Intraoperative Registration of Pathology for Adjuvant Postoperative Radiotherapy

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Project #4

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Mentors

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Overview

- Pre-Operative CT Scan
- Remove a Piece of Pig Tongue
- Insert Markers on Tongue
- Register Polaris Points of Markers
- CT Scan
- Close Surgical Wound
- CT Scan

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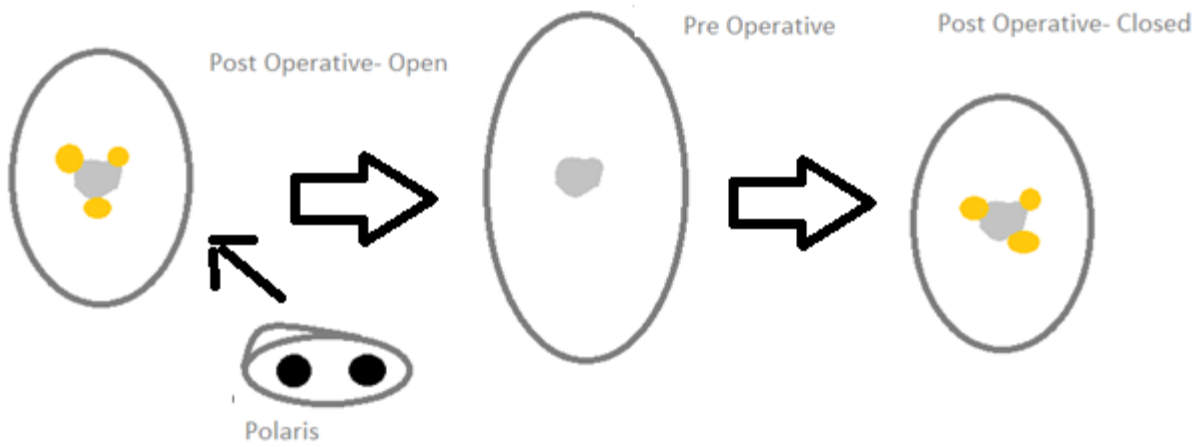
Overview



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Large Deformation Three-Dimensional Image Registration in Image-Guided Radiation Therapy

Journal of Physics in Medicine and Biology

Mark Foskey, Brad Davis, Lav Goyal, Sha Chang, Ed Chaney, Nathalie Strehl, Sandrine Tomei, Julian Rosenman, and Sarang Joshi

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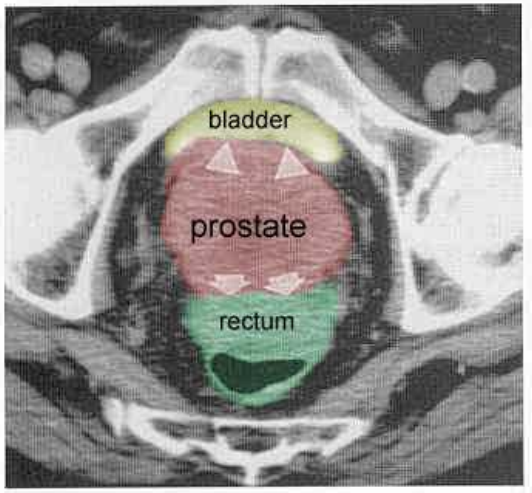
Abstract

- CT Image of the Prostate
- Deformable Registration Algorithm between Planning Scan and Treatment Scan



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Introduction

- Radiotherapy can be delivered in high doses to a localized region
- Critical any organ movement be monitored
- Traditionally, organ movement is assumed to be uniform

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Introduction

- Organ movement is not uniform as organs are not rigid
- Changes in Bladder Size
- Gas in the Rectum

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Introduction

- Organ Movement can be monitored by the difference in two CT scans

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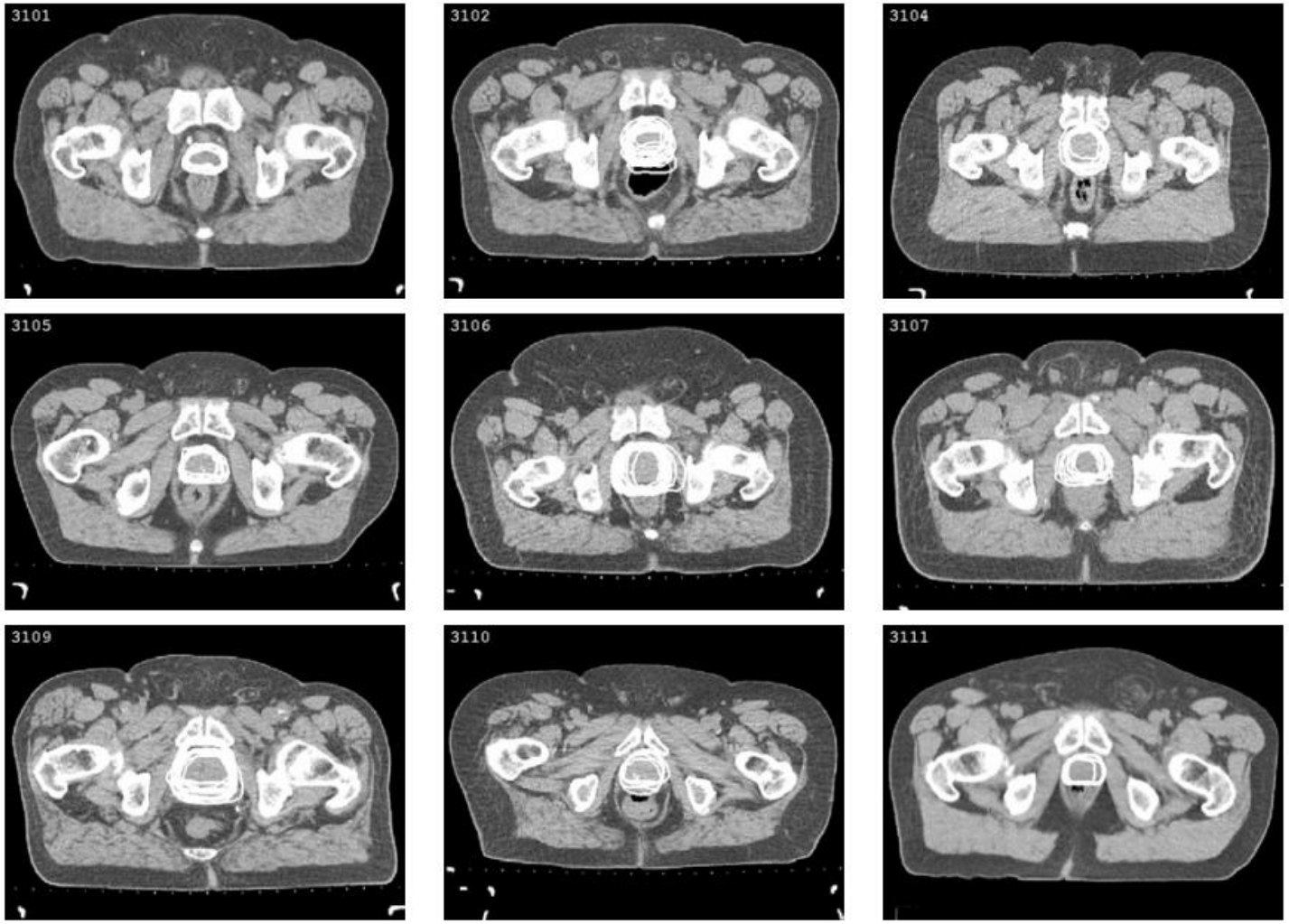

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Introduction

- Tongue is not Rigid
- Removal of Part of the Tongue will remove one-to-one point correspondences

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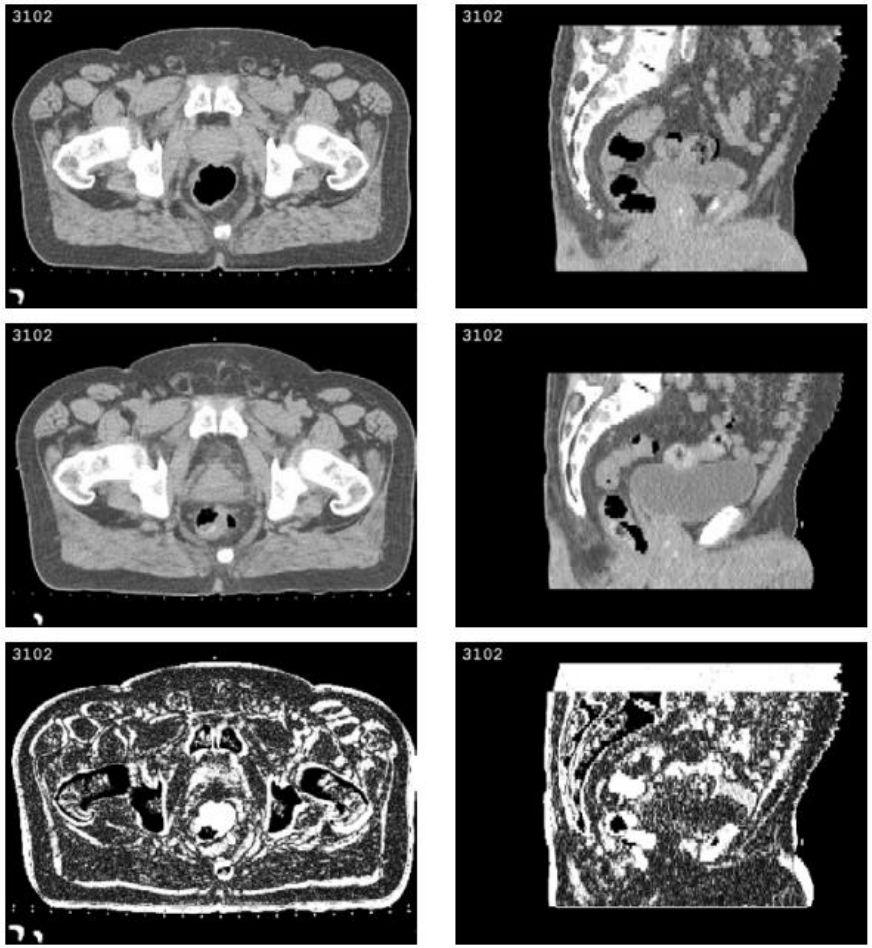

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Deformable Image Registration

- *Minimize Energy Term*

- $E(h) = \int_V \left(I_p(x) - I_T\left(h(x)\right)\right)^2 dx$

- $I_p is\ the\ intensity\ of\ a\ voxel\ in\ the\ planning\ image$
- $I_T is\ the\ intensity\ of\ a\ voxel\ in\ the\ treatment\ image$
- $h\colon V \rightarrow V$
- $maps\ a\ voxel\ in\ the\ planning\ image\ to\ the\ treatment\ image$

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Rigid Motion

- *In the case of Rigid Motion:*
- $h(x) = x + \tau$

- So the energy term reduces to:
- $E(\tau) = \int_V \left(I_p(x) - I_T(x+\tau)\right)^2 dx$

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Rigid Motion

- Using a method developed in :
- Structural and radiometric asymmetry in brain images (2003)
- Med. Imaging Analysis
- Joshi S, Lorenzen P, Gerig G and Bullitt E
- $E(\tau) = \int_V \left(I_p(x) - I_T(x+\tau)\right)^2 dx$

Rigid Motion

- $Let\ \tau_{k+1} = \tau_k + \Delta\tau_k\ and\ x' = x + \tau_k$
- $I_T(x + \tau_{k+1}) = I_T(x' + \Delta\tau_k)$
- First Order Taylor Series About x'
- $E(\tau_{k+1}) \approx \int_V (I_P(x) - I_T(x') + \nabla I_T(x') \cdot \Delta\tau_k)^2 dx$
- $\Delta\tau_k$ that minimizes $E(\tau_{k+1})$
- $\Delta\tau_k =$

$$\left(\int_V \nabla I_T(x')\nabla I_T(x')^T dx\right)^{-1} \int_V \left(I_p(x) - I_T(x'))\ \nabla\ I_T(x')\right)dx$$

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Rigid Motion

- Now suppose h depends on more than just τ
- *A parameter vector a, and x*
- $h = h_a(x)$
- $\Delta a_k =$
  $\left(\int_V \nabla_a I_T(h_a(x)) \nabla_a I_T(h_a(x))^T dx\right)^{-1} \int_V \left(I_p(x) - I_T(h_a(x))\right) \nabla_a I_T(h_a(x))\big) dx$

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Rigid Motion

- Affine: Translation, Rotation, Scaling and Shearing
- In the case where $h(x) = Ax + \tau$
- $a = [A_{11}\, A_{12} \ldots A_{32}\, A_{33}\, \tau_1\, \tau_2\, \tau_3]^T$
- $X =$

$$\begin{bmatrix} x_1 & x_2 & x_3 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & x_1 & x_2 & x_3 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & x_1 & x_2 & x_3 & 0 & 0 & 1 \end{bmatrix}$$

- $Ax + \tau = Xa$
- $\nabla_a I_T(h_a(x)) = (\nabla I_T \Big|_{h_a(x)})^T X$

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Deformation

- $E(h) = \int_V \left(I_p(x) - I_T\left(h(x,t)\right)\right)^2 dx + E_{reg}(h)$
- $h(x,t) = x + \int_0^t v(h(x,s),s)ds$
- $E_{reg}(h) = \int_{V,t} \left|\left|L_{reg} v(x,t)\right|\right|^2 dxdt$

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Deformation

- $Lv = \propto \nabla^2 v + \beta \nabla(\nabla \cdot v) + \gamma v$
- Motivated by Navier-Stokes

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Deformation

- Optimized using methods developed in
- Miller et al (2002)
- Beg et al (2005)

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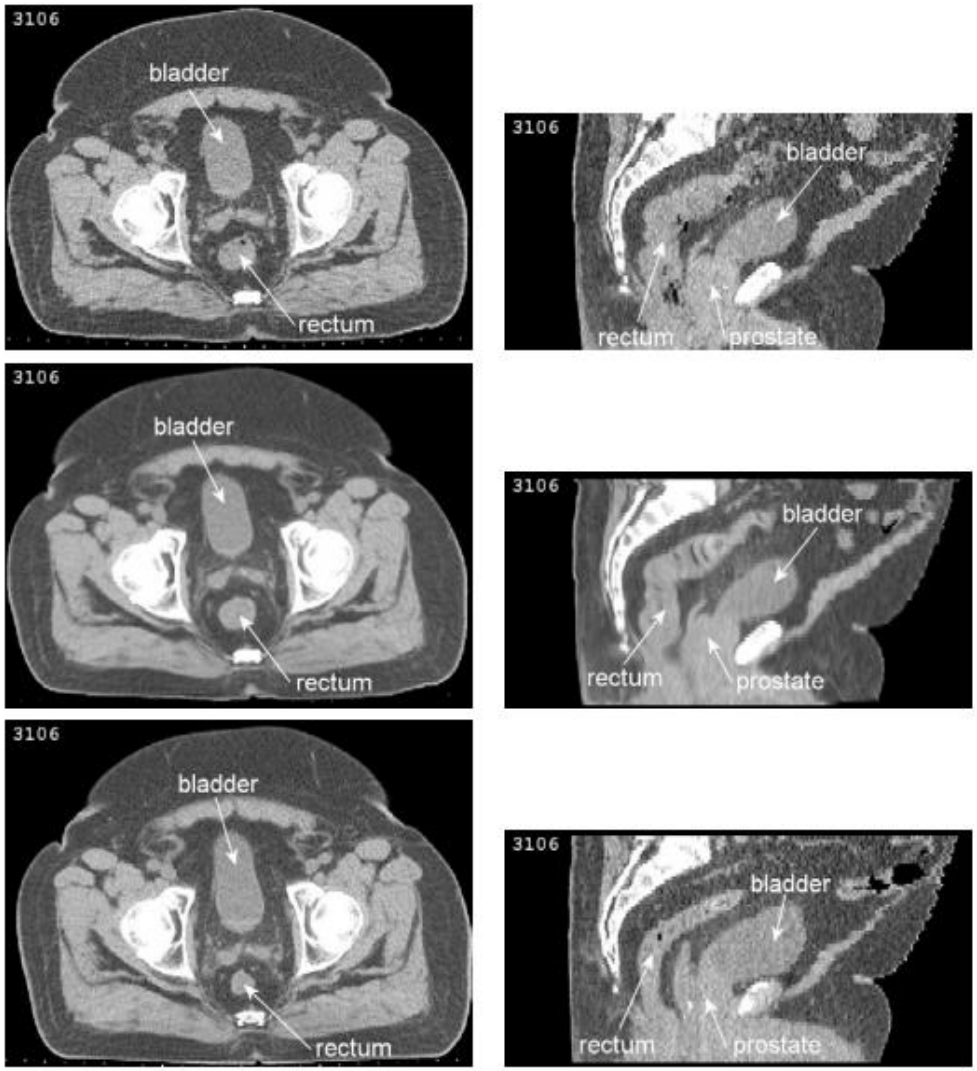

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Bowel Gas

- Bowel Gas will appear in some CT scans causing deformation in the image
- Resolved by ‘Deflation’
- Threshold image
- Image force is given by the gradient of intensity, thus causing bubbles to shrink towards the center.
- Not Tissue Motion Because it Disappears

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Bowel Gas

- Similar to Tissue removal?

Photo Credit: Dr. Junghoon Lee

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Composite Transformation

- Rigid Transformation
- Deflation
- Deformable Registration

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Segmentation

- If original planning image is segmented, subsequent treatment images can automatically be segmented using the registration technique

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Results

- Due to inherent differences that exist between human raters, the authors compared the difference between a manual segmentation and the automatic segmentation and between to manual segmentations
- They found there was no significant difference in the two variations

Analysis

- Pelvic Organ Motion vs Tongue Motion

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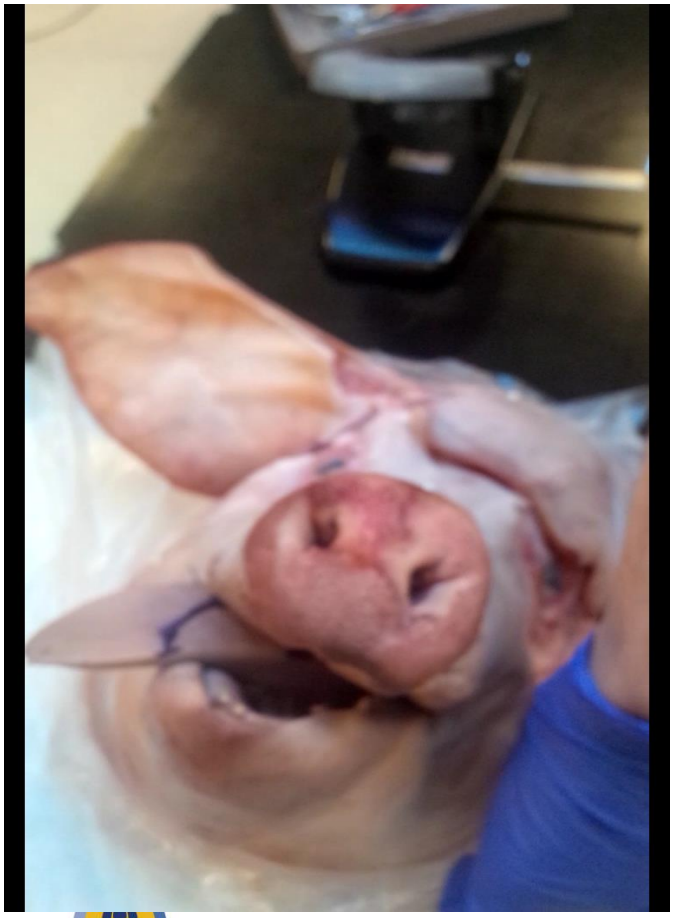
Analysis

- Tongue Mass change vs change in gas deformation



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Criticism

- $E(h) = \int_V \left(I_p(x) - I_T\left(h(x)\right)\right)^2 dx$
- Why not

$$E(h) = \int_V \left(I_p(x) - cI_T\left(h(x)\right)\right)^2 dx$$

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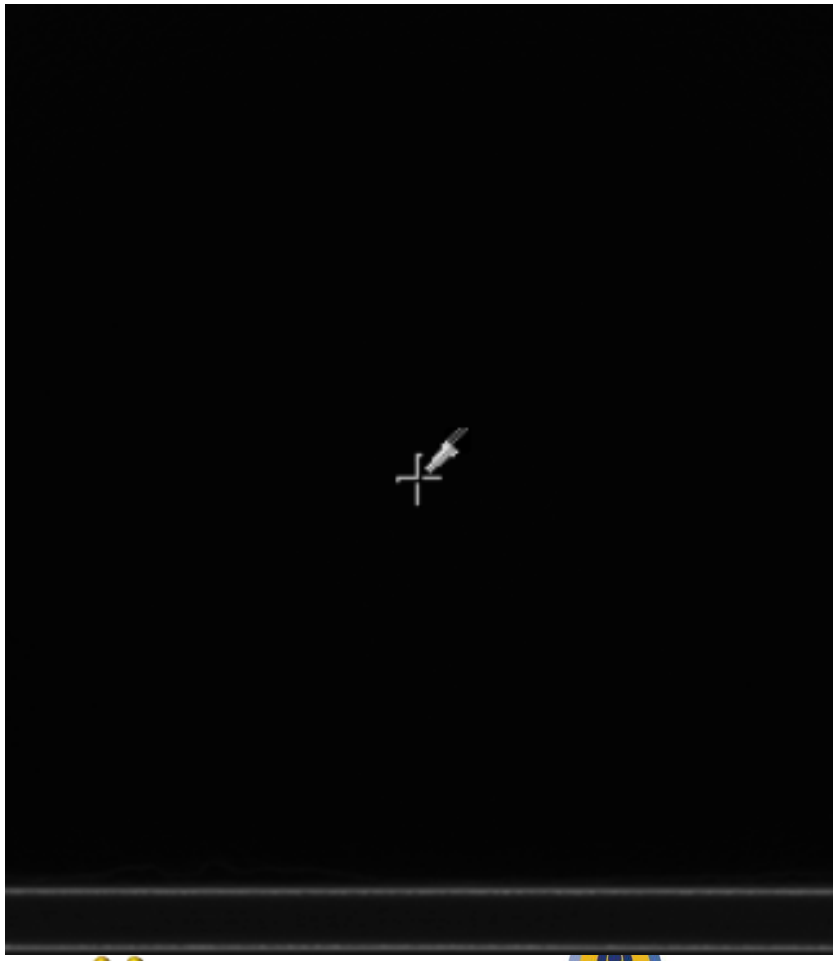
Criticism



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Thank you!

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