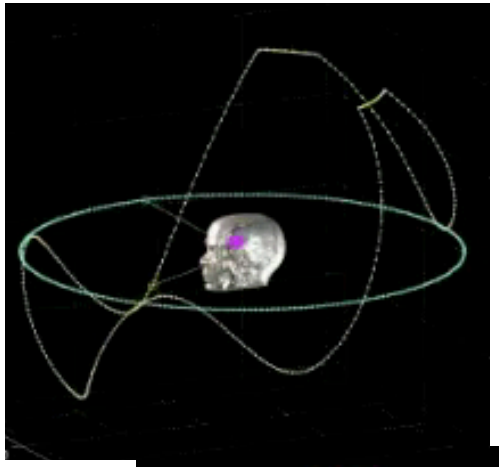
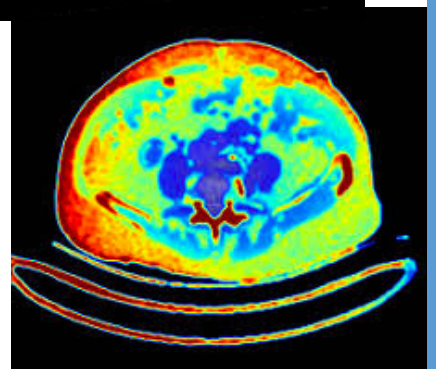
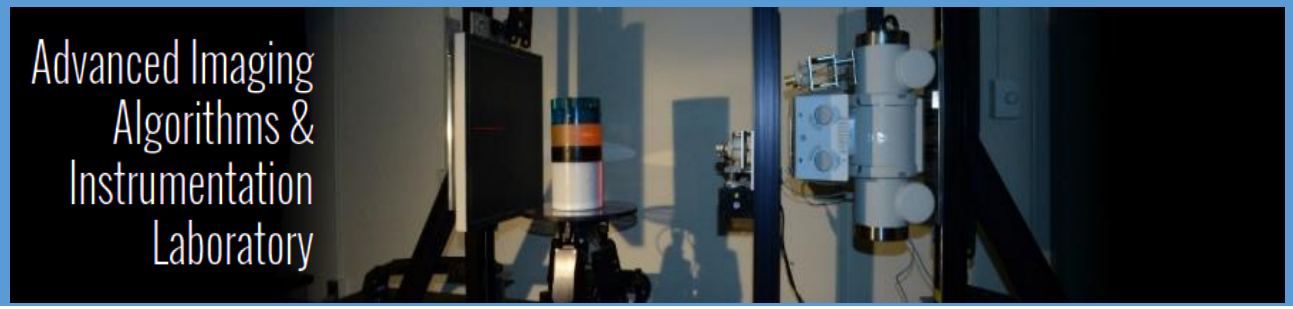




Dynamic x-ray beam positioning for low-dose CT

Computer Integrated Surgery II Checkpoint Presentation

Andrew Mao, William Shyr
Mentor: J. Web Stayman Ph.D.



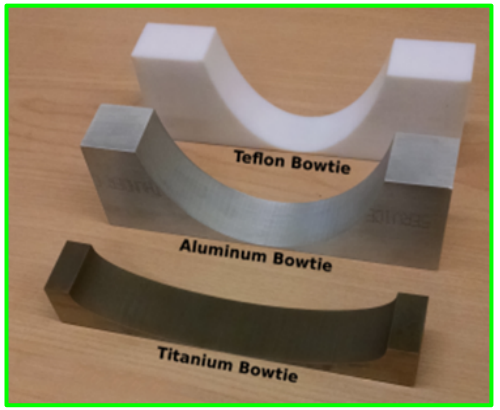
AIAI Lab

JOHNS HOPKINS BIOMEDICAL ENGINEERING

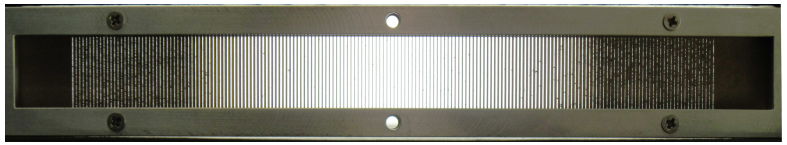
JOHNS HOPKINS MEDICINE

Project Background

- CT is an important modality in the ED
- Patient often miscentered within bore
  - Average 3cm below center
- Dose and image quality consequences
  - 25.8% dose increase
  - up to 22% noise increase
- Requires repositioning and retaking images
- Impractical in emergency medicine
- Bowtie filters often simply removed, leading to increased dose



Bowtie filters

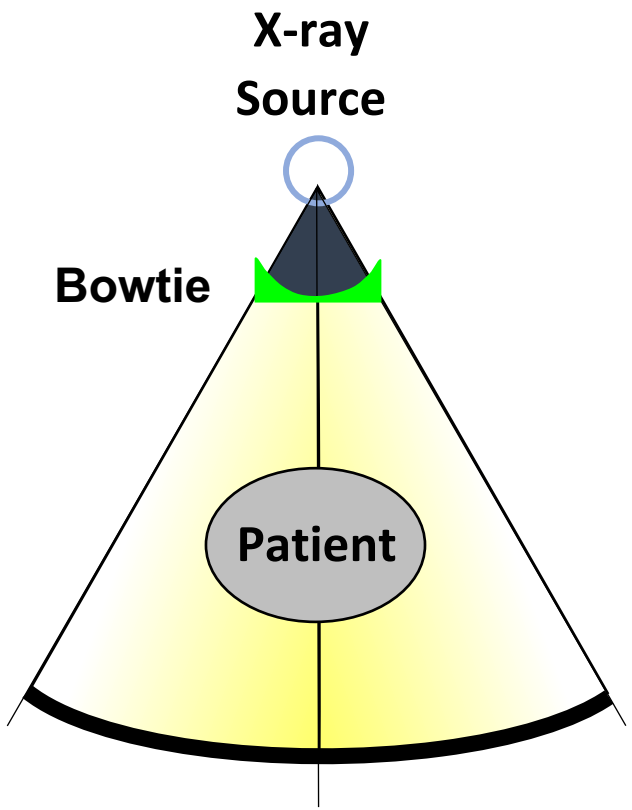


Multiple aperture device (MAD)

Toth et. al., Med. Phys., 2007

Project Goal

To achieve dynamic x-ray beam positioning in low-dose CT acquisitions and quantitative performance assessment for arbitrary patient positioning in emergency medicine applications



Deliverables

Deliverables
Minimum
Constructed test bench setup & control software
Working dose assessment and image reconstruction frameworks
Calibration of object position in FOV using multiple view low-dose scans
Computed beam filter trajectory for 360° acquisition
Expected
Simulated image reconstructions on digital phantoms
Performance assessment on phantom acquisitions using bowtie filters
Maximum
Artifact correction for MAD imaging (*potential pitfall)*
Performance assessment on phantom acquisitions using bowtie filters

Updated Deliverables

Deliverables	Status
Minimum	
Constructed test bench setup & control software	✓
Working dose assessment and image reconstruction frameworks	✓
Calibration of object position in FOV using multiple view low-dose scans	✓
Computed beam filter trajectory for 360° acquisition	✓
Expected	
Implement approach 2 of step 3 for 360° acquisition	In progress
Dose plots ($CTDI_w$ vs 3 off-center locs) with & without bowtie	In progress
Noise plots (σ vs 3 off-center locs) with & without bowtie	Not started
Maximum	
Artifact correction for MAD imaging (*potential pitfall)*	In progress
Noise plots (σ vs 3 off-center locs) with & without MAD	Not started

JOHNS HOPKINS BIOMEDICAL ENGINEERING

Technical Implementation Details

INPUTS

2D Scout Scans

- Anteroposterior projection
- Lateral projection
- Acquisition parameters
  - kV
  - mAs
  - Filtration

Calibration

- Gain, offset correction
- Detector offset
- System geometry
  - Pixel size
  - Detector size
  - SAD, SDD
  - Detector source center: (u_0, v_0)
- Beam filter model

STEP 1

Phantom Model

- Assume rectellipse
- 6 Parameters
  - Center
  - Semiaxes widths
  - Squarness parameter
  - Attenuation coefficient

STEP 2: OPTIMIZATION

Forward projection

Minimize RMSE of projection with scout data

STEP 3: COMPUTE FILTER TRAJECTORY

Approach 1:

Forward project filter model to give gain correction → Minimize variance of detector fluence at each projection

OR

Approach 2:

Calculate translation analytically to match bowtie center with object center

Data Pre-Processing

INPUTS

2D Scout Scans

- Anteroposterior projection
- Lateral projection
- Acquisition parameters
  - kV
  - mAs
  - Filtration

Calibration

- Gain, offset correction
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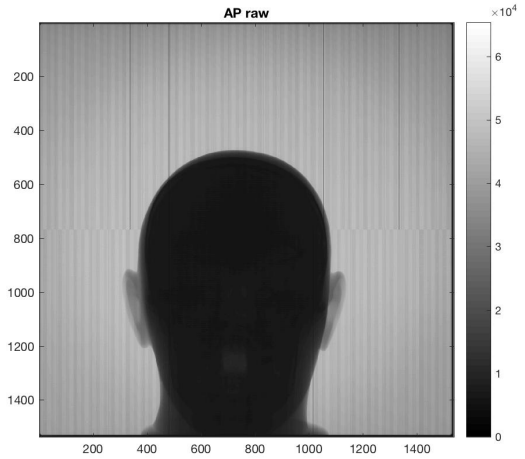
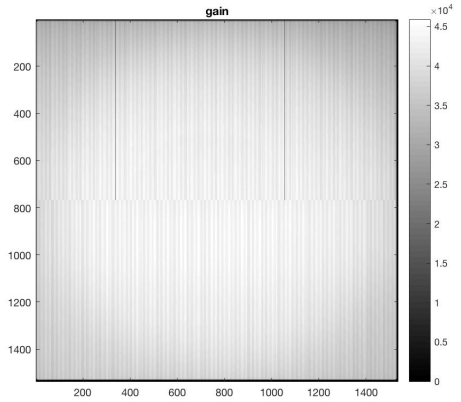
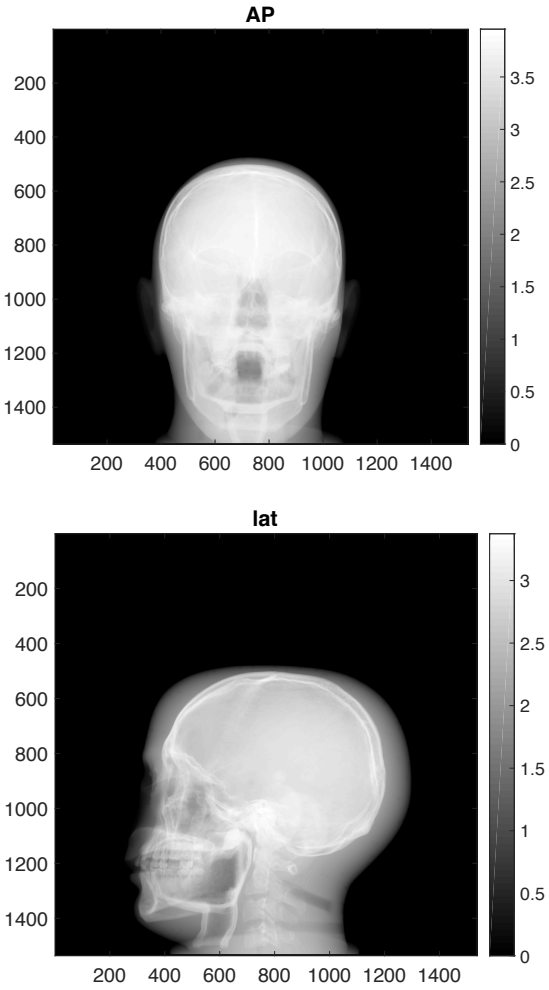




Subtract dark current → Divide by gain → log

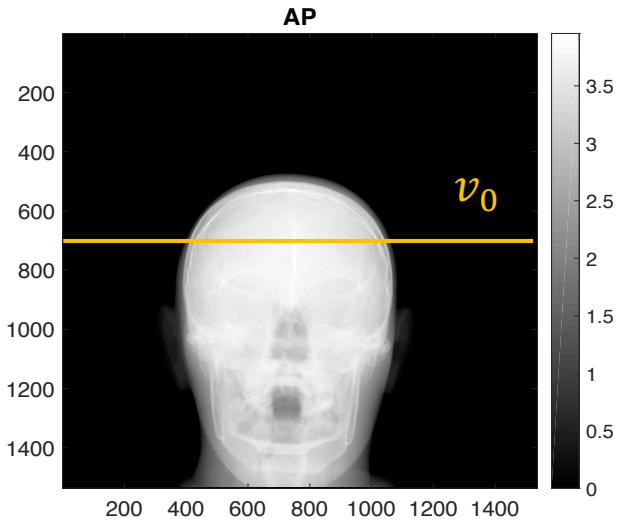
$$y = I_0 e^{-A\mu} + s$$

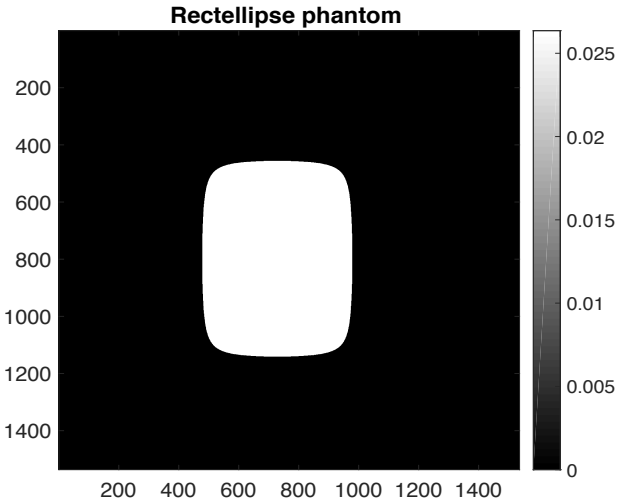
$$A\mu = -log\left(\frac{y - s}{I_0}\right)$$



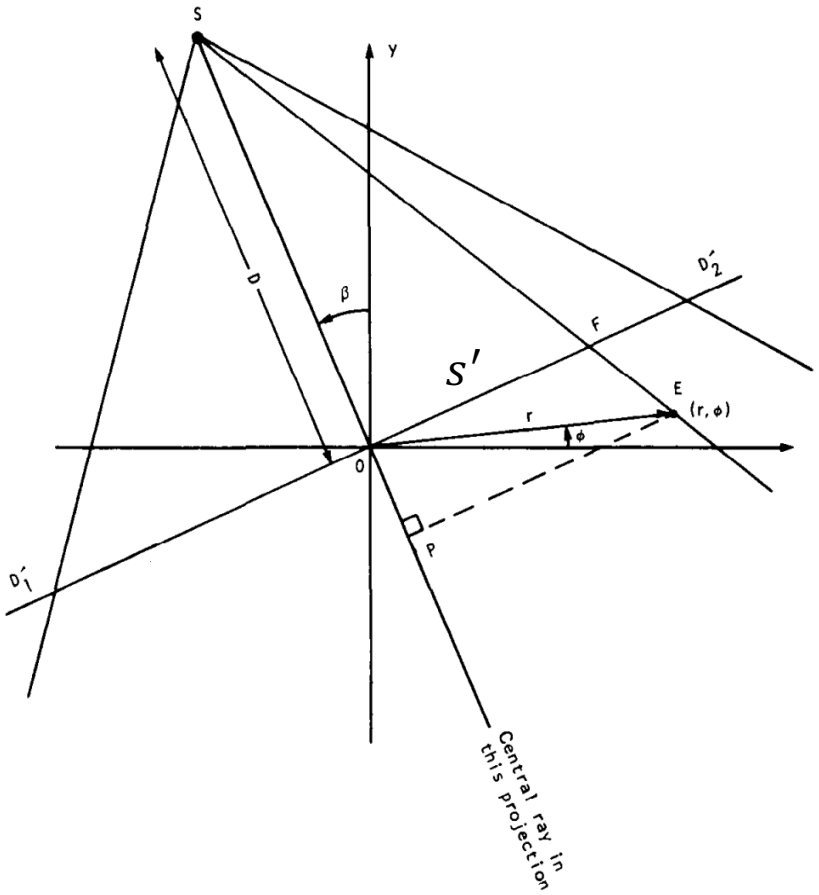
Forward Projector

- Take slice of projection at v_0 so we can assume fan-beam projection
- Initial phantom model with parameters $s, \mu, x_c, y_c, x_{width}, y_{width}$
- Calculate theta value at each pixel in image
- For each detector pixel, move backwards in image, summing up attenuation





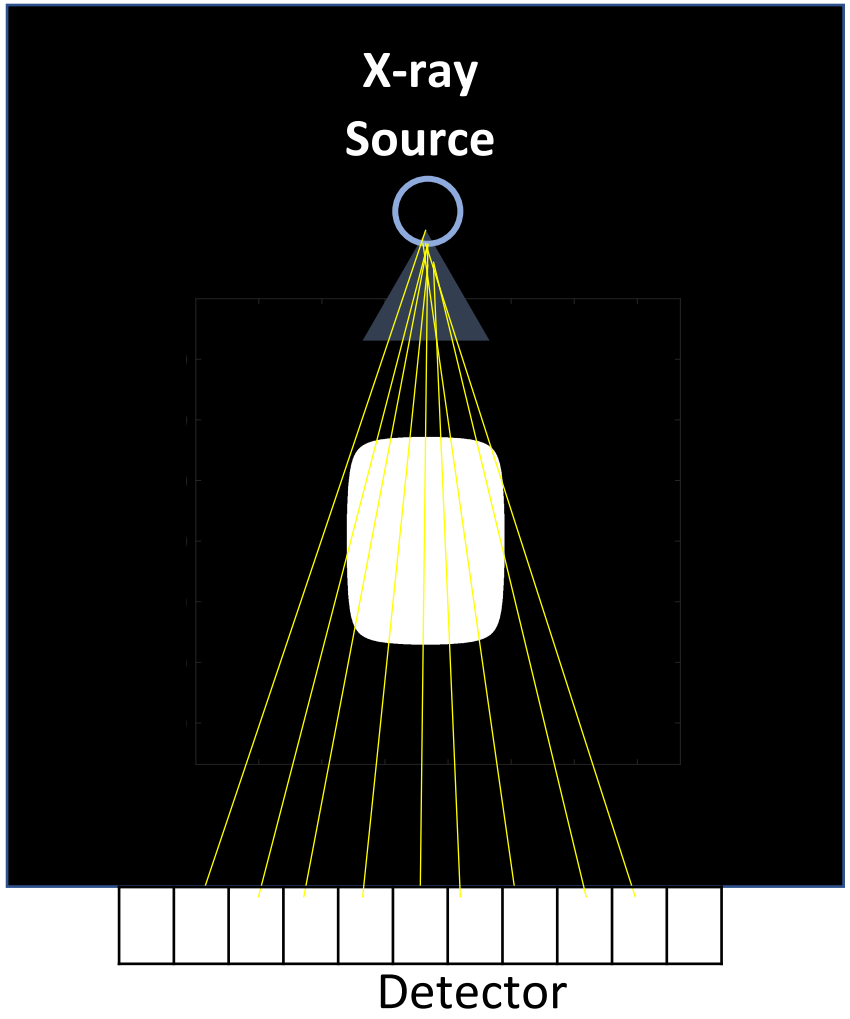
Forward Projector



$$s' = D\frac{rcos(\beta - \phi)}{D + rsin(\beta - \phi)}$$

$$\Theta = \tan^{-1}\left(\frac{s'}{D}\right)$$

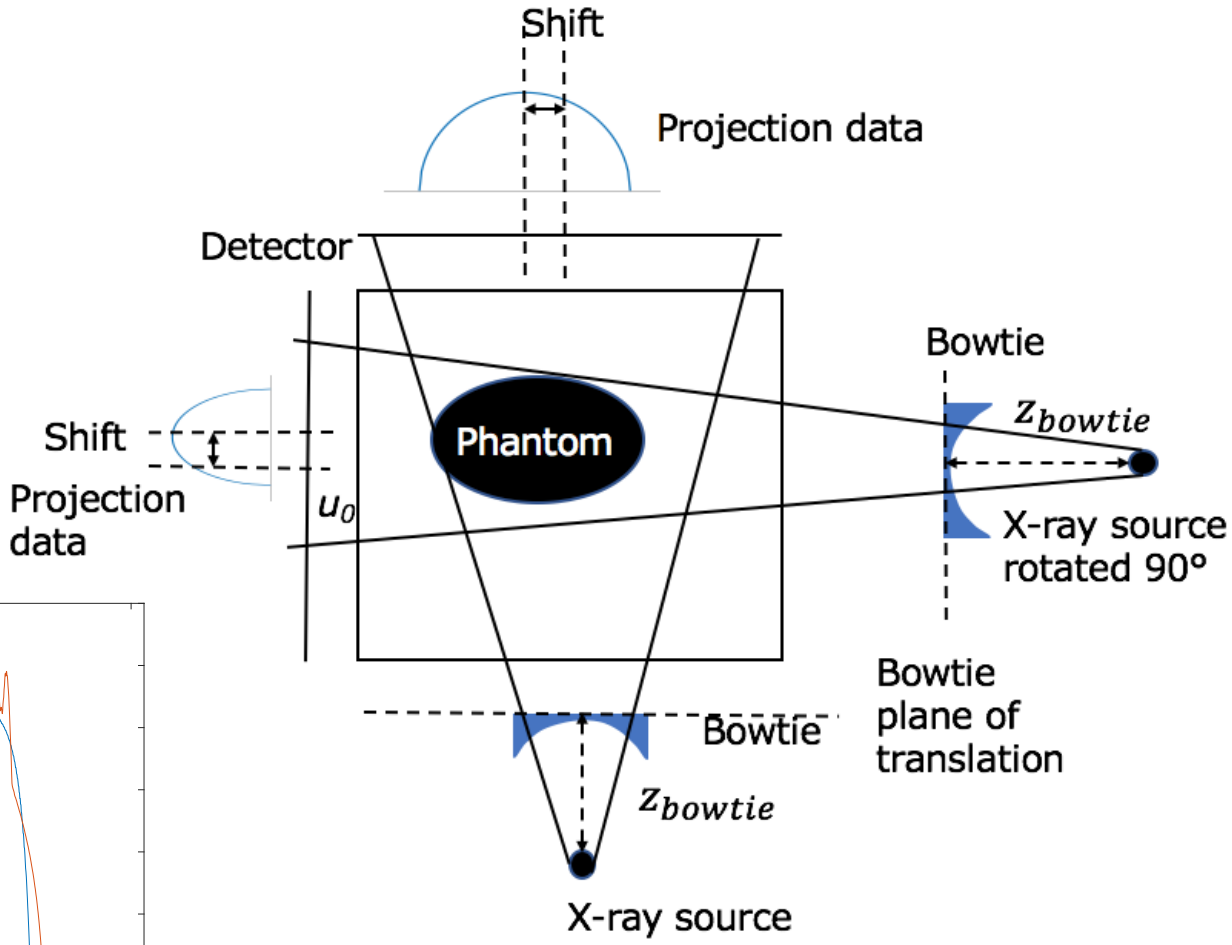
$$D = SAD$$



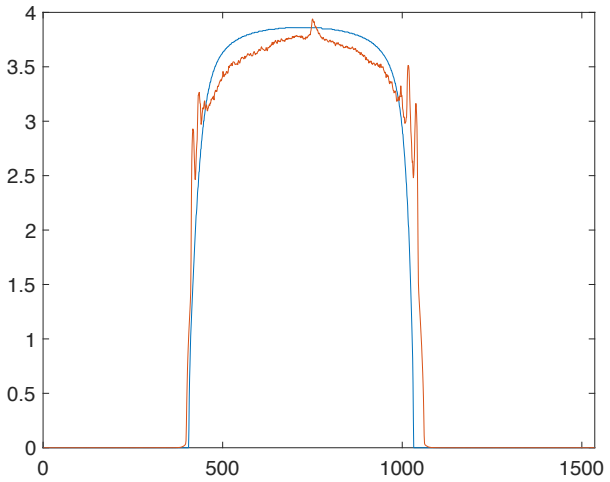
Kak & Slaney, Princ. of Comp. Tomographic Imaging, 1998

Step 2: Calibration

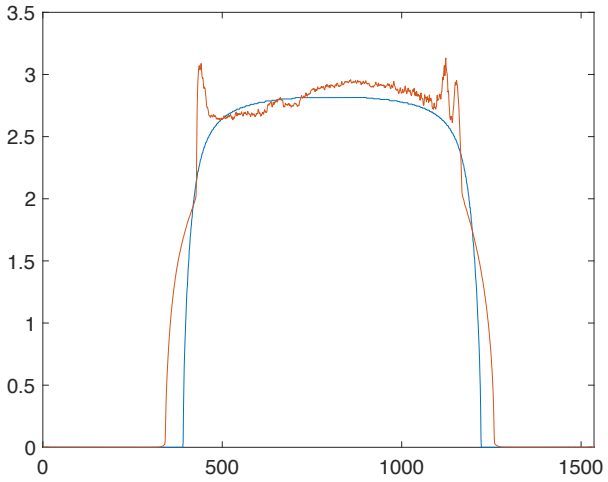
- $\arg\min_{\vec{x}} \|P\vec{x} - g\|^2$
- P is forward projection operator, g is the data, and $\vec{x}$ is the vector of phantom parameters



AP



Lat



Step 3: Filter Trajectory

STEP 3:
COMPUTE FILTER TRAJECTORY

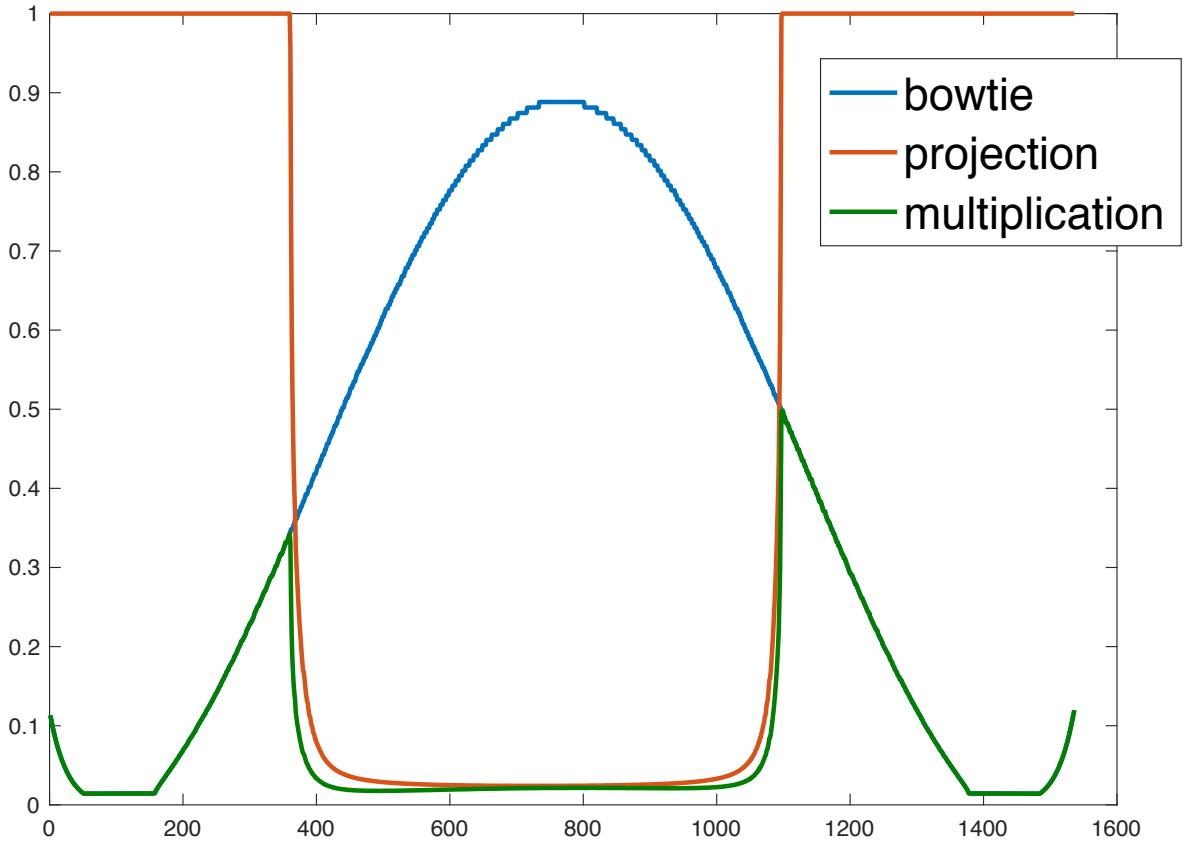
Approach 1:

Forward project filter model to give gain correction → Minimize variance of detector fluence at each projection

OR

Approach 2:

Calculate translation analytically to match bowtie center with object center



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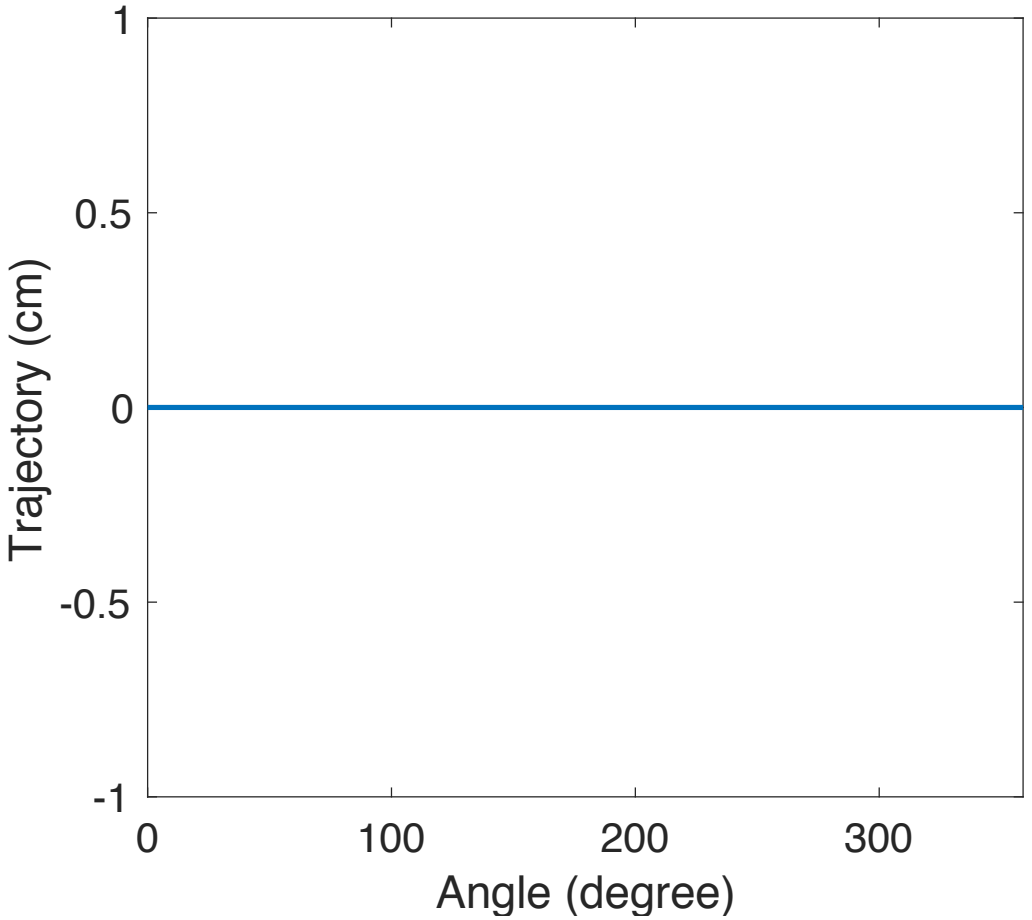

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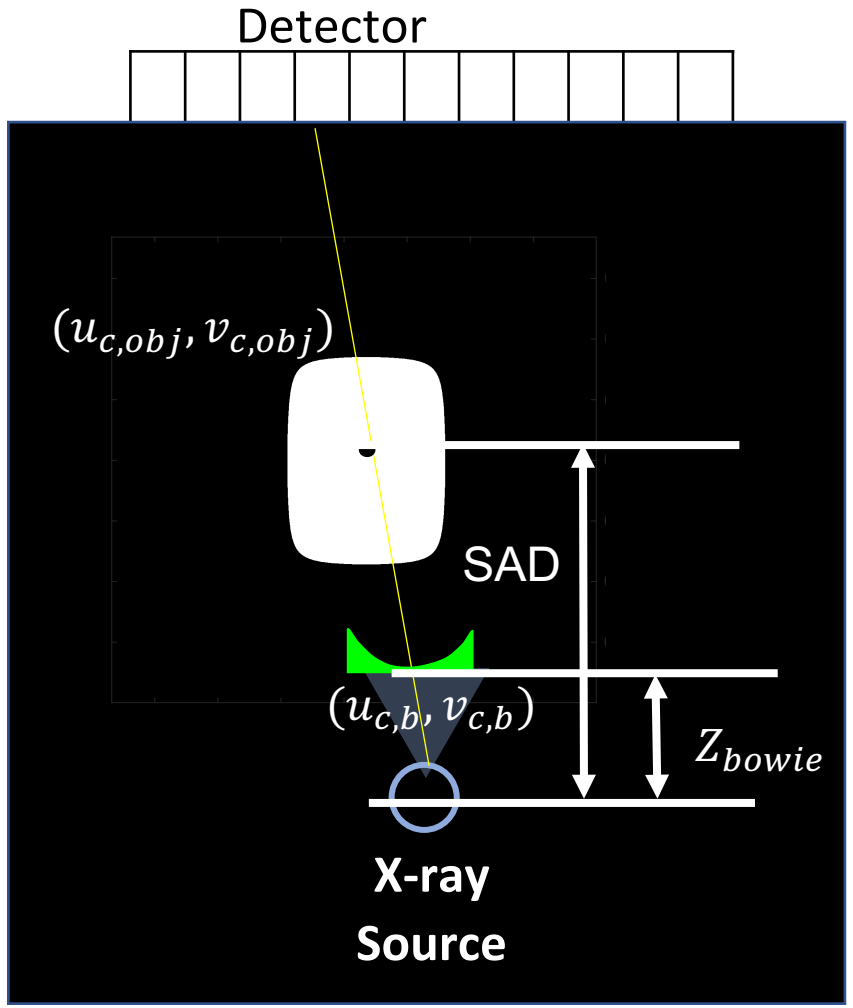

Compute Trajectory

STEP 3: COMPUTE FILTER TRAJECTORY
Approach 2:

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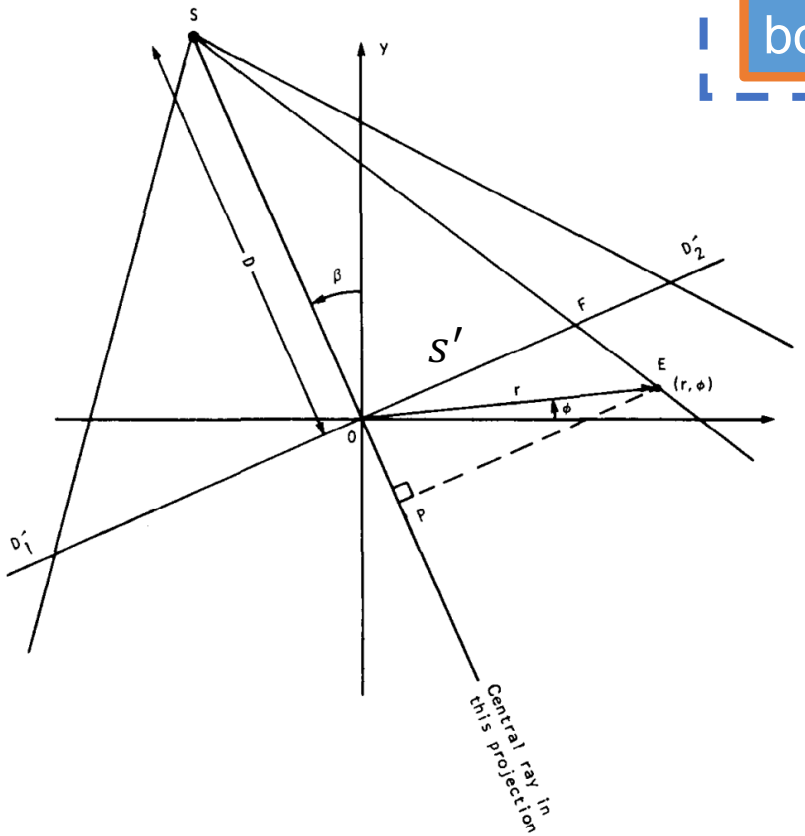
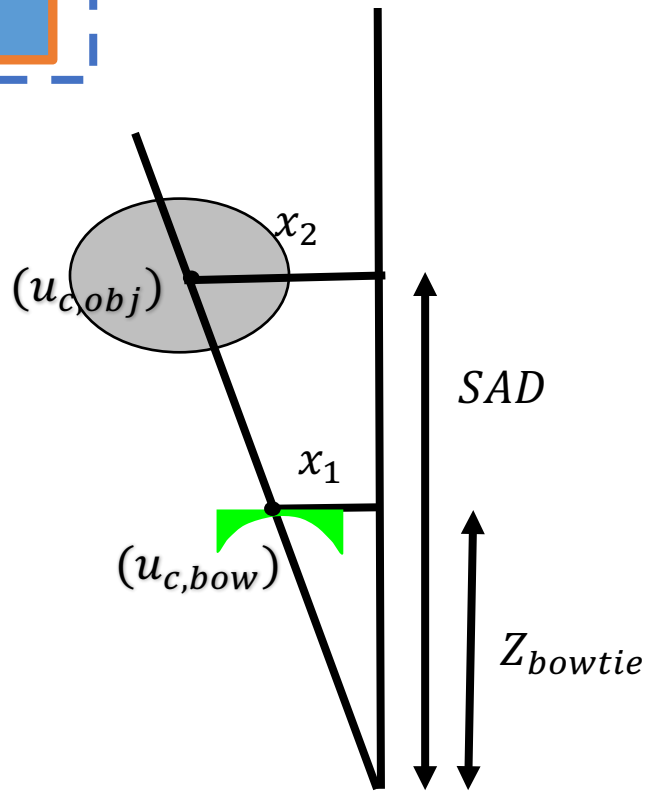


$$s' = D\frac{r\cos(\beta - \phi)}{D + r\sin(\beta - \phi)}$$

$$\frac{x_2}{SAD} = \frac{x_1}{z_{bowtie}}$$

$$x_2 = s'(u_{c,obj}, v_{c,obj})$$



Kak & Slaney, Princ. of Comp. Tomographic Imaging, 1998

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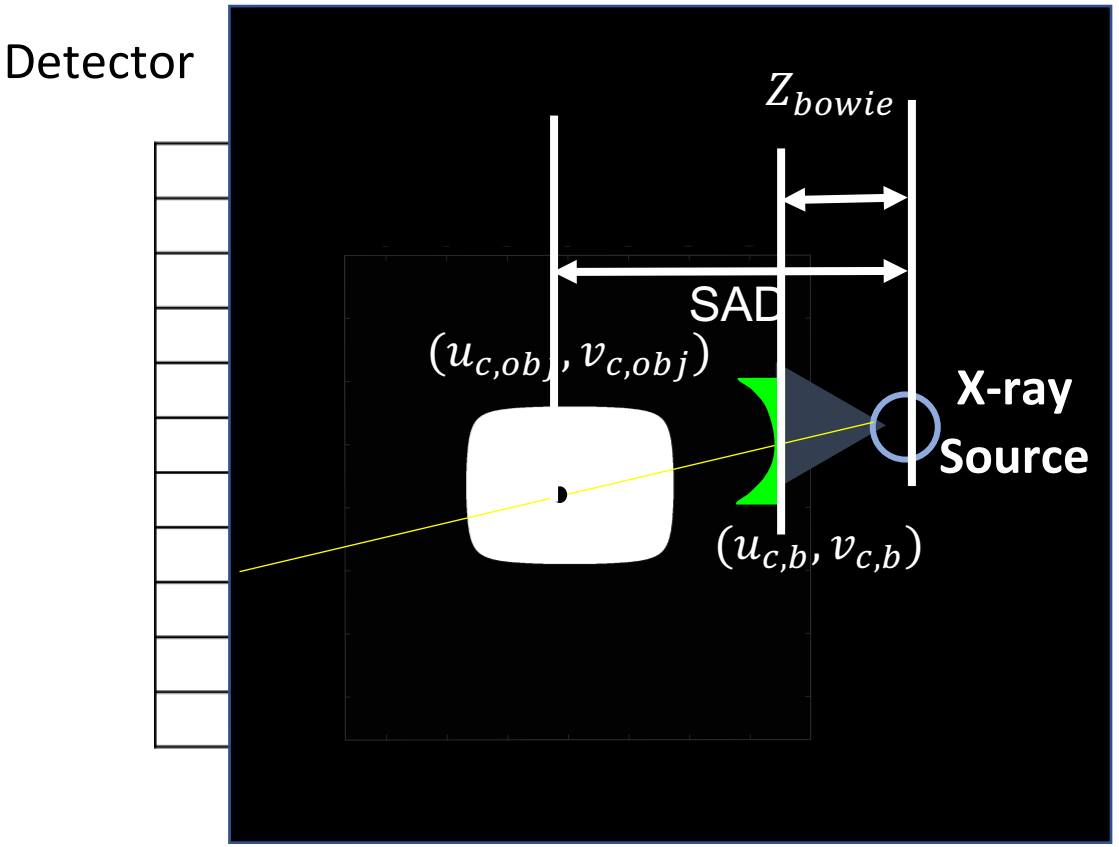

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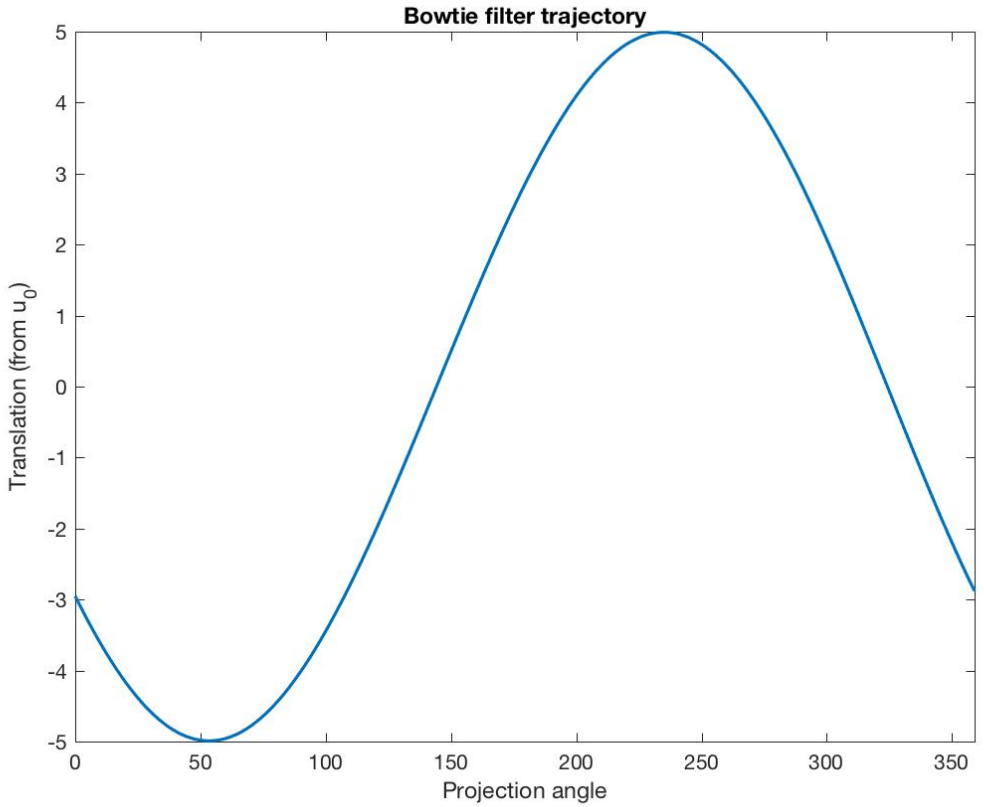
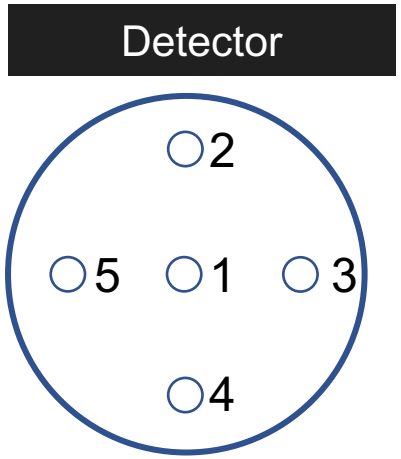


Experimental Details

- Dose measurements using the Computed tomography dose index (CDTI)
- Gas filled ionization chamber with dosimeter measures the accumulated dose (mGy) at each point in the phantom over 360° acquisition
- ~75 mGy for adult head CT
- 100 kV, 12.5 mAs, 2 mm Al + 0.2 mm Cu source filtration
- Aluminum bowtie



16cm diameter PMMA Plastic Cylinder

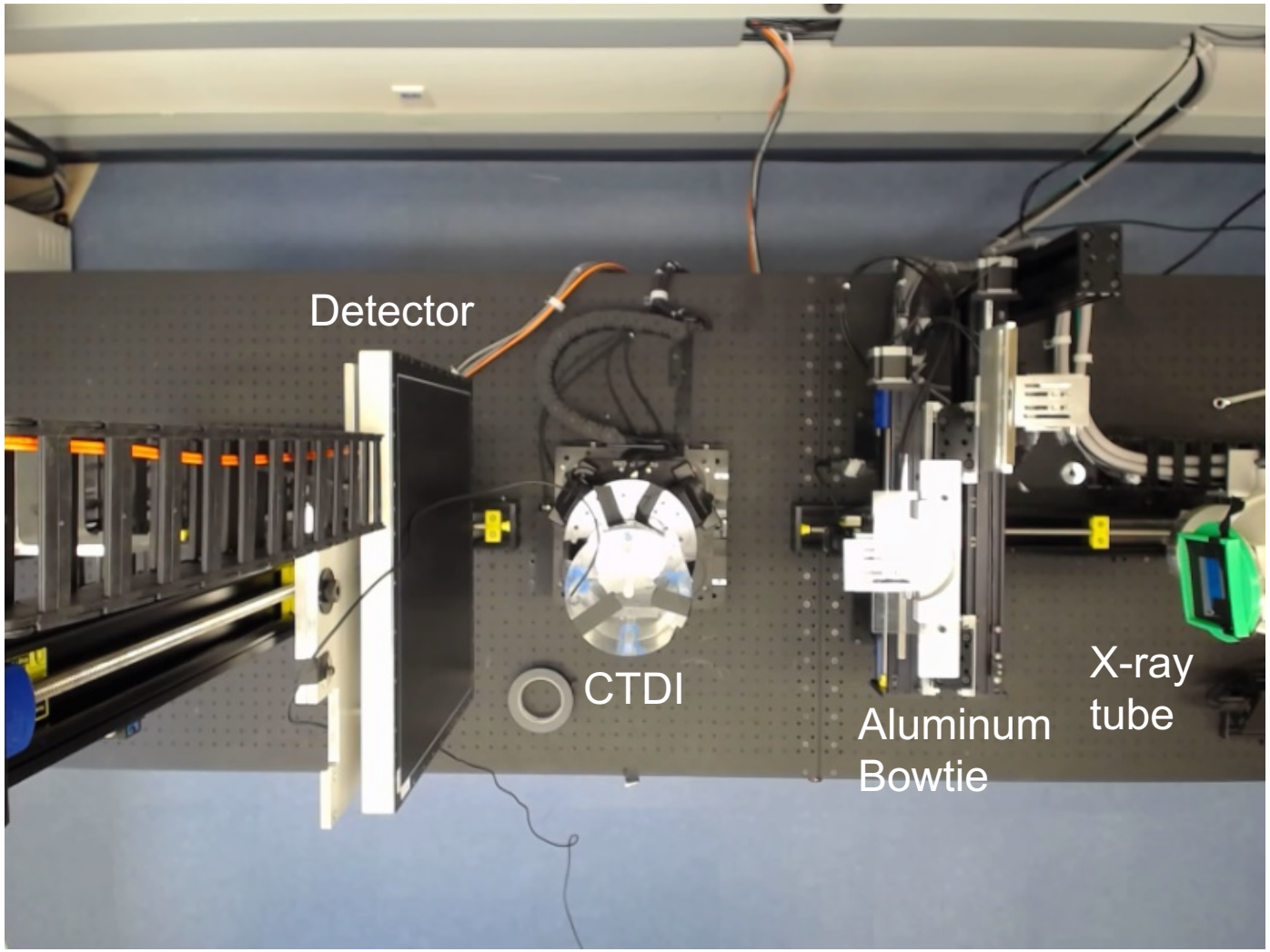
Gas ionization chamber

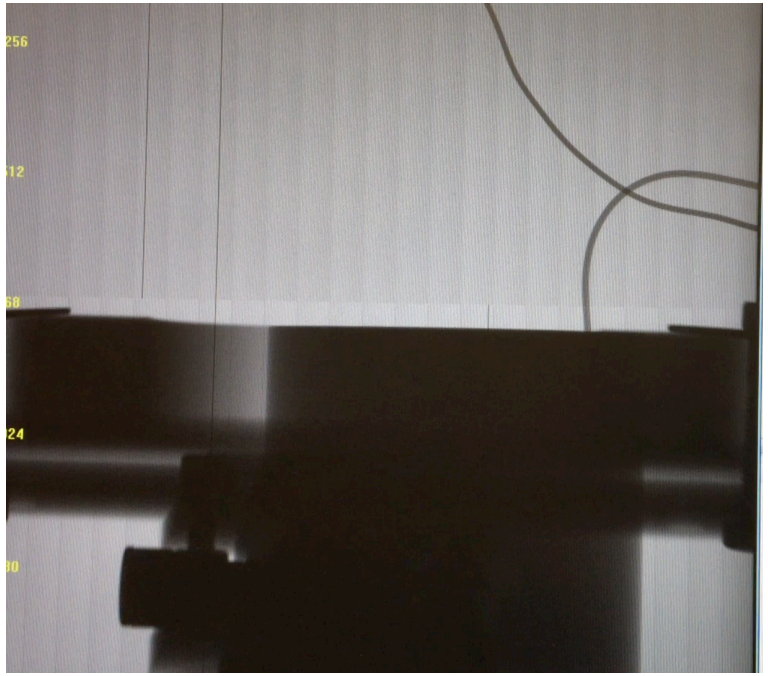
$$CTDI_w = \frac{1}{3}d_1 + \frac{2}{3}\frac{(d_2 + d_3 + d_4 + d_5)}{4}$$

$$d_i = dose\ at\ the\ ith\ hole$$

AAPM Report, CTDI Measurement, 2016

CBC Test Bench Setup





JOHNS HOPKINS BIOMEDICAL ENGINEERING

Dose Measurements

Off-center: 4cm, with bowtie	
Hole Number	Dose (mGy)
1	2.236
2	2.010
3	2.099
4	1.997
5	1.849
$CTDI_w$	2.071

Off-center: 4cm, without bowtie	
Hole Number	Dose (mGy)
1	7.475
2	8.643
3	8.875
4	9.310
5	8.995
$CTDI_w$	8.462

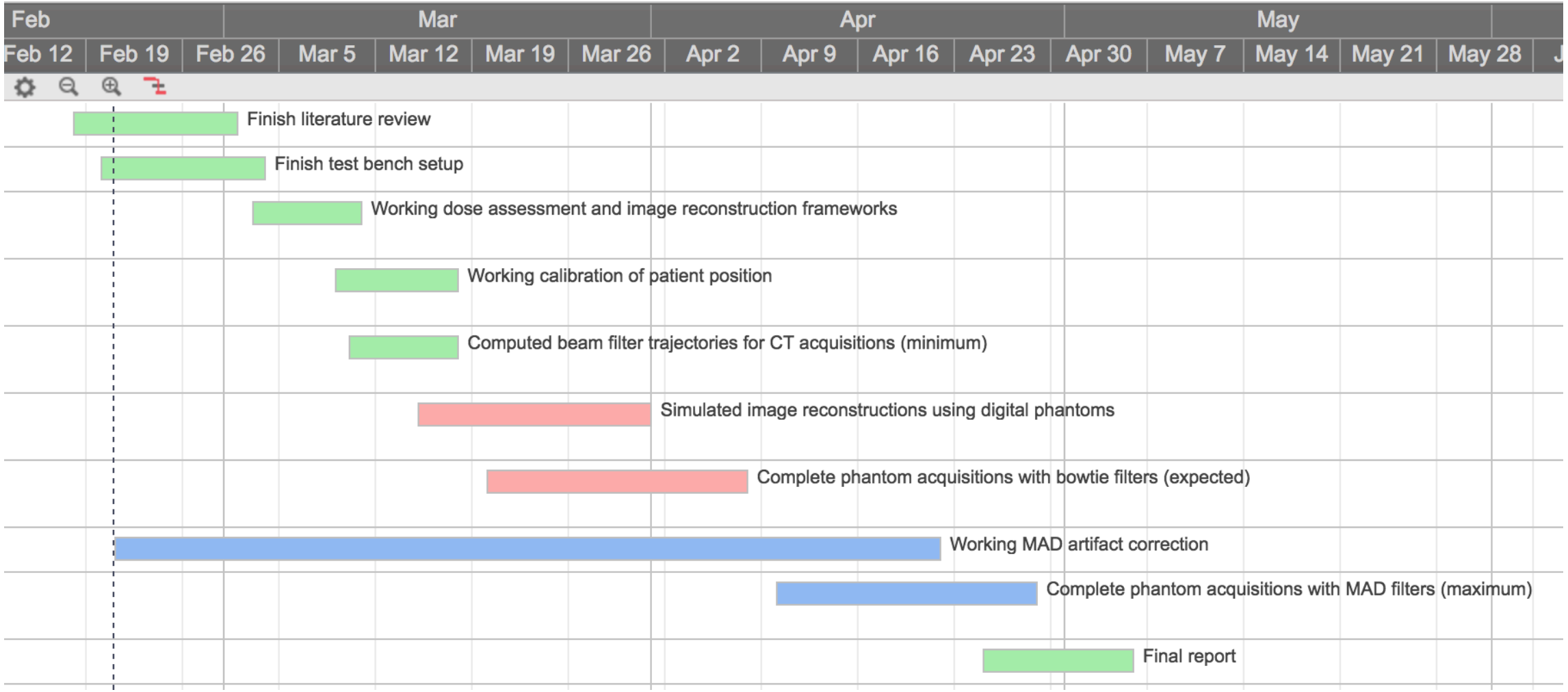
Centered with bowtie	
Hole Number	Dose (mGy)
1	2.370
2	1.975
3	2.014
4	2.148
5	1.893
$CTDI_w$	2.128

Off-center: 4cm, with bowtie translation	
Hole Number	Dose (mGy)
1	2.235
2	1.723
3	2.721
4	2.238
5	1.422
$CTDI_w$	2.096

Experimental Details

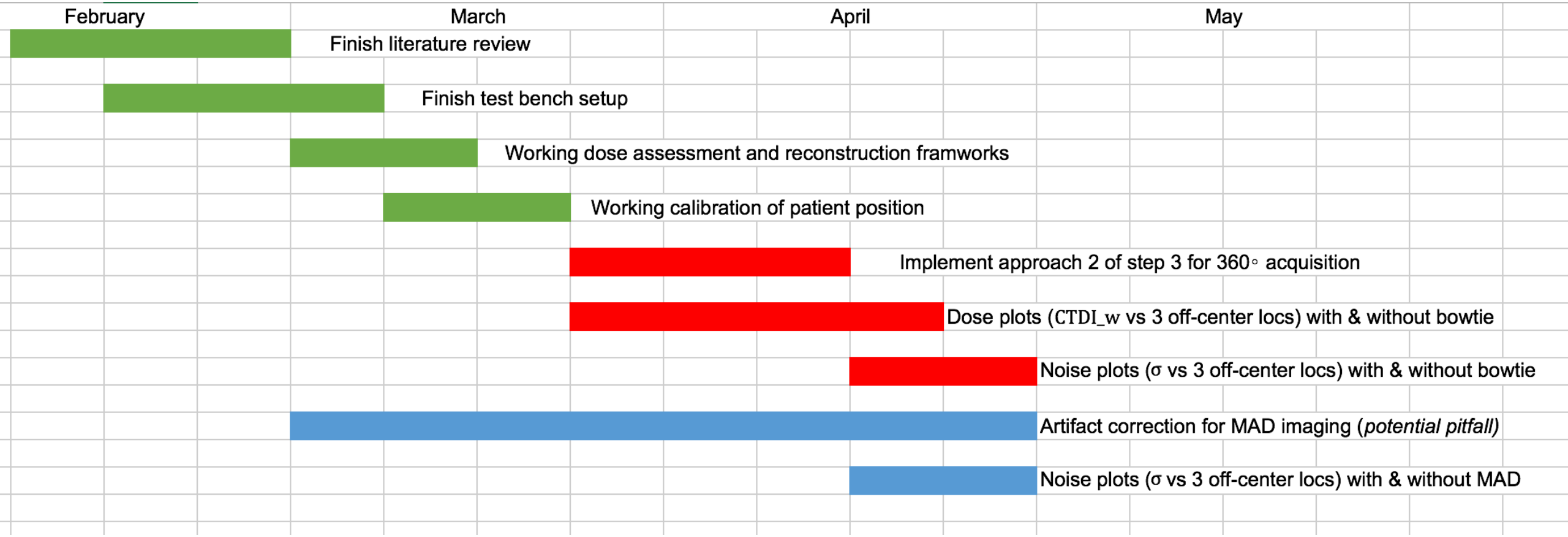
- Important differences from clinical CT measurements
  - no z-collimation
  - Bowtie not designed for cone-beam CT
  - object rotation vs gantry rotation
  - pulsed vs continuous x-ray source
  - Cone beam vs helical
  - No $CTDI_{vol}$, DLP, or effective dose values
- These differences mean we cannot rely on literature values, such as those from Toth et. al., Med. Phys., 2007

Timeline


Feb
Mar
Apr
May
Feb 12
Feb 19
Feb 26
Mar 5
Mar 12
Mar 19
Mar 26
Apr 2
Apr 9
Apr 16
Apr 23
Apr 30
May 7
May 14
May 21
May 28
Finish literature review
Finish test bench setup
Working dose assessment and image reconstruction frameworks
Working calibration of patient position
Computed beam filter trajectories for CT acquisitions (minimum)
Simulated image reconstructions using digital phantoms
Complete phantom acquisitions with bowtie filters (expected)
Working MAD artifact correction
Complete phantom acquisitions with MAD filters (maximum)
Final report

JOHNS HOPKINS
BIOMEDICAL ENGINEERING

Updated Timeline



Milestones

Date	Description
3/1/17	Finish literature review
3/3/17	Finish test bench setup
3/10/17	Working dose assessment and image reconstruction frameworks
3/17/17	Working calibration of patient position
3/17/17	Computed beam filter trajectories for CT acquisitions (**minimum**)
3/31/17	Simulated image reconstructions using digital phantoms
4/7/17	Complete phantom acquisitions with bowtie filters (**expected**)
4/21/17	Working MAD artifact correction
4/28/17	Complete phantom acquisitions with MAD filters (**maximum**)
5/5/17	Final report

Updated Milestones

Date	Description	Status
3/1/17	Finish literature review	✔
3/3/17	Finish test bench setup	✔
3/10/17	Working dose assessment and image reconstruction frameworks	✔
3/17/17	Working calibration of patient position	✔
3/17/17	Computed beam filter trajectories for CT acquisitions (**minimum**)	✔
4/14/17	Implement approach 2 of step 3 for 360° acquisition	In Progress
4/21/17	Dose plots ($CTDI_w$ vs 3 off-center locs) with & without bowtie	In Progress
4/21/17	Noise plots (σ vs 3 off-center locs) with & without bowtie (**expected**)	Not Started
4/25/17	Artifact correction for MAD imaging (*potential pitfall)*	In Progress
4/28/17	Noise plots (σ vs 3 off-center locs) with MAD (**maximum**)	Not Started

References

1. Toth, T., Ge, Z. and Daly, M. P. (2007), The influence of patient centering on CT dose and image noise. Med. Phys., 34: 3093–3101. doi:10.1118/1.2748113
2. A. C. Kak and Malcolm Slaney, Principles of Computerized Tomographic Imaging, IEEE Press, 1988.
3. "AAPM REPORT NO. 96 The Measurement, Reporting, and Management of Radiation Dose in CT" (PDF). AAPM. Retrieved 12 December 2016.