Cross Modality Medical Image Synthesis and Registration through Machine Learning

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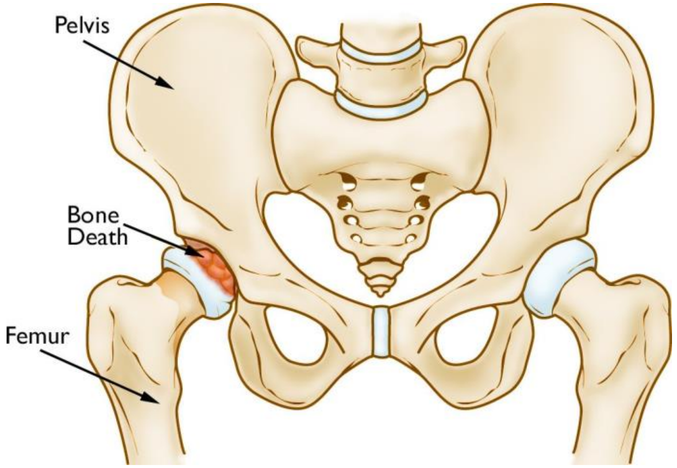
Background – Osteonecrosis of the Hip

- Cause
  - Osteonecrosis occurs when blood supply to the femoral head is disrupted and the bone in the head of the femur dies and gradually collapses.
- Surgical treatments
  - Core Decompression – Drilling several holes into the femoral head to relieve pressure in the bone and create channels for new blood vessels to nourish the affected areas of the hip



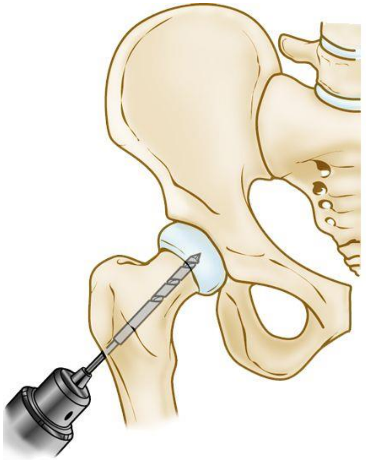


Image source (Left and right image): [1] orthoinfo - aaos. Retrieved February 16, 2021

Background – Surgical Procedure

- Core decompression is a commonly used surgical method for the removal of the ostenecrotic tissue (dead bone) from the femoral head.
- X-rays provides images of dense structures (like bones) and intraoperative x-ray shots are taken to monitor the surgical procedure.
- Early hip osteonecrosis can be detected on an x-ray. To remove necrotic tissue in the femoral head, surgeons also rely on preoperative MR scans for tool trajectory planning.

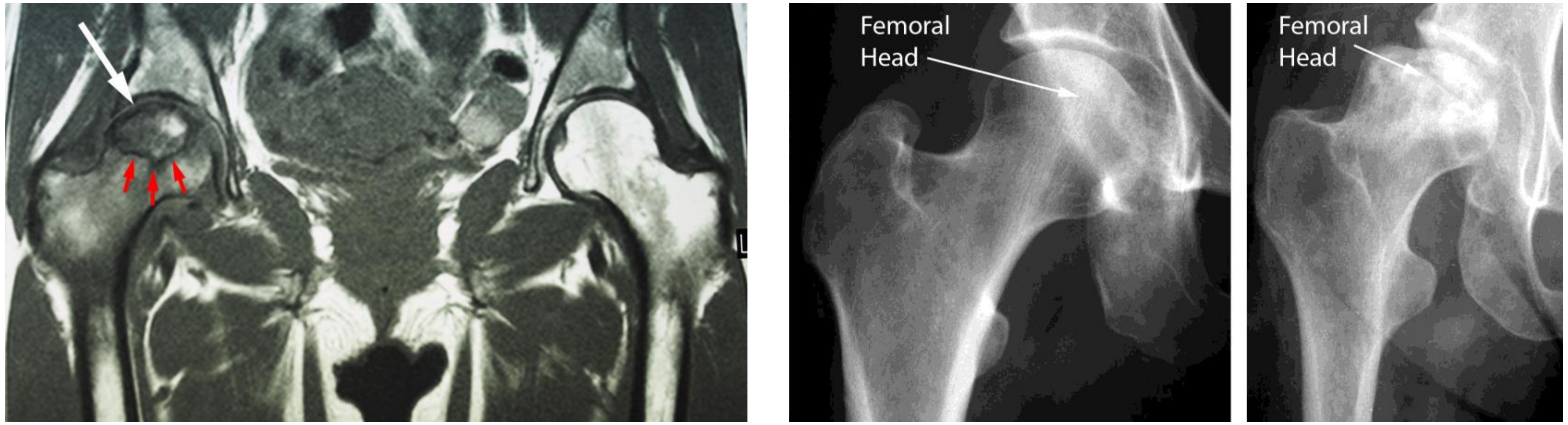


Image source (Left and right image): [1] orthoinfo - aaos. (n.d.). Retrieved February 16, 2021

Problem Statement

- We would like to convert the annotations of segmentation of the necrotic tissues and the drill insertion paths from preoperative MR images to intraoperative x-rays would be helpful for surgeons.
- Radiographs may be negative when attempting to detect early-stage osteonecrosis and surgeons have to rely on MR or CT images.
- Registration from CT scans to x-ray has been vastly studied, but CT scans are less ideal for osteonecrosis detection.
- Direct registration between MR images and x-ray images is difficult due to the lack of cross-modality information.

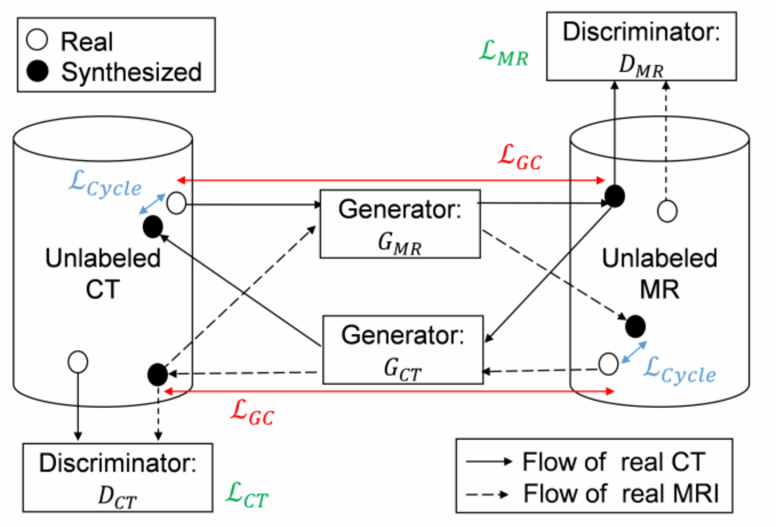
Technical Approach

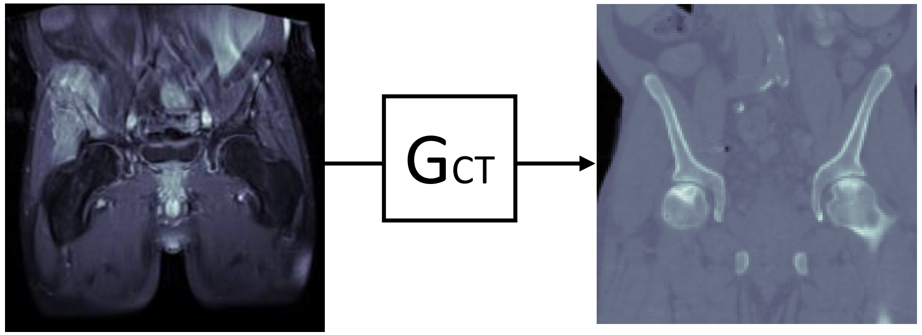
- Registration from MR to x-ray
  - 2-step registration
    - Synthesize CT images given MR images
      - CycleGAN [2]
    - Registration between CT and x-ray (2D/3D Registration)
      - Normalized cross correlation
      - Point-Of-Interest Network for Tracking and Triangulation (POINT) [3]
  - Direct registration (future goal)
    - Perform direct registration between MR and x-ray
      - Non-learning-based methods: anatomical structure[4]
      - Learning-based methods

Reference: [2] Zhu, J et al. [3] Liao, H. et al. [4] Toth, D et al.

Technical Approach – MR to CT synthesis

- Dataset
  - AVN dataset
    - Medical images from 30 patients (mixture of CT, MR and x-rays)
    - Preprocessing
- CycleGAN Training
  - Train robust generator model that converts MR to synthesized CT images





Reference: [5] Hiasa, Y et al.

Technical Approach – 2D/3D registration

- Registration between synthesized CT and x-ray
  - Methods
    - Generation of digitally reconstructed radiographs (DRRs) using the synthesized CT
    - Compute the similarity between DRRs and the target x-ray image
    - Optimization problem:

$$\min_{\theta} \quad \lambda \cdot S(P(\theta), I) + (1 - \lambda) \cdot R(\theta)$$

S: Normalized cross correlation R: regularization function θ: CT bone poses

P(θ): Generated DRR given θ I: target x-ray image λ: regularization parameter

    - DeepFluoroLabeling for automatic annotation of hip anatomy and registration[5]

Reference: [5] Grupp, R et al.

Dependencies

Dependency	Plan	Estimated time
GPU resource access for network training	Talk to Dr. Armand to get access to MARCC	2/26
	(alternative) Lab GPU resource (thin6), Google cloud	Resolved
Access to CT dataset for additional training images	Request access to New Mexico Database	2/26
Acquire tool path annotations in MR images	Check with Alejandro if we can get collect annotated MRs from surgeons	3/18
	(alternative) Generate simulated tool paths ourselves	

Deliverables

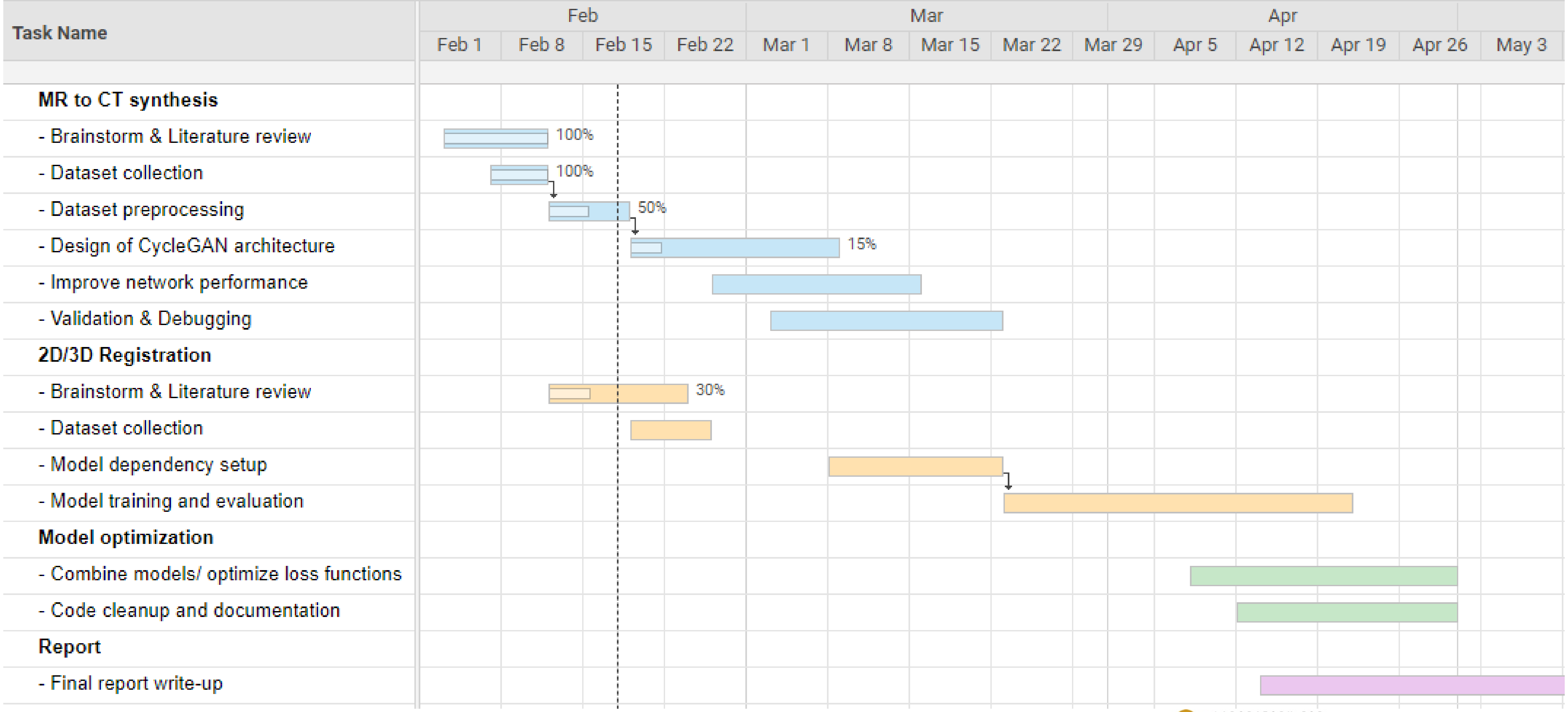
	Task	Date
Minimum	Generate reasonable synthesized CT images from unpaired MR images.	3/15
	Validate the performance of registration between synthesized CT and the x-ray images.	4/6
Expected	Code optimization and generation of best trained network models and ideal parameters.	4/15
	Validate the registration workflow by registering manually annotated paths from MR to x-ray images.	4/20
Maximum	Improve the workflow and combine both networks for loss optimization.	4/29
	Develop a direct MR to x-ray registration method.	4/29
	Proper code documentation and repository publishment.	5/6

Responsibility

- The Team:
  - Ku Ping-Cheng: Takes the responsibilities for all tasks

- Mentors:
  - Mehran Armand (Mehran.Armand@jhuapl.edu)
  - Alejandro Martin Gomez (alejandro.martin@jhu.edu)

Project Schedule



Reading List

1. Yi, X., Walia, E., & Babyn, P. (2019). Generative adversarial network in medical imaging: A review. *Medical Image Analysis, 58*, 101552. doi:10.1016/j.media.2019.101552
2. Grupp, R. B., Unberath, M., Gao, C., Hegeman, R. A., Murphy, R. J., Alexander, C. P., . Taylor, R. H. (2020). Automatic annotation of hip anatomy in FLUOROSCOPY for robust and efficient 2D/3D REGISTRATION. *International Journal of Computer Assisted Radiology and Surgery, 15*(5), 759-769. doi:10.1007/s11548-020-02162-7
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4. Hiasa, Y., Otake, Y., Takao, M., Matsuoka, T., Takashima, K., Carass, A., . . . Sato, Y. (2018). Cross-Modality image synthesis From UNPAIRED data Using CycleGAN. *Simulation and Synthesis in Medical Imaging,* 31-41. doi:10.1007/978-3-030-00536-8_4

Reference

1. Osteonecrosis of the hip - orthoinfo - aaos. (n.d.). Retrieved February 16, 2021, from https://orthoinfo.aaos.org/en/diseases--conditions/osteonecrosis-of-the-hip
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5. Hiasa, Y., Otake, Y., Takao, M., Matsuoka, T., Takashima, K., Carass, A., . . . Sato, Y. (2018). Cross-Modality image synthesis From UNPAIRED data Using CycleGAN. *Simulation and Synthesis in Medical Imaging,* 31-41. doi:10.1007/978-3-030-00536-8_4
6. Grupp, R. B., Unberath, M., Gao, C., Hegeman, R. A., Murphy, R. J., Alexander, C. P., . . . Taylor, R. H. (2020). Automatic annotation of hip anatomy in FLUOROSCOPY for robust and efficient 2D/3D REGISTRATION. *International Journal of Computer Assisted Radiology and Surgery, 15*(5), 759-769. doi:10.1007/s11548-020-02162-7