Standalone X-ray/Bioluminescence Imaging System: Design, Construction, and Calibration

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Outline

- Introduction
- Design and construction of a standalone system
- CBCT Imaging and calibration
- Implementation of the radiation shielding
- Results by verifying image quality with different phantoms
- Optimal Imaging*
- Conclusions and future works
Small Animal Radiation Research Platform

Detector panel
X-ray tube
Animal stage

Image guided focal irradiation
Design and Construction of a Standalone System

Integrated X-Ray/Bioluminescence Imaging (BLI) System

- 2 Rotary Stages
- Mirror Box
- Detector Panel
- X-Ray Source
- CCD Camera

Intro. | Des. | CBCT | Calib. | BLI | C. & F.W.

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Communication and Schematic Block Diagram

X-ray source (Kevex PXS10-65W)

Dexela CMOS 1512 detector panel

Encoder readings and execution commands

Motor stage

Control commands

Galil® Motion Controller

Camera Link

PC

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Communication and Schematic Block Diagram

<table>
<thead>
<tr>
<th>SDD (mm)</th>
<th>SAD (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>274</td>
<td>180</td>
</tr>
</tbody>
</table>

Dexela CMOS 1512 Detector panel

Encoder readings and execution commands

Motor stage

Control commands

Galil® Motion Controller

PC

Camera Link

Intro.  Des.  CBCT  Calib.  BLI  C. & F.W.
X-ray/BLI System Configuration

CCD Camera
Galil Controller

3 first surface mirrors
Radiation Survey Results before installing shielding

Setup: 65 kVp, 110 μA (normal mouse imaging setup)

Max leakage:
Left → close to the frame 3 mR/h

Background 10 μR/h
Implementation of the Radiation Shielding

Front (toward the detector)

<table>
<thead>
<tr>
<th>Location</th>
<th>Radiation Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front</td>
<td>0.23 mR/h</td>
</tr>
<tr>
<td>46 µR/h</td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>30 µR/h</td>
</tr>
<tr>
<td>Top</td>
<td>33 µR/h</td>
</tr>
<tr>
<td>Right</td>
<td>0.86 mR/h</td>
</tr>
<tr>
<td>20 µR/h</td>
<td></td>
</tr>
<tr>
<td>Back</td>
<td>41 µR/h</td>
</tr>
<tr>
<td>12 µR/h</td>
<td></td>
</tr>
</tbody>
</table>
Intro. Des. CBCT Calib. BLI C. & F.W.
Principle of Cone Beam Computed Tomography (CBCT)

- **Axis of rotation**
- **Step by step rotation (1°) from 0° to 360°**
- **Detector Panel**
- **X-Ray**
- **X-Ray source**

**Intro.**
**Des.**
**CBCT**
**Calib.**
**BLI**
**C. & F.W.**
CBCT Imaging System Calibration

Image setup: 65 kVp; 110 uA; 100 ms; Binning 1x1

Dark Current: acquired 10 images and average

Flood: acquired 10 images and average

CBCT calibration: Used different phantoms
Dark Current and Flood Field Correction

Dark Current

Flood Correction
In-plane trace of 7 BBs
Note that BB7 was out of plane at some angles. So it’s not used in calibration.
Compare two Scintillator Screens (150um Gd and 600um CsI)

150um screen

Wire with 0.24mm diameter

600um screen

FWHM = 0.25mm

Pixel intensity

Pixel number

150um

600um

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150um, No filter  150um, 1mm Al filter

Resolution of 0.1mm can be achieved
600um, No filter

600um, 1mm Al filter

Still can differentiate 0.1mm pairs but worse than 150um panel.
Resolution phantom at highest resolution: 50um at iso-center
4-rod contrast phantom 150um Gd screen

Beam Hardening Effect for high density material
Contrast phantom 600um CsI screen

coronal  
sagittal

axial
Profiles along the long axis

The 600um CsI screen has more flat profile along the long axis
Profiles along the short axis

The 600um CsI screen has better contrast for very high density material
Conclusions for the comparison of two screens

- For image resolution above 100um, using 600um CsI screen achieve better sensitivity, uniformity, and contrast. Setup: 65kVp, 110uA, 160ms exposure and 1mm Al filter. (0.018mAs)

- For image resolution below 100um, using 150um Gd screen due to its superior resolution. It can achieve minimal of 50um at the isocenter. It needs more projections to improve signal-to-noise ratio. Setup: 65kVp, 110uA, 400ms exposure and 1mm Al filter. (0.044mAs)
Online image acquisition procedure

Image resolution: 1944 x 1536
Pixel size: 74.8 um
Panel frame rate (1x1 binning): 27 Hz

1. Pick the sequence exposure
2. Choose chunk size
3. Select no. of exposures (1 < n < 65536)
4. Choose a binning mode: (1x1 to 4x4)
5. Choose a full well mode: (low/high)
6. Select the desired exposure time: (38 ms)
7. How to save data: *.tiff / *.raw

Connect to detector

Is m < n?

Yes

Unscramble and save data onto the hard drive

Stop image acquisition

Start reading images (m = m+1)

No

Start
Integrating and synchronizing detector panel and stage motion

Standalone System

<table>
<thead>
<tr>
<th>Functionality</th>
<th>1x1 binning</th>
<th>2x2 binning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>T &lt; 6 min</td>
<td>T &lt; 54 s</td>
</tr>
<tr>
<td></td>
<td>Discrete imaging</td>
<td>T &lt; 40 s</td>
</tr>
<tr>
<td></td>
<td></td>
<td>T &lt; 18 s</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Continuous imaging</td>
</tr>
</tbody>
</table>

SARRP (1x1 binning): T = 90 s
Optical Imaging

- Bioluminescence is emitted when chemical energy is converted to light (450-650nm)
  \[\text{ATP} + \text{Luciferin} + \text{O}_2 \xrightarrow{\text{Luciferase}} \text{Oxyluciferin} + \text{AMP} + \text{CO}_2 + \text{Light}\]

- Fluorescence is emitted by fluorophores when excited with laser (400-900nm)


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**Optical Imaging Workflow**

**Cone Beam x-ray CT (CBCT)**
- provides anatomical and surface contour information
- segment into tissue types with different scattering and absorption characteristics

**Diffuse Optical Tomography (DOT)**
- reconstruct tissue optical properties

**Bioluminescence Tomography (BLT)**
- reconstruct bioluminescence/fluorescence labeled cells using optical properties recovered from DOT measurements

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Optical Tomography System

Mirror assembly rotates 90°

Stage 1

Stage 2

First surface mirrors (#3)

Optical path

CCD Camera

Laser

White light lamp

Filter wheel

Motorized Mirror system

X-ray source

a:Si det.

Filter wheel

1x9, fiber optical switch

Optical fiber cables

CCD

Intro.  Des.  CBCT  Calib.  BLI  C. & F.W.

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Flat-Field Correction

Integrating sphere

Light source

CCD camera

10x10cm

Correction factor vs. Pixel number

- 590nm
- 610nm
- 630nm
- 650nm
- 830nm

Intro.  Des.  CBCT  Calib.  BLI  C. & F.W.
Absolute Calibration

![Graph showing powermeter measurement vs. ccd fluence for different wavelengths (590nm, 610nm, 630nm, 650nm).](image)
Bioluminescence Light Sources

Orange color

Intensity (AU)

Wavelength (nm)

400 500 600 700 800
Tissue-simulated Phantom – Half Cylinder

Cover

Hole: 2 mm dia. x 3 mm in distance
Phantom: 41 mm x 30 mm

Locked pin location
Bioluminescence Images

Photograph

Overlay with BLI
Physically Registered Images

BLT

Light intensity (nW/mm$^3$)

distance along x axis (mm)

T

CBCT

Light intensity (nW/mm$^3$)

distance along x axis (mm)

T

BLT

Light intensity (nW/mm$^3$)

distance along y axis (mm)

S

Low

High

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Conclusions

- Designed and constructed a standalone X-ray/BLI system.
- Detector panel was integrated with the animal rotating stage.
- CBCT and camera calibrations were carried out.
- Implementation of the radiation shielding was done.
- Tested image resolution, contrast of different scintillator screens.
- Improved optical tomography system.
Future Works

- Performing 4D CBCT.
- Integration of projection acquisition and image reconstruction modules.
- Installing optical switch and develop software for optical switch control.
- Performing DOT imaging.
- Acquire BLT projection data.
- Design and install the image guidance on-board SARRP.
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