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Citation for published version (APA):

Incetan, K., Mohan, R., Stoutjesdijk, H., Fernandes, N., & de Jager, B. (2019). RGB-D camera based collision prediction and avoidance for X-ray rotational angiography. In *Proceedings of IEEE Sensors Conference 2019* Article 8956899 Institute of Electrical and Electronics Engineers.
<https://doi.org/10.1109/SENSORS43011.2019.8956899>

DOI:

[10.1109/SENSORS43011.2019.8956899](https://doi.org/10.1109/SENSORS43011.2019.8956899)

Document status and date:

Published: 01/10/2019

Document Version:

Accepted manuscript including changes made at the peer-review stage

Please check the document version of this publication:

- A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
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RGB-D Camera Based Collision Prediction and Avoidance for X-ray Rotational Angiography

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Abstract—Optimal clinical workflow leads to faster treatment times and a potential to cater to a larger number of patients. A key part of this is preventing collisions between moving medical systems and patient. For interventional environments, high-speed rotational angiography (RA) scans are prone to potential collisions between the C-arm X-ray system and the patient. To ensure safety, a low speed safety-run is executed before the actual high-speed scan. However, several iterations of the safety-run are often required before a scan is collision-free leading to a suboptimal clinical work-flow. This work proposes a RGB-D camera based collision prediction system which detects collisions before the actual RA scan. Additionally, a motion planner is designed to provide appropriate patient repositioning such that the collision is avoided. The system is introduced as a first proof-of-concept to eliminate the safety-run and improve clinical safety and workflow.

I. INTRODUCTION

Minimally invasive X-ray coronary angiography is the gold standard to treat coronary artery disease [1]. To allow such procedures, C-arm based X-ray imaging devices (Fig. 1) are used in Rotational Angiography (RA) scans, during which the C-arm is rotated about one or more axes at high speeds [2], [3]. In order to avoid delays in patient treatment and potentially cater to a larger number of patients, optimal clinical workflow is imperative [4]. However, in today's interventional environments, clinical workflow is often hampered by the initial patient positioning setup which is a time consuming process [4], [5].

A key factor for high setup times is (re-)positioning of the patient for a collision-free RA scan. During RA, there is the risk of collision between the C-arm detector and the patient [6], [7]. Such collisions pose a challenge for patient safety and potentially lead to suspension of the intervention wasting valuable treatment time [8], [9]. The current practice for patient safety during RA is to execute a low speed safety-run during which the C-arm trajectory is checked for collisions [10], [11]. If a collision is detected, the C-arm stops, the patient is re-positioned and the safety-run is executed again. This procedure often takes several iterations before a RA scan is collision-free and these iterations are performed manually. Further, a collision might be unavoidable (due to patient's size and/or treatment position) and this can be concluded only after

a few iterations of the safety-run. This process leads to a suboptimal clinical workflow, prolonging patient set-up and treatment time [9].

Previous works such as [10], [12] have investigated collision detection for C-arm systems. However, these solutions lack a collision avoidance strategy and using them during RA does not eliminate the manual patient re-positioning process. While the solution in [4] can provide a collision-free position of the C-arm relative to the patient, it lacks the ability to warn the physicians if collision avoidance is not possible. Instead of suspending the RA scan straight-away, it might take several (automatic) re-positioning iterations before addressing the situation.

To address these shortcomings, this work proposes a RGB-D camera (Kinect™ v2) based collision prediction and avoidance system. The contributions are as follows:

- 1) A RGB-D camera based collision prediction system which highlights potential collisions between the C-arm detector and the patient before the RA scan.
- 2) A motion planning algorithm for the patient table is developed such that detected collisions can be avoided.
- 3) The system provides information on situations when a collision cannot be avoided without using multiple manual iterations.

The system presented in this work is provided as a first proof-of-concept to eliminate the safety-run (Fig. 1), thereby minimizing patient set-up times and optimizing clinical workflow.

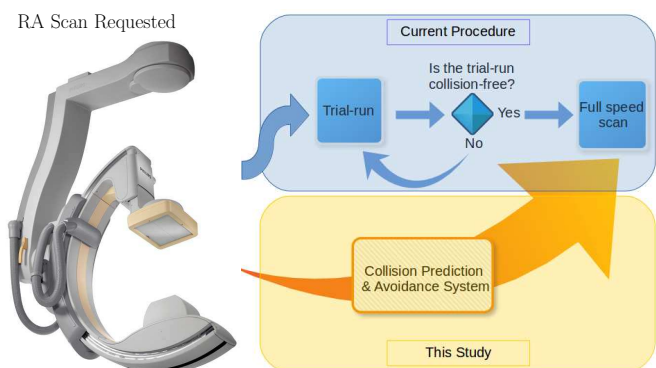


Fig. 1: Comparison between current practice and concept developed in this work

The authors gratefully acknowledge Rob Gielen² for useful feedback and discussions.

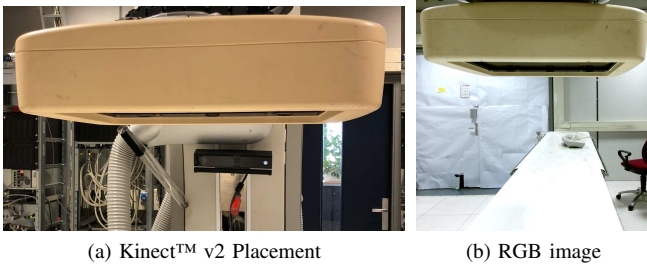


Fig. 2: Camera placement and environment representation

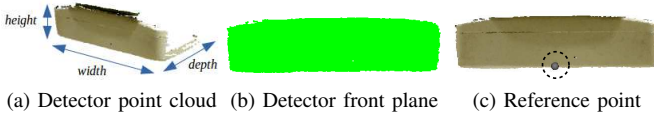


Fig. 3: Detector location and reference point generation

II. COLLISION PREDICTION AND AVOIDANCE SYSTEM

In this work, environment information is obtained using a static Kinect™ v2 camera which provides depth and colour (RGB) information of the environment [4]. This information is processed as a point cloud using libraries “libfreenect2” [13] and “Point Cloud Library” [14]. Due to the close proximity of the detector and patient during RA, most collisions occur when the detector is trying to clear the patient body during C-arm rotation. Consequently, the camera is placed on the C-arm such that the detector path during RA and patient in treatment position can be observed (Fig. 2).

A. Collision Prediction

Predicting collisions requires information about the volume swept by the C-arm detector during a RA scan. Any objects detected within this volume are at risk of collision. To compute this volume, the detector is first located in 3D space by segmenting it from the rest of the point cloud using colour and shape segmentation algorithms [15] (Fig. 3a). Next, a specific reference point on the detector is found which is used to represent the trajectory of the detector during a scan and in-turn used to construct the volume swept by the detector. The reference point is identified by segmenting the front plane of the detector (the surface closest to the camera) (Fig. 3b) and computing the centre of the bottom edge of this plane (Fig. 3c). During RA, the detector rotates around the isocenter, sweeping a hollow cylindrical volume (\mathcal{T}) centred at the isocenter with inner radius r_{iso} , outer radius $r_{iso} + h$ and depth l (Figs. 4a and 4b). Here, r_{iso} is the normal distance from isocenter to the reference point and h and l are the height and depth of the detector (Fig. 3a). The space bounded by the inner surface of \mathcal{T} is thus collision-free. For increased safety, an additional margin (d_{margin}) is introduced and the “safe zone” is represented by a cylindrical volume (\mathcal{S}) centred at the isocenter with height l and radius $r_S = r_{iso} - d_{margin}$ (Fig. 4).

Determining collisions involves checking the occupancy of \mathcal{T} . To reduce computational demands while collision checking, only the inner and outer surfaces of \mathcal{T} are considered and discretized by uniform gridding (Fig. 4c). The environment is

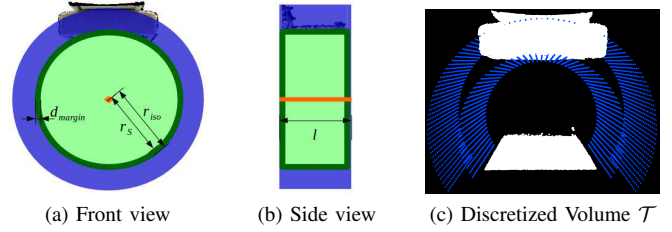


Fig. 4: Representations of the trajectory volume \mathcal{T} (blue), safe zone \mathcal{S} (green), safety margin d_{margin} (dark green) and the isocenter (orange)

represented by a point cloud \mathcal{P}_N with N points. Each point $P_i \in \mathcal{P}_N, i \in \{1, \dots, N\}$ is a point in Cartesian coordinates (x, y, z) . A point P_i is considered as a collision point if

$$\exists d_{in} \in \mathcal{D}_{in}, d_{out} \in \mathcal{D}_{out} \text{ such that } d_{in} \leq d_{P_i} \leq d_{out} \quad (1)$$

where \mathcal{D}_{in} and \mathcal{D}_{out} represent the Euclidean distance of grid points on the inner and outer surface from the isocenter and d_{P_i} is the Euclidean distance of points in \mathcal{P}_N from the isocenter. Figure 5a represents a scenario where the detector will collide with a mannequin for 3D-RA.

B. Collision Avoidance

To avoid predicted collisions, an algorithm is developed to move the patient table, in vertical and horizontal direction, such that the RA scan is collision free. Motion for the table is planned such that \mathcal{P}_{coll} is moved into \mathcal{S} . The planned motion should be minimal since the table is initially positioned after isocentering by the physician [3]. A large movement will result in the region of interest being placed away from the isocenter. Further, the algorithm should account for situations when avoiding a collision is not possible.

Let \mathcal{P}_{coll} consist of K points, where $P_{coll_j}, j \in \{1, \dots, K\}$ represents a point in Cartesian coordinates. To plan a table movement such that $\mathcal{P}_{coll} \in \mathcal{S}$, the point which is furthest away (in direction of possible table movements) from the isocenter is found (P_{coll}^{max}). The table movements M_x and M_y in X- and Y-direction respectively are generated as

$$M_x = -\cos(\phi) \cdot (d_C - d_A), \quad M_y = -\sin(\phi) \cdot (d_C - d_A)$$

where d_C is the distance of P_{coll}^{max} from the isocenter, d_A is the distance of \mathcal{S} to the isocenter along the direction of d_C and ϕ is the angle between the horizontal axis and the line defined by P_{coll}^{max} and isocenter.

It should be noted, since \mathcal{S} is an enclosed region, avoiding collisions might be impossible if the volume occupied due to patient size and pose does not fit inside \mathcal{S} . Figure 6 presents such a case when the algorithm cannot return a valid motion. A collision is predicted with the right arm of the mannequin (Fig. 6a) and the algorithm provides the appropriate movement with respect to the predicted collision. After the movement is applied, the collision detection algorithm still marks \mathcal{T} as occupied (Fig. 6b). It can be observed that \mathcal{T} being unoccupied will never be satisfied and the algorithm will iterate infinitely to compute table movements. Therefore, before planning a motion, it is required to check if the patient fits inside \mathcal{S} . To this

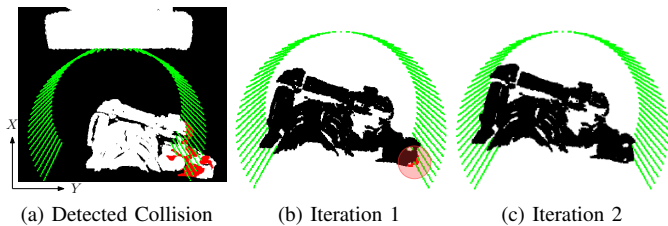


Fig. 5: Collision scenario and iterative table movement for 3D-RA with Boundary of \mathcal{S} (green) and \mathcal{P}_{coll} (red)

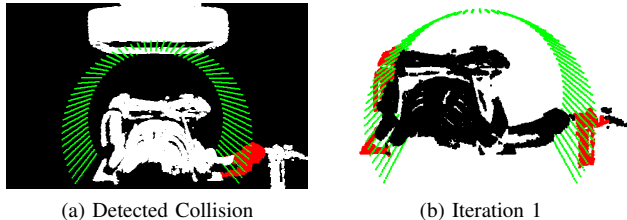


Fig. 6: Scenario in which collision cannot be avoided

end, let \mathcal{P}_α be the set of points such that $\mathcal{P}_\alpha \subset (\mathcal{P}_N \cap \mathcal{T} + \mathcal{S})$. The smallest possible circle with diameter d_{enc} which encloses all points in \mathcal{P}_α is generated and avoiding a collision is not possible for the condition $d_{enc} \geq 2 \cdot r_S$.

If $d_{enc} \leq 2 \cdot r_S$, motion planning is applied iteratively once a collision is detected. For 3D-RA, $d_A = r_S$ since \mathcal{S} is defined by a cylindrical volume of radius r_S . The proposed movement (M_x, M_y) is computed and the environment point cloud \mathcal{P}_N is moved accordingly. The collision check is then applied to this translated point cloud with the process being repeated till \mathcal{T} is unoccupied (collision-free). The application can be seen in Fig. 5 in which the motion planning continues until all collisions are avoided and the algorithm returns the final movement and direction as the summation of M_x and M_y of each iteration.

III. RESULTS AND DISCUSSION

The collision avoidance system proposed in Section II is experimentally validated against the safety-run which uses a capacitance-based collision avoidance system (“Bodyguard” or **BG**). Two different C-arm systems, X_1 and X_2 , are used and experiments for X_1 are performed with two different background conditions (B_1 - light and B_2 - dark). Different C-arm systems validate the robustness of the algorithm to locate the detector and compute the reference point. The two different backgrounds provide insight on the effect of changing lighting conditions on environment representation. In order to ensure a realistic and reliable comparison to real-life scenarios, collision detection is tested with the right shoulder of a person lying on the patient table (Fig. 7a).

Collision Test: The test subject and table are positioned such that the centre of the detector touches the right shoulder when the C-arm is rotated. The C-arm is rotated from its starting position (propeller angle 0°) at a low speed with the capacitance safety system active. The **BG** detects a collision and the C-arm is prevented from rotating further. With the **BG** now disabled, the Kinect-based system is enabled and the



Fig. 7: Collision scenario: System X_1 , Background B_1

collision is predicted at the right shoulder (Fig. 7b) without the need for rotating the C-arm. The method in (II-B) provides the appropriate table movement (Fig. 7c) to avoid this collision.

The two C-arm systems with different backgrounds generate three testing scenarios (X_1B_1, X_1B_2, X_2B_1). For each scenario, the collision test procedure is carried out 60 times with the results listed in Table I. Since the **BG** is current state-of-the-art, it does not fail to detect a collision. Thus, a collision test is marked “True Positive” when the Kinect-based system detects the same collision that is detected by the **BG**, i.e., the Kinect-based system is as good as the **BG** in this case. Based on Table I, it can be concluded that the proposed Kinect-based system detects all except 3 collisions in comparison to the **BG**.

TABLE I: Results - Collision Detection

Scenario	Number of Collision Tests	True Positives
X_1, B_1	60	60
X_1, B_2	60	60
X_2, B_1	60	57

With the proposed collision prediction system being comparable to the **BG** and the planning algorithm providing the table movement, the entire process of the safety-run can be concluded automatically in a single process. Moreover, in case a collision is unavoidable, the proposed system provides this knowledge to the physician without multiple manual trials.

IV. CONCLUSION AND FUTURE WORK

This paper presents a collision prediction and avoidance system for C-arm X-ray systems during Rotational Angiography (RA). Using a Kinect™ v2 camera, collisions between the detector and patient are detected before the start of RA scans. In addition, a motion planning algorithm determines the patient table movement required to prevent a collision and complete the high-speed RA scan. The system is introduced as a first proof-of-concept to eliminate the low-speed safety-run which requires several iterations and disrupts clinical work-flow.

A potential area of improvement is the detector segmentation from the point cloud based on colour (Fig. 3a). This might not be robust as change in detector colour will require parameter calibration for the segmentation. Future work by the authors aims to solve this using machine learning to classify and localize the detector irrespective of colour. Additionally, collisions between the detector and other objects were not considered along with the omission of collisions with the X-ray source. Future work by the authors aims to solve these issues.

REFERENCES

- [1] S. Çimen, A. Gooya, M. Grass, and A. F. Frangi, "Reconstruction of coronary arteries from X-ray angiography: A review," *Med. Image Anal.*, vol. 32, pp. 46–68, 2016.
- [2] R. Fahrig, J. Starman, E. Girard, A. Al-Ahmad, H. Gao, N. Kothary, and A. Ganguly, "C-arm CT in the interventional suite: Current status and future directions," *Cone Beam Computed Tomography*, pp. 199–221, 2014.
- [3] A. J. Klein and J. A. Garcia, "Rotational coronary angiography," *Cardiology Clinics*, vol. 27, no. 3, pp. 395–405, 2009.
- [4] C. Schaller, C. Rohkohl, J. Penne, M. Stürmer, and J. Hornegger, "Inverse C-arm positioning for interventional procedures using real-time body part detection," in *MICCAI 2009*. Berlin, Heidelberg: Springer, 2009, pp. 549–556.
- [5] S. Bauer, A. Seitel, H. Hofmann, T. Blum, J. Wasza, M. Balda, H.-P. Meinzer, N. Navab, J. Hornegger, and L. Maier-Hein, "Real-time range imaging in health care: A survey," in *Time-of-Flight and Depth Imaging. Sensors, Algorithms, and Applications*. Springer, 2013, pp. 228–254.
- [6] D. Schäfer, C. Meyer, R. Bullens, A. Saalbach, and P. Eshuis, "Limited angle C-arm tomography and segmentation for guidance of atrial fibrillation ablation procedures," in *MICCAI 2012*. Berlin, Heidelberg: Springer, 2012, pp. 634–641.
- [7] L. Wang, P. Fallavollita, R. Zou, X. Chen, S. Weidert, and N. Navab, "Closed-form inverse kinematics for interventional C-arm X-ray imaging with six degrees of freedom: modeling and application," *IEEE Trans. Med. Imaging*, vol. 31, no. 5, pp. 1086–1099, 2012.
- [8] R. A. Cardan, R. A. Popple, and J. Fiveash, "A priori patient-specific collision avoidance in radiotherapy using consumer grade depth cameras," *Med. Phys.*, vol. 44, no. 7, pp. 3430–3436, 2017.
- [9] L. Padilla, E. A. Pearson, and C. A. Pelizzari, "Collision prediction software for radiotherapy treatments," *Med. Phys.*, vol. 42, no. 11, pp. 6448–6456, 2015.
- [10] A. Ladikos, S. Benhimane, and N. Navab, "Real-time 3D reconstruction for collision avoidance in interventional environments," in *MICCAI 2008*. Berlin, Heidelberg: Springer, 2008, pp. 526–534.
- [11] N. Strobel, O. Meissner, J. Boese, T. Brunner, B. Heigl, M. Hoheisel, G. Lauritsch, M. NaGel, M. Pfister, E.-P. Rührnschopf *et al.*, "3D imaging with flat-detector C-arm systems," in *Multislice CT, Medical Radiology*, M. Reiser, C. Becker, K. Nikolaou, and G. Glazer, Eds. Springer, Berlin, Heidelberg, 2009, pp. 33–51.
- [12] I. W. J. Hamersma, J. J. Dries, M. J. H. den Hartog, Y. Morvan, and M. J. G. van de Molengraft, "Safety in dynamic 3D healthcare environment," Jan. 23 2014, US Patent App. 14/007,654.
- [13] L. Xiang *et al.*, "libfreenect2: Release 0.2," 2016. [Online]. Available: <https://doi.org/10.5281/zenodo.50641>
- [14] R. B. Rusu and S. Cousins, "Point cloud library (pcl)," in *2011 IEEE international conference on robotics and automation*. IEEE, 2011, pp. 1–4.
- [15] M. A. Fischler and R. C. Bolles, "Random sample consensus: A paradigm for model fitting with applications to image analysis and automated cartography," *Communications of the ACM*, vol. 24, no. 6, pp. 381–395, 1981.