans Med Imag*, 12(8):957–961, 2003. Cité page 40.

P.M. Joseph : Improved algorithm for reprojecting rays through pixel images. *IEEE Trans Med Imag*, MI-1:192–196, 1982. Cité page 41.

M. Kachelriess, S. Ulzheimer et W.A. Kalender : ECG-correlated image reconstruction from subsecond multi-slice spiral CT scans of the heart. *Med Phys*, 27(8):1881–1902, 2000. Cité page 62.

S. Kaczmarz : Angenäherte auflösung von systemen linearer gleichungen. *Bull. Acad. Polonaise. Sci. et Lettres A*, 35:335–357, 1937. Cité page 39.

A.C. Kak et M. Slaney : *Principles of computerized tomographic imaging*. IEEE Press, 1988. Cité pages 32, 35 et 37.

W.A. Kalender : X-ray computed tomography. *Phys Med Biol*, 51(13):R29–R43, 2006. Cité pages 20, 21 et 22.

W.A. Kalender, W. Seissler, E. Klotz et P. Vock : Spiral volumetric CT with single-breath-hold technique, continuous transport, and continuous scanner rotation. *Radiology*, 176(1):181–183, Jul 1990. Cité page 21.

P.J. Keall : 4-dimensional computed tomography imaging and treatment planning. *Radiation Oncology*, 14(1):80–90, 2004. Cité pages 18 et 62.

P.J. Keall, G.S. Mageras, J.M. Balter, R.S. Emery, K.M. Forster, S.B. Jiang, J.M. Kapatoes, D.A. Low, M.J. Murphy, B.R. Murray, C.R. Ramsey, M. Van Herk, S.S. Vedam, J.W. Wong et E. Yorke : The management of respiratory motion in radiation oncology report of AAPM task group 76. *Med Phys*, 33(10):3874–3900, 2006. Cité page 18.

P.J. Keall, G. Starkschall, H.P. Shukla, K.M. Forster, V. Ortiz, C.W. Stevens, S.S. Vedam, R. George, T. Guerrero et R. Mohan : Acquiring 4D thoracic CT scans using a multislice helical method. *Phys Med Biol*, 49(10):2053–2067, 2004. Cité pages 27, 63 et 68.

T. Kleshneva, J. Muzik et M. Alber : An algorithm for automatic determination of the respiratory phases in four-dimensional computed tomography. *Phys Med Biol*, 51 (16):N269–N276, 2006. Cité pages 68 et 74.

N. Koch, H.H. Liu, G. Starkschall, M. Jacobson, K.M. Forster, Z. Liao, R. Komaki et C.W. Stevens : Evaluation of internal lung motion for respiratory-gated radiotherapy using MRI : part I-correlating internal lung motion with skin fiducial motion. *Int J Radial Oncol Biol Phys*, 60(5):1459, 2004. Cité pages 63, 64 et 68.

A. Koenig, P. Grangeat, S. Bonnet et P. Hugonnard : Dynamic reconstruction for radiotherapy planning. *In Computer Assisted Radiology and Surgery*, pages 521–526, Paris, France, 2002. Cité page 98.

B.-U. Kohler, C. Hennig et R. Orglmeister : The principles of software QRS detection. *IEEE Engineering in Medicine and Biology Magazine*, 21(1):42–57, Jan.-Feb. 2002. Cité page 74.

T. Kondo, I. Kobayashi, Y. Taguchi, Y. Ohta et N. Yanagimachi : A dynamic analysis of chest wall motions with MRI in healthy young subjects. *Respirology*, 5 (1):19, 2000. Cité page 64.

S. Kriminski, M. Mitschke, S. Sorensen, N.M. Wink, P.E. Chow, S. Tenn et T.D. Solberg : Respiratory correlated cone-beam computed tomography on an isocentric C-arm. *Phys Med Biol*, 50(22):5263–5280, 2005. Cité pages 59, 63 et 73.

H.D. Kubo et B.C. Hill : Respiration gated radiotherapy treatment : a technical study. *Phys Med Biol*, 41(1):83–91, 1996. Cité page 63.

H. Kunze, K. Stierstorfer et W. Härer : Pre-processing of projections for iterative reconstruction. *In Eighth International Meeting on Fully Three-dimensional Image Reconstruction in Radiology and Nuclear Medicine*, 2005. Cité page 43.

I.S. Kyprianou, A. Badal, A. Badano, D.P.T. Banh, K.J. Myers et L. Thompson : Monte Carlo simulated coronary angiograms of realistic anatomy and pathology models. *In SPIE Medical Imaging*, 2007. Cité page 52.

K. Lackner et P. Thurn : Computed tomography of the heart : ECG-gated and continuous scans. *Radiology*, 140(2):413–420, Aug 1981. Cité pages 62 et 74.

P.G. Lacroute : *Fast volume rendering using a shear-warp factorization of the viewing transformation*. Thèse de doctorat, Stanford University, 1995. URL http://www-graphics.stanford.edu/papers/lacroute_thesis/. Cité page 41.

F. Lamare, T. Cresson, J. Savean, C. Cheze Le Rest, A.J. Reader et D. Visvikis : Respiratory motion correction for PET oncology applications using affine transformation of list mode data. *Phys Med Biol*, 52(1):121–140, Jan 2007. Cité pages 97 et 98.

J. Li, R.J. Jaszczak, H. Wang et R.E. Coleman : A filtered-backprojection algorithm for fan-beam SPECT which corrects for patient motion. *Phys Med Biol*, 40(2):283–294, Feb 1995. Cité page 98.

M. Li, H. Kudo et H. Yang : Improved 3D blood vessel reconstruction algorithm with Gibbs smoothing prior from a limited number of projections. *In International Meeting on Fully 3D Image Reconstruction in Radiology and Nuclear Medicine*, Saint-Malo, France, 2003. Cité page 84.

M. Li, H. Yang et H. Kudo : An accurate iterative reconstruction algorithm for sparse objects : application to 3D blood vessel reconstruction from a limited number of projections. *Phys Med Biol*, 47(15):2599–2609, Aug 2002. Cité page 84.

T. Li, E. Schreibmann, Y. Yang et L. Xing : Motion correction for improved target localization with on-board cone-beam computed tomography. *Phys Med Biol*, 51(10): 253–267, 2006a. Cité pages 98 et 100.

T. Li et L. Xing : Optimizing 4D cone-beam CT acquisition protocol for external beam radiotherapy. *Int J Radiat Oncol Biol Phys*, 67(4):1211–1219, Mar 2007. Cité pages 63, 73 et 74.

T. Li, L. Xing, P. Munro, C. McGuinness, M. Chao, Y. Yang, B. Loo et A. Koong : Four-dimensional cone-beam computed tomography using an on-board imager. *Med Phys*, 33(10):3825–3833, 2006b. Cité pages 63, 64, 73, 74 et 93.

U. Linsenmaier, C. Rock, E. Euler, S. Wirth, R. Brandl, D. Kotsianos, W. Mutschler et K.J. Pfeifer : Three-dimensional CT with a modified C-arm image intensifier : feasibility. *Radiology*, 224(1):286–292, Jul 2002. Cité pages 22 et 23.

H.H. Liu, P. Balter, T. Tutt, B. Choi, J. Zhang, C. Wang, M. Chi, D. Luo, T. Pan, S. Hunjan, G. Starkschall, I. Rosen, K. Prado, Z. Liao, J. Chang, R. Komaki, J.D. Cox, R. Mohan et L. Dong : Assessing respiration-induced tumor motion and internal target volume using four-dimensional computed tomography for radiotherapy of lung cancer. *Int J Radial Oncol Biol Phys*, Mar 2007. Cité page 27.

L. Livieratos, L. Stegger, P.M. Bloomfield, K. Schafers, D.L. Bailey et P.G. Camici : Rigid-body transformation of list-mode projection data for respiratory motion correction in cardiac PET. *Phys Med Biol*, 50(14):3313–3322, Jul 2005. Cité pages 97 et 98.

D.A. Low, M.M. Nystrom, E. Kalinin, P.J. Parikh, J.F. Dempsey, J.D. Bradley, S. Mutic, S.H. Wahab, T. Islam, G.E. Christensen, D.G. Politte et B.R. Whiting : A method for the reconstruction of four-dimensional synchronized CT scans acquired during free breathing. *Med Phys*, 30(6):1254–1263, 2003. Cité pages 27, 63 et 68.

D.A. Low, P.J. Parikh, W. Lu, J.F. Dempsey, S.H. Wahab, J.P. Hubenschmidt, M.M. Nystrom, M. Handoko et J.D. Bradley : Novel breathing motion model for radiotherapy. *Int J Radial Oncol Biol Phys*, 63(3):921–929, Nov 2005. Cité page 126.

W. Lu et T.R. Mackie : Tomographic motion detection and correction directly in sinogram space. *Phys Med Biol*, 47:1267–1284, 2002. Cité pages 96, 97 et 98.

W. Lu, M.M. Nystrom, P.J. Parikh, D.R. Fooshee, J.P. Hubenschmidt, J.D. Bradley et D.A. Low : A semi-automatic method for peak and valley detection in free-breathing respiratory waveforms. *Med Phys*, 33(10):3634–3636, 2006a. Cité page 74.

W. Lu, P.J. Parikh, J.P. Hubenschmidt, J.D. Bradley et D.A. Low : A comparison between amplitude sorting and phase-angle sorting using external respiratory measurement for 4D CT. *Med Phys*, 33(8):2964–2974, 2006b. Cité page 74.

W. Lu, P.J. Parikh, I.M. El Naqa, M.M. Nystrom, J.P. Hubenschmidt, S.H. Wahab, S. Mutic, A.K. Singh, G.E. Christensen, J.D. Bradley et D.A. Low : Quantitation of the reconstruction quality of a four-dimensional computed tomography process for lung cancer patients. *Med Phys*, 32(4):835–1228, 2005. Cité pages 63 et 68.

A.E. Lujan, E.W. Larsen, J.M. Balter et R.K. Ten Haken : A method for incorporating organ motion due to breathing into 3D dose calculations. *Med Phys*, 26(5):715–720, 1999. Cité page 57.

C-M.C. Ma et K. Paskalev : In-room CT techniques for image-guided radiation therapy. *Medical Dosimetry*, 31(1):30–39, 2006. Cité pages 23 et 24.

T.R. Mackie, J.M. Kapatoes, K. Ruchala, W. Lu, C. Wu, G. Olivera, L. Forrest, W. Tome, J. Welsh, R. Jeraj, P. Harari, P. Reckwerdt, B. Paliwal, M. Ritter, H. Keller, J. Fowler et M. Mehta : Image guidance for precise conformal radiotherapy. *Int J Radial Oncol Biol Phys*, 56(1):89–105, May 2003. Cité page 24.

R. Manzke, M. Grass et D.J. Hawkes : Artifact analysis and reconstruction improvement in helical cardiac cone beam CT. *IEEE Trans Med Imag*, 23(9):1150–1164, Sept. 2004. Cité pages 73 et 87.

J.R. McClelland, J.M. Blackall, S. Tarte, A.C. Chandler, S. Hughes, S. Ahmad, D.B. Landau et D.J. Hawkes : A continuous 4D motion model from multiple respiratory cycles for use in lung radiotherapy. *Med Phys*, 33(9):3348–3358, Sep 2006. Cité page 126.

P. Milanfar : A model of the effect of image motion in the Radon transform domain. *IEEE Transactions on Image Processing*, 8(9):1276 – 1281, 1999. Cité page 97.

S. Mori, M. Endo, T. Tsunoo, S. Kandatsu, S. Tanada, H. Aradate, Y. Saito, H. Miyazaki, K. Satoh, S. Matsushita et M. Kusakabe : Physical performance evaluation of a 256-slice CT-scanner for four-dimensional imaging. *Med Phys*, 31(6): 1348–1356, 2004. Cité page 22.

O. Morin, A. Gillis, J. Chen, M. Aubin, M.K. Bucci, M. Roach et J. Pouliot : Megavoltage cone-beam CT : system description and clinical applications. *Medical Dosimetry*, 31(1):51–61, 2006. Cité page 24.

M.A. Mosleh-Shirazi, P.M. Evans, W. Swindell, S. Webb et M. Partridge : A cone-beam megavoltage CT scanner for treatment verification in conformal radiotherapy. *Radiotherapy and Oncology*, 48(3):319–328, Sep 1998. Cité page 24.

K. Mueller : *Fast and accurate three-dimensional reconstruction from cone-beam projection data using algebraic methods*. Thèse de doctorat, Ohio State University, 1998. Cité pages 42 et 43.

K. Mueller, T. Moller, J.E. Swan II, R. Crawfis, N. Shareef et R. Yagel : Splatting errors and antialiasing. *In IEEE Transactions on Visualization and Computer Graphics*, volume 4, pages 178–191, April-June 1998. Cité page 41.

K. Mueller, F. Xu et N. Neophytou : Why do commodity graphics hardware boards (GPUs) work so well for acceleration of computed tomography ? *In SPIE Medical Imaging*, San Diego, California, USA, 2007. Cité page 125.

K. Mueller et R. Yagel : Fast perspective volume rendering with splatting by utilizing a ray-driven approach. *In Proceedings of the 7th conference on Visualization*, pages 65–72,468, 27 Oct.-1 Nov. 1996. Cité page 41.

K. Mueller, R. Yagel et J.F. Cornhill : The weighted-distance scheme : a globally optimizing projection ordering method for ART. *IEEE Trans Med Imag*, 16(2):223–230, 1997. Cité page 43.

K. Mueller, R. Yagel et J.J. Wheller : Anti-aliased three-dimensional cone-beam reconstruction of low-contrast objects with algebraic methods. *IEEE Trans Med Imag*, 18(6):519–537, 1999a. Cité pages 43 et 44.

K. Mueller, R. Yagel et J.J. Wheller : Fast implementations of algebraic methods for three-dimensional reconstruction from cone-beam data. *IEEE Trans Med Imag*, 18 (6):538–548, 1999b. Cité page 43.

R.T. Mull : Mass estimates by computed tomography : physical density from CT numbers. *AJR Am J Roentgenol*, 143(5):1101–1104, Nov 1984. Cité page 99.

F. Natterer : *The mathematics of computerized tomography.* John Wiley & Sons, 1986. Cité page 32.

T. Nielsen, R. Manzke, R. Proksa et M. Grass : Cardiac cone-beam CT volume reconstruction using ART. *Med Phys*, 32(4):851–860, 2005. Cité pages 73 et 87.

F. Noo, R. Clackdoyle et J.D. Pack : A two-step Hilbert transform method for 2D image reconstruction. *Phys Med Biol*, 49(17):3903–3923, Sep 2004. Cité pages 38 et 125.

B. Ohnesorge, T. Flohr, K. Schwarz, J.P. Heiken et K.T. Bae : Efficient correction for CT image artifacts caused by objects extending outside the scan field of view. *Med Phys*, 27(1):39–46, 2000. Cité page 38.

M. Orkisz et P. Clarysse : Estimation du flot optique en présence de discontinuités : une revue. *Traitement du signal*, 13:489–513, 1996. Cité page 53.

J.D. Pack, F. Noo et R. Clackdoyle : Cone-beam reconstruction using the backprojection of locally filtered projections. *IEEE Trans Med Imag*, 24(1):70–85, 2005. Cité page 38.

T. Pan, T.Y. Lee, E. Rietzel et G.T.Y. Chen : 4D-CT imaging of a volume influenced by respiratory motion on multi-slice CT. *Med Phys*, 31(2):333–341, 2004. Cité pages 63 et 68.

J. Pouliot, A. Bani-Hashemi, J. Chen, M. Svatos, F. Ghelmansarai, M. Mitschke, M. Aubin, P. Xia, O. Morin et M.K. Bucci : Low-dose megavoltage cone-beam CT for radiation therapy. *Int J Radial Oncol Biol Phys*, 61(2):552–560, 2005. Cité page 24.

T.G. Purdie, D.J. Moseley, J.-P. Bissonnette, M.B. Sharpe, K. Franks, A. Bezjak et D.A. Jaffray : Respiration correlated cone-beam computed tomography and 4DCT for evaluating target motion in stereotactic lung radiation therapy. *Acta Oncologica*, 45 (7):915–922, 2006. Cité pages 63, 73 et 74.

F. Qiao, T. Pan, J.W. Clark et O.R. Mawlawi : Region of interest motion compensation for PET image reconstruction. *Phys Med Biol*, 52(10):2675–2689, May 2007. Cité page 125.

B.W. Raaymakers, J.J.W. Lagendijk, U.A. Van der Heide, J. Overweg, K. Brown, R. Topolnjak, H. Dehnad, I.M. Jurgenliemk-Schulz, J. Welleweerd et C.J.G. Bakker : Integrating a MRI scanner with a 6 MV radiotherapy accelerator : impact of the surface orientation on the entrance and exit dose due to the transverse magnetic field. *In International Conference on the Use of Computers in Radiation Therapy (ICCR)*, Seoul, Korea, 2004. Cité page 23.

D. Rey, G. Subsol, H. Delingette et N. Ayache : Automatic detection and segmentation of evolving processes in 3D medical images : Application to multiple sclerosis. *Med Image Anal*, 6(2):163–179, Jun 2002. Cité page 99.

M. Reyes, G. Malandain, P.M. Koulibaly, M.A. Gonzàlez-Ballester et J. Darcourt : Model-based respiratory motion compensation for emission tomography image reconstruction. *Phys Med Biol*, 52:3579–3600, 2007. Cité pages 97, 98 et 108.

E. Rietzel, T. Pan et G.T.Y. Chen : Four-dimensional computed tomography : Image formation and clinical protocol. *Med Phys*, 32(4):874–889, 2005. Cité page 74.

J. Rinkel : *Correction du diffusé pour la reconstruction tomographique quantitative avec un capteur plan numérique*. Thèse de doctorat, Université Joseph-Fourier - Grenoble I, 2006. Cité page 51.

S. Rit, D. Sarrut, V. Boldea et C. Ginestet : Extraction du signal respiratoire à partir de projections cone-beam. *Traitement du signal*, 23(3–4):307–319, 2006. Cité page 72.

C.J. Ritchie, C.R. Crawford, J.D. Godwin, K.F. King et Y. Kim : Correction of computed tomography motion artifacts using pixel-specific back-projection. *IEEE Trans Med Imag*, 15(3):333–342, 1996. Cité pages 96, 98 et 100.

C.J. Ritchie, J.D. Godwin, C.R. Crawford, W. Stanford, H. Anno et Y. Kim : Minimum scan speeds for suppression of motion artifacts in CT. *Radiology*, 185(1):37–42, 1992. Cité page 27.

C.J. Ritchie, J. Hsieh, M.F. Gard, C.R. Crawford et Y. Kim : Predictive respiratory gating : a new method to reduce motion artifacts on CT scans. *Radiology*, 190:847–852, 1994. Cité page 62.

S. Roux : *Modèles dynamiques en tomographie - Application à l'imagerie cardiaque*. Thèse de doctorat, Université Joseph-Fourier - Grenoble I, 2004. Cité pages 97, 98, 100 et 105.

S. Roux, L. Desbat, A. Koenig et P. Grangeat : Exact reconstruction in 2D dynamic CT : compensation of time-dependent affine deformations. *Phys Med Biol*, 49:2169–2182, 2004. Cité pages 97 et 98.

D. Sarrut : Deformable registration for image-guided radiation therapy. *Z Med Phys*, 16 (4):285–297, 2006. Cité page 97.

D. Sarrut, V. Boldea, M. Ayadi, J.-N. Badel, C. Ginestet et S. Clippe : Non-rigid registration method to assess reproducibility of breath-holding with ABC in lung cancer. *Int J Radial Oncol Biol Phys*, 61(2):281–294, 2005. Cité pages 18 et 27.

D. Sarrut, V. Boldea, S. Miguet et C. Ginestet : Simulation of 4D CT images from deformable registration between inhale and exhale breath-hold CT scans. *Med Phys*, 33 (3):605–617, 2006. Cité pages 27, 97 et 99.

A. Sawada, K. Yoda, M. Kokubo, T. Kunieda, Y. Nagata et M. Hiraoka : A technique for noninvasive respiratory gated radiation treatment system based on a real time 3D ultrasound image correlation : a phantom study. *Med Phys*, 31(2):245–250, Feb 2004. Cité page 23.

D. Schäfer, J. Borgert, V. Rasche et M. Grass : Motion-compensated and gated cone beam filtered back-projection for 3D rotational X-ray angiography. *IEEE Trans Med Imag*, 25(7):898–906, 2006. Cité page 98.

A. Schweikard, H. Shiomi et J. Adler : Respiration tracking in radiosurgery without fiducials. *International Journal of Medical Robotics and Computer Assisted Surgery*, 1 (2):19–27, 2005. Cité page 97.

W.P. Segars : *Development and application of the new dynamic NURBS-based cardiac-torso (NCAT) phantom*. Thèse de doctorat, University of North Carolina at Chapel Hill, 2001. Cité page 52.

W.P. Segars, D.S. Lalush et B.M.W. Tsui : Modeling respiratory mechanics in the MCAT and spline-based MCAT phantoms. *IEEE Trans Nucl Sci*, 48(1):89–97, Feb 2001. Cité page 52.

W.P. Segars, B.M.W. Tsui, E.C. Frey et E.K. Fishman : Extension of the 4d ncat phantom to dynamic x-ray ct simulation. *In Nuclear Science Symposium Conference Record, 2003 IEEE*, volume 5, pages 3195–3199Vol.5, 19-25 Oct. 2003. Cité page 52.

Y. Seppenwoolde, H. Shirato, K. Kitamura, S. Shimizu, M. Van Herk, J.V. Lebesque et K. Miyasaka : Precise and real-time measurement of 3D tumor motion in lung due to breathing and heartbeat, measured during radiotherapy. *Int J Radial Oncol Biol Phys*, 53(4):822–834, 2002. Cité page 18.

G.W. Sherouse, K. Novins et E.L. Chaney : Computation of digitally reconstructed radiographs for use in radiotherapy treatment design. *Int J Radial Oncol Biol Phys*, 18 (3):651–658, Mar 1990. Cité page 41.

R.L. Siddon : Fast calculation of the exact radiological path for a three-dimensional CT array. *Med Phys*, 12(2):252–255, 1985. Cité page 41.

J.H. Siewerdsen, D.J. Moseley, S. Burch, S.K. Bisland, A. Bogaards, B.C. Wilson et D.A. Jaffray : Volume CT with a flat-panel detector on a mobile, isocentric C-arm : pre-clinical investigation in guidance of minimally invasive surgery. *Med Phys*, 32 (1):241–254, Jan 2005. Cité page 23.

T. Sikora : MPEG-1 and MPEG-2 digital bideo coding standards. *IEEE Signal Processing Management*, 14(5):82–100, 1997. Cité page 64.

J. Sillanpaa, J. Chang, G.S. Mageras, E. Yorke, F. De Arruda, K.E. Rosenzweig, P. Munro, E. Seppi, J. Pavkovich et H. Amols : Low-dose megavoltage cone-beam computed tomography for lung tumors using a high-efficiency image receptor. *Med Phys*, 33(9):3489–3497, 2006. Cité page 24.

B.A. Simon : Regional ventilation and lung mechanics using X-ray CT. *Academic Radiology*, 12(11):1414–1422, 2005. Cité page 99.

I. Sluimer, A. Schilham, M. Prokop et B. Van Ginneken : Computer analysis of computed tomography scans of the lung : a survey. *IEEE Trans Med Imag*, 33(9):3116–3123, 2006. Cité page 97.

A.R. Smith : A pixel is not a little square, a pixel is not a little square, a pixel is not a little square ! (and a voxel is not a little cube). Rapport technique, Microsoft, 1995. Cité page 41.

J.-J. Sonke, L. Zijp, P. Remeijer et M. Van Herk : Respiratory correlated cone beam CT. *Med Phys*, 32(4):1176–1186, 2005. Cité pages 63, 68, 73, 74, 93 et 124.

S.P. Sorensen, P.E. Chow, S. Kriminski, P.M. Medin et T.D. Solberg : Image-guided radiotherapy using a mobile kilovoltage X-ray device. *Medical Dosimetry*, 31(1):40–50, 2006. Cité page 24.

J.P. Thirion : Image matching as a diffusion process : an analogy with Maxwell's demons. *Med Image Anal*, 2(3):243–260, Sep 1998. Cité page 53.

H. Turbell : *Cone-beam reconstruction using filtered backprojection*. Thèse de doctorat, Linköping University, 2001. Cité page 41.

H. Tuy : An inversion formula for cone-beam reconstruction. *SIAM Journal of Applied Mathematics*, 43:91–100, 1983. Cité page 35.

M. Uematsu, T. Fukui, A. Shioda, H. Tokumitsu, K. Takai, T. Kojima, Y. Asai et S. Kusano : A dual computed tomography linear accelerator unit for stereotactic radiation therapy : A new approach without cranially fixated stereotactic frames. *Int J Radial Oncol Biol Phys*, 35(3):587–592, Jun 1996. Cité pages 23 et 24.

R.W.M. Underberg, F.J. Lagerwaard, J.P. Cuijpers, B.J. Slotman, J.T. Van Sörnsen de Koste et S. Senan : Four-dimensional CT scans for treatment planning in stereotactic radiotherapy for stage I lung cancer. *Int J Radial Oncol Biol Phys*, 60(4):1283–1290, 2004. Cité pages 63 et 68.

M. Van Herk, L. Zijp, P. Remeijer, J. Wolthaus et J.-J. Sonke : On-line 4D cone beam CT for daily correction of lung tumour position during hypofractionated radiotherapy. *In International Conference on the Use of Computers in Radiation Therapy (ICCR)*, Toronto, Canada, 2007. Cité page 126.

J. Vandemeulebroucke, D. Sarrut et P. Clarysse : Point-validated pixel-based breathing thorax model. *In International Conference on the Use of Computers in Radiation Therapy (ICCR)*, Toronto, Canada, 2007. URL http://www.creatis.insa-lyon.fr/rio/popi-model. Cité page 53.

J. Vandemeulebroucke, E. Vansteenkiste et W. Philips : A multi-modal 2D/3D registration scheme for preterm brain images. *In Engineering in Medicine and Biology Society (EMBS)*, pages 3341–3344, New York, USA, 2006. Cité page 118.

S.S. Vedam, P.J. Keall, V.R. Kini et R. Mohan : Determining parameters for respiration-gated radiotherapy. *Med Phys*, 28(10):2139–2146, Oct 2001. Cité page 74.

S.S. Vedam, P.J. Keall, V.R. Kini, H. Mostafavi, H.P. Shukla et R. Mohan : Acquiring a four-dimensional computed tomography dataset using an external respiratory signal. *Phys Med Biol*, 48(1):45–62, 2003. Cité pages 63 et 68.

P.F. Villard : *Simulation du mouvement pulmonaire pour un traitement oncologique*. Thèse de doctorat, Université Claude Bernard - Lyon 1, 2006. Cité page 26.

M. Von Siebenthal, G. Székely, U. Gamper, P. Boesiger, A. Lomax et P. Cattin : 4D MR imaging of respiratory organ motion and its variability. *Phys Med Biol*, 52 (6):1547–1564, 2007. Cité page 27.

G. Wang et M.W. Vannier : Preliminary study on helical CT algorithms for patient motion estimation and compensation. *IEEE Trans Med Imag*, 14(2):205–211, 1995. Cité pages 97 et 98.

S. Webb : Motion effects in (intensity modulated) radiation therapy : a review. *Phys Med Biol*, 51(13):R403–R425, 2006. Cité page 18.

J. Weese, R. Gocke, G. Penney, P. Desmedt, T. Buzug et H. Schumann : Fast voxel-based 2D/3D registration algorithm using a volume rendering method based on the shear-warp factorization. *In SPIE Medical Imaging*, San Diego, California, USA, 1999. Cité page 41.

N.M. Wink, M.F. McNitt-Gray et T.D. Solberg : Optimization of multi-slice helical respiration-correlated CT : the effects of table speed and rotation time. *Phys Med Biol*, 50(23):5717–5729, 2005a. Cité page 63.

N.M. Wink, C. Panknin et T.D. Solberg : Phase versus amplitude sorting of 4D-CT data. *Journal of Applied Clinical Medical Physics*, 7(1):77–85, 2005b. Cité pages 68 et 74.

G. Wolberg : *Digital image warping*. IEEE Computer Society Press, 1990. Cité pages 38, 41, 107 et 108.

J.W. Wolthaus, M. Van Herk, S.H. Muller, J.S.A. Belderbos, J.V. Lebesque, J.A. De Bois, M.M.G. Rossi et E.M.F. Damen : Fusion of respiration-correlated PET and CT scans : correlated lung tumour motion in anatomical and functional scans. *Phys Med Biol*, 50(7):1569–1583, 2005. Cité page 63.

J.W. Wong, M.B. Sharpe, D.A. Jaffray, V.R. Kini, J.M. Robertson, J.S. Stromberg et A.A. Martinez : The use of active breathing control (ABC) to reduce margin for breathing motion. *Int J Radial Oncol Biol Phys*, 44(4):911–919, 1999. Cité page 18.

L. Xing, B. Thorndyke, E. Schreibmann, Y. Yang, T. Li, G.-Y. Kim, G. Luxton et A. Koong : Overview of image-guided radiation therapy. *Medical Dosimetry*, 31 (2):91–112, 2006. Cité page 18.

F. Xu et K. Mueller : A comparative study of popular interpolation and integration methods for use in computed tomography. *In IEEE International Symposium on Biomedical Imaging (ISBI)*, 2006. Cité page 41.

D. Yan, F. Vicini, J.W. Wong et A.A. Martinez : Adaptive radiation therapy. *Phys Med Biol*, 42(1):12–32, 1997. Cité page 115.

L. Zagni : Sommation spatio-temporelle d'image 4D pour le cumul rétrospectif de doses en radiothérapie du poumon. Mémoire de master, Institut National des Sciences Appliquées (INSA), 2006. Cité page 58.

W. Zbijewski et F.J. Beekman : Characterization and suppression of edge and aliasing artefacts in iterative X-ray CT reconstruction. *Phys Med Biol*, 49(1):145–157, Jan 2004. Cité page 43.

W. Zbijewski et F.J. Beekman : Comparison of methods for suppressing edge and aliasing artefacts in iterative X-ray CT reconstruction. *Phys Med Biol*, 51(7):1877–1889, 2006. Cité page 43.

G.L. Zeng et G.T. Gullberg : Unmatched projector/backprojector pairs in an iterative reconstruction algorithm. *IEEE Trans Med Imag*, 19(5):548–555, May 2000. Cité page 42.

R. Zeng et J.A. Fessler : Respiratory motion estimation from slowly rotating X-ray projections theory and simulation. *Med Phys*, 32(4):984–991, 2005. Cité page 97.

R. Zeng, J.A. Fessler et J.M. Balter : Estimating 3-D respiratory motion from orbiting views by tomographic image registration. *IEEE Trans Med Imag*, 26(2):153–163, 2007. Cité pages 97, 112 et 126.

D. Zerfowski : Motion artifact compensation in CT. *In SPIE Medical Imaging*, San Diego, California, USA, 1998. Cité pages 96, 97 et 98.

B. Zhang et G.L. Zeng : Two-dimensional iterative region-of-interest (ROI) reconstruction from truncated projection data. *Med Phys*, 34(3):935–944, 2007. Cité page 44.

T. Zhang, H. Keller, M.J. O'Brien, T.R. Mackie et B. Paliwal : Application of the spirometer in respiratory gated radiotherapy. *Med Phys*, 30(12):3165–3171, 2003. Cité page 63.

W. Zhuang, S.S. Gopal et T.J. Hebert : Numerical evaluation of methods for computing tomographic projections. *IEEE Trans Nucl Sci*, 41(4):1660–1665, 1994. Cité pages 41 et 108.

L. Zijp, J.-J. Sonke et M. Van Herk : Extraction of the respiratory signal from sequential thorax cone-beam X-ray images. *In International Conference on the Use of Computers in Radiation Therapy*, Seoul, Korea, 2004. Cité pages 63, 64 et 124.