An Open-Source Application for Monitoring Cardiorespiratory Motion with Bi-Planar Fluoroscopic Imaging

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Objective

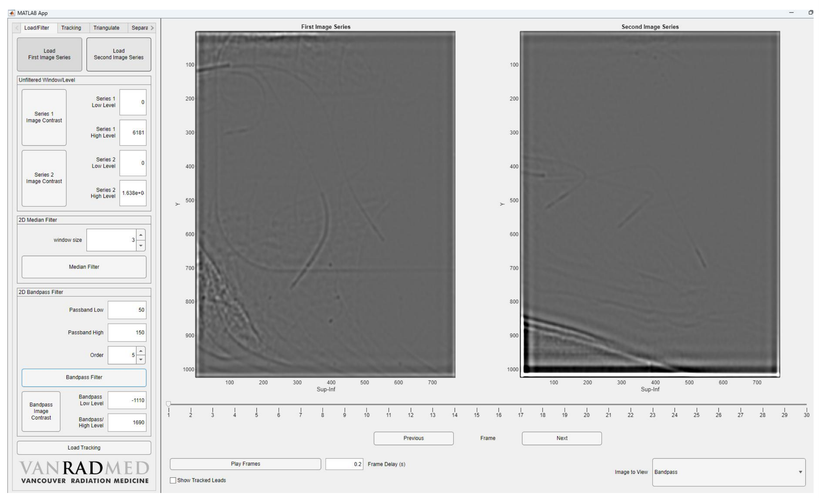
To develop an open-source application capable of retrospectively monitoring the position of radiopaque markers from bi-planar fluoroscopy images.

Introduction

- Understanding physiological motions is necessary to effectively manage them
- Bi-planar fluoroscopy can monitor radio-opaque objects with a high spatial and temporal resolution
- Example use case includes monitoring implanted cardiac leads typical of cardiac radioablation patients
- A motion monitoring application was developed to garner data for several investigations [1-4]

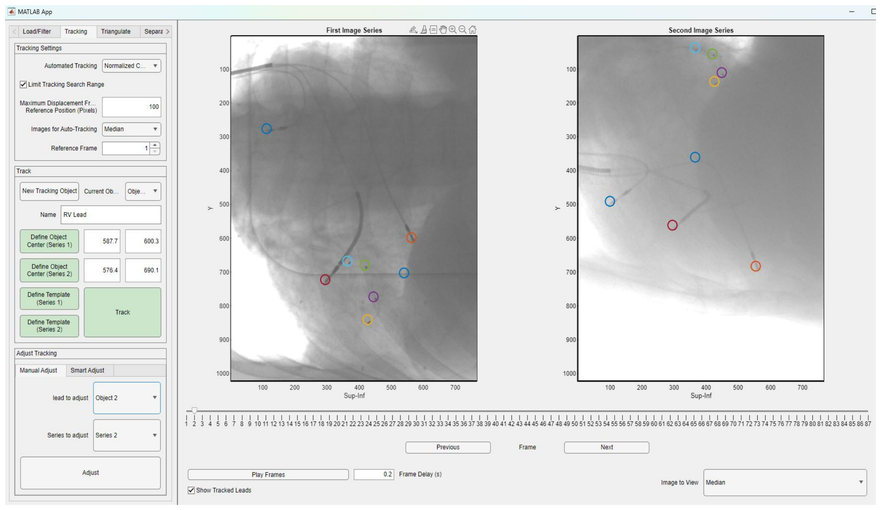
1) Load / Filter Tab

- Data is loaded into the MATLAB application
- Currently .raw files are supported but this can easily be extended
- Basic image processing tools such as window/level, 2D median filtering, and 2D bandpass filtering can aide in object tracking



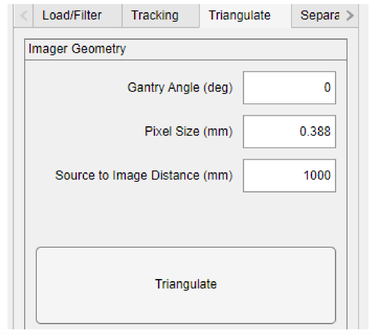
2) Tracking

- Normalized cross correlation image template matching is used to semi-automatically track objects across fluoroscopy frames
- Manual adjustment of tracked points mitigates algorithm errors

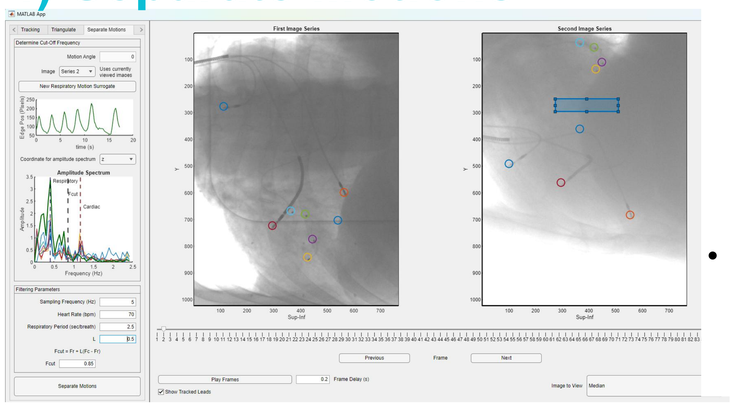


3) Triangulate

- 3D positions are triangulated from 2D projections based on geometry.
- Configured for Brainlab ExacTrac on the Vero4DRT linac, with potential extension to conventional C-arm linacs and other dual-imaging systems.



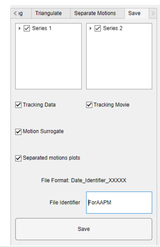
4) Separate Motions



- For cardiorespiratory motions, separating the respiratory (low frequency) and cardiac (high frequency) motions is performed with multi-band filtering
- Monitoring the sup-inf motion of the diaphragm is also semi-automatically performed

5) Save

- Data export/save tab to export imaging and motion monitoring data for further analysis
- Data saves to a .mat file



Testing

- Sinusoids programmed to cardiorespiratory motion phantom (Fig 1).
- Extracted cardiac and respiratory motions fit to sinusoids in MATLAB and compared to the expected values

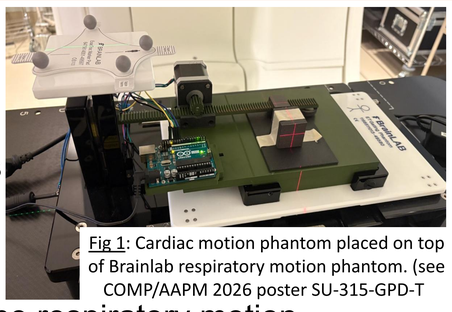


Fig 1: Cardiac motion phantom placed on top of Brainlab respiratory motion phantom. (see COMP/AAPM 2026 poster SU-315-GPD-T

- Motion monitoring application revealed the respiratory motion phantom moved slower than programmed. Found to coincide with a digital counter.
- Motion monitoring application (App.) measurements compared to those expected in table 1.

Imager Angles	Ring	Direction	Scenario	Respiratory Amplitude (mm)	Respiratory Period (s)	Cardiac Amplitude (mm)	Cardiac BPM
340°, 70°	0°	SI	App	3.0 [3.0,3.1]	4.3 [4.3,4.3]	1.8 [1.8,1.9]	63.1 [63.1,63.1]
			Expected	3.0	4.3	2.0	60.0
55°, 145°	0°	SI	App	4.1 [4.0,4.2]	3.3 [3.3,3.3]	4.9 [4.9,5.0]	52.1 [52.1,52.1]
			Expected	4.1	3.3	5.0	50.0
95°, 185°	0°	SI	App	5.1 [5.0,5.2]	6.5 [6.5,6.5]	3.9 [3.9,4.0]	82.7 [82.7,82.7]
			Expected	5.0	6.5	4.0	80.0
95°, 185°	330°	SI	App	2.6 [2.5,2.6]	6.5 [6.5,6.5]	1.9 [1.9,2.0]	82.7 [82.7,82.7]
			Expected	2.5	6.5	2.0	80.0
95°, 185°	330°	LR	App	4.5 [4.4,4.5]	6.5 [6.5,6.5]	3.3 [3.3,3.4]	82.7 [82.7,82.7]
			Expected	4.4	6.5	3.5	80.0

Open source

https://github.com/jakobmarshall/Fluoroscopy-Motion-Monitoring

Conclusions

- The developed application allows for monitoring the position of radiopaque objects from bi-planar fluoroscopy images.
- Future work extending the application to similar use-cases such as motion monitoring using CBCT projections, is warranted. Further work is needed to benchmark its performance.

References

[1] Marshall et al. Towards the use of implanted cardiac leads or the diaphragm for active respiratory motion management in stereotactic arrhythmia radioablation. Int J Radiat Oncol Biol Phys. 2025.
[2] Marshall et al. Margins to account for cardiac and respiratory motion in cardiac radioablation. Med Phys. 2025;52(10):e70041.
[3] Marshall et al. The role of abdominal compression in the reduction of respiratory motion for cardiac radioablation. J Appl Clin Med Phys. 2026.
[4] Marshall et al. Multi-lead monitoring to deduce translations and rotations of the heart through respiration and its geometric implications for motion management in cardiac radioablation. Int J Radiat Oncol Biol Phys. 2026.

Acknowledgements

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