Visual Perception and Path Planning for Human Assistive Robotics

Members
Karthik D (1047)
A Anirudh (1015)

Supervisor
Prof T T Mirnalinee, M.E., PhD

Dept. of Computer Science and Engineering
SSN College of Engineering, Chennai

November 7, 2022

Table of contents

Introduction

- A stroke is a medical emergency. Prompt treatment is crucial to reduce brain damage and other complications.
- There are *two prominent causes of stroke*: a blocked artery (**ischemic stroke**), or leaking or bursting of a blood vessel (**hemorrhagic stroke**).

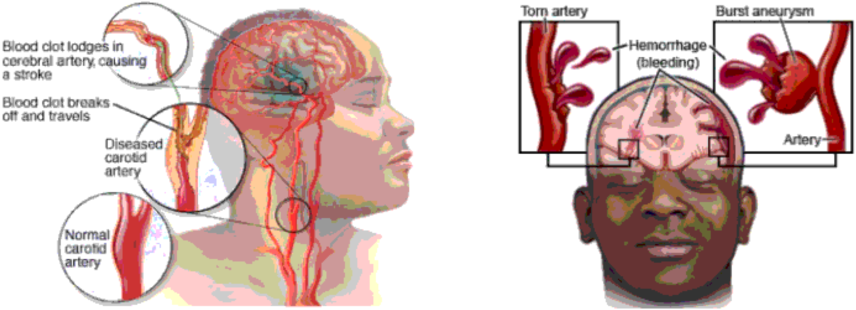

Figure: Depiction of Ischemic Stroke (left) and Hemorrhagic Stroke (right).

Introduction

- The identification of the stroke type is crucial to treatment decisions.
- *Computed Tomography (CT)* and *Magnetic Resonance Imaging (MRI)* are the typical imaging methods in screening stroke patients.
- *Thrombectomy*, the invasive excision of a clot, is the preferred treatment for Ischemic Strokes.
- Treatment of Hemorrhagic Strokes is more complex and case-specific, and is not the focus of this study beyond the level of type identification.

Problem Statement

A. Differentiate: *Ischemic Stroke* Vs. *Hemorrhagic Stroke*
B. Localization and Visualization of the site of stroke origin

- 3D reconstruction of CT-series.
- Simultaneous localization of the site(s) of stroke origin.
- ML-assisted algorithm to identify the stroke type.
- Rendering a 3D visualization of the stroke epicenter and context.

For cases of Ischemic Stroke,

C. Path-planning for assistive robot to perform thrombectomy

- Supervised autonomous operation to excise the clot.
- Interventional surgical staff provides onsite supervision.
- Reconstructed CT is used to guide the robot, and the surgical staff.
- Computational Vascular Model and CT-configured simulation environment to test the robot on specific cases of stroke.

Problem Statement

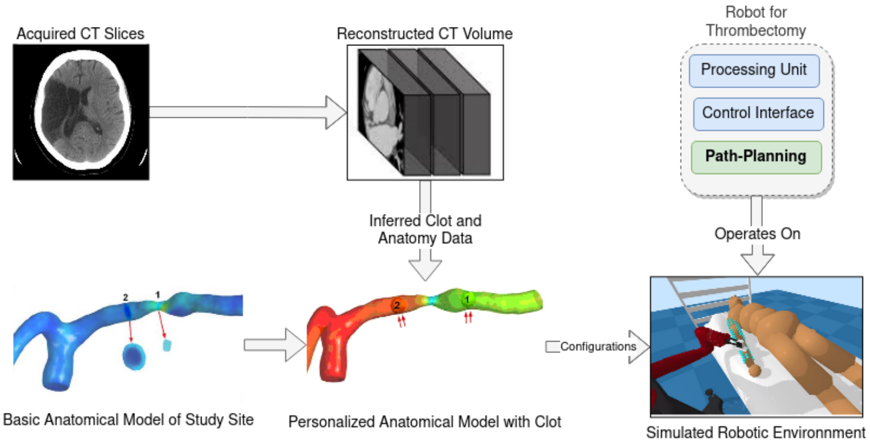

Figure: Proposed clinical workflow for Ischemic Stroke detection and treatment.

Problem Statement

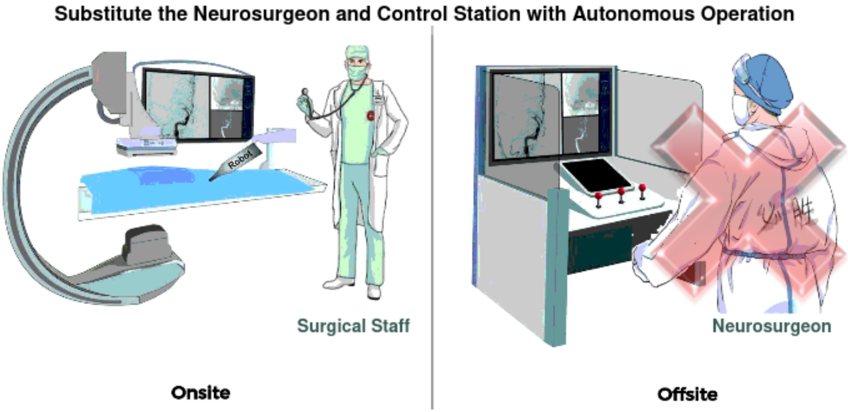

Figure: Role of the assistive robot, and introduction of autonomous capabilities.

Justification of the Statement

The Need to Differentiate Stroke Types

- The strokes manifest through *nearly identical symptoms*.
- The causes, and consequently, the treatments for the two types of stroke are *strikingly different*.
- *Ischemic stroke* is treated with *blood-thinning* drugs to dissolve the clot.
- *Hemorrhagic stroke* requires major surgery. *Coagulants* are injected.
- Administering the *incorrect class of drug* will certainly and immediately *exacerbate the stroke*.

Definitions

Ischemic: Blood supply to part of the brain is interrupted by a clot.
Hemorrhagic: A ruptured blood vessel causes bleeding inside the brain.

Justification of the Statement

State of and Gaps in Stroke Type Differentiation

- Limited investigation of the third axis — prediction models frequently miss stroke sites that span the third axis.
- Existing models apply Machine Learning (ML) directly — not interpretable and hard to verify the decision basis of ML models.
- Existing predictors, ML or otherwise, working on 3D CTs have high inference times and achieve one single objective.

- Simplified class hierarchy for this use-case.
- 3D reconstruction to detect cross-slice stroke sites.
- Simultaneous analysis and stacking of slices to track arteries whilst reconstructing the 3D scan.
- Algorithmic detection of clots/hemorrhage during reconstruction [1]. ML is used only when algorithm is not conclusive, on small volumes for faster inference.

Justification of the Statement

The Need for Robotic Assistance and Operation

"It should be possible to treat a diagnosed case of **ischemic stroke** *from a close-by center remotely by specialized interventional staff"*

- Thrombectomy is the preferred treatment. Reduces post-operative repercussions compared to conventional thrombolytic methods.
- Over 80% of world population **cannot** reach a thrombectomy-capable center within 1-hour of stroke onset [2].
- Manual laparoscopic approaches often cause discomfort to the surgeon — awkward stance and long procedure.

- Medical staff can assist patients remotely, or in transit [3].
- A robot can, in theory, operate more precisely and tirelessly than a human practitioner — eliminating the possibility of human-error.

Justification of the Statement

State of and Gaps in Robotic Assistance and Operation

- ✓ Effective motion compensation algorithms do exist.
  - *Precision path-planning* needs significant improvement to operate on arteries and veins (2 to 4 mm in diameter) .
  - Most robots function in a *purely manual mode*, with limited autonomy. The need for a neurosurgeon has **not** been eliminated yet.
  - Development of thrombectomy robots is still in its early stages — most of them being primitive and largely manual.
- ■ Assistive robot with the ability to switch to telerobotic control in emergencies is proposed.

Definition

Motion Compensation Algorithms achieve cancellation of organ motion in the surgical field. Helps to maintain a steady pose with respect to the field by tracking its motion and moving along with it.

Feasibility Study

Datasets to validate stroke type differentiation

- *Proprietary* annotated series-CT data provided by *Chettinad Academy of Research and Education*.
- *Open-access* CT imaging data sets available for additional needs [4, 5, 6, 7].

Simulation Environments to test path-planning

- Need robust configurable environments for validating the path-planning algorithms.
- Such environments applicable to the medical domain exist: Assistive Gym [8], OpenAI Gym [9], Asynchronous Multi-Body Framework [10], Vinci Surgical System [11].
- The environments can be configured using the reconstructed CT and the compuational vascular model.

Feasibility Study

Configuring vascular models using CT

- Structural and mechanical properties of *pediatric femurs* were captured using a CT-based modeling approach in [12].
- Computational patient-specific vascular models were generated using MRIs of ischemic stroke, factoring geometry and hemodynamics in [13].
- A basic anatomical structure of the vascular structure at the site of study will be modeled based on standard parameters.
- The reconstructed CT can be used to translate specific anatomic and clot location information to produce personalized models [14].
- The computational model configures a robotic environment to validate the path-planning algorithm.

Feasibility Study

Path-planning for assistive autonomy

- Existing *motion compensation algorithms* will be effective in achieving pose stability.
- The state-of-the-art Trauma Pod (TP) performs critical acute stabilization and procedures [15].
- TP performs some autonomous tasks and precise operations — we intend to extend this for thrombectomy.
- Reliable switching between autonomous and teleoperative intervention has been implemented in [15, 3].
- Successful surgical procedures have been performed using robotic arms in precision environments [16, 17, 18, 19] — with effective path-planning, precision can be achieved in autonomous operation.

Tentative Deliverables

At the end of the project execution phase, we aim to deliver the following software elements:

- *Algorithm* to 3D visualize, localize and classify the stroke type from series-CT imaging.
- *Path-planning for a precision robot* that performs assistive thrombectomy autonomously, with the ability to switch to telerobotic control in critical situations.
- *Computational vascular model* of a chosen vascular system chosen for the study.
- *CT-configurable robotic simulation environment* that translates the computational model to evaluate the robot.

R. Kanchana and R. Menaka, "Ischemic stroke lesion detection, characterization and classification in ct images with optimal features selection," *Biomedical Engineering Letters*, vol. 10, no. 3, pp. 333–344, 2020.

O. Adeoye, K. C. Albright, B. G. Carr, C. Wolff, M. T. Mullen, T. Abruzzo, A. Ringer, P. Khatri, C. Branas, and D. Kleindorfer, "Geographic access to acute stroke care in the united states," *Stroke*, vol. 45, no. 10, pp. 3019–3024, 2014.

J. Singer, S. VanOosterhout, and R. Madder, "Remote robotic endovascular thrombectomy for acute ischaemic stroke," *BMJ Neurology Open*, vol. 3, no. 1, 2021.

"Brain ct images with intracranial hemorrhage masks." `https://www.kaggle.com/datasets/vbookshelf/computed-tomography-ct-images`.

"Brain stroke ct image dataset." `https://www.kaggle.com/datasets/afridirahman/brain-stroke-ct-image-dataset`.

"Ct and mri brain scans." https://www.kaggle.com/datasets/darren2020/ct-to-mri-cgan.

"Brain ct hemorrhage dataset." https://www.kaggle.com/datasets/abdulkader90/brain-ct-hemorrhage-dataset.

Z. Erickson, V. Gangaram, A. Kapusta, C. K. Liu, and C. C. Kemp, "Assistive gym: A physics simulation framework for assistive robotics," *IEEE International Conference on Robotics and Automation (ICRA)*, 2020.

G. Brockman, V. Cheung, L. Pettersson, J. Schneider, J. Schulman, J. Tang, and W. Zaremba, "Openai gym," 2016.

A. Munawar, Y. Wang, R. Gondokaryono, and G. S. Fischer, "A real-time dynamic simulator and an associated front-end representation format for simulating complex robots and environments," in *2019 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pp. 1875–1882, Nov 2019.

- F. Richter, R. K. Orosco, and M. C. Yip, “Open-sourced reinforcement learning environments for surgical robotics,” 2019.
- X. Li, M. Viceconti, M. C. Cohen, G. C. Reilly, M. J. Carré, and A. C. Offiah, “Developing ct based computational models of pediatric femurs,” *Journal of Biomechanics*, vol. 48, no. 10, pp. 2034–2040, 2015.
- T. I. Józsa, J. Petr, F. Barkhof, S. J. Payne, and H. J. M. M. Mutsaerts, “Mri-based computational model generation for cerebral perfusion simulations in health and ischaemic stroke,” *bioRxiv*, 2022.
- A. Corti, M. Colombo, F. Migliavacca, J. F. Rodriguez Matas, S. Casarin, and C. Chiastra, “Multiscale computational modeling of vascular adaptation: a systems biology approach using agent-based models,” *Frontiers in bioengineering and biotechnology*, p. 978, 2021.
- P. Garcia, J. Rosen, C. Kapoor, M. Noakes, G. Elbert, M. Treat, T. Ganous, M. Hanson, J. Manak, C. Hasser, *et al.*, “Trauma pod: a semi-automated telerobotic surgical system,” *The International*

Journal of Medical Robotics and Computer Assisted Surgery, vol. 5, no. 2, pp. 136–146, 2009.

R. Rusch, G. Hoffmann, M. Rusch, J. Cremer, and R. Berndt, "Robotic-assisted abdominal aortic surgery: evidence and techniques," *Journal of Robotic Surgery*, pp. 1–7, 2022.

B. D. Martinez and C. S. Wiegand, "Robotics in vascular surgery," *The American journal of surgery*, vol. 188, no. 4, pp. 57–62, 2004.

M. Yamamoto, T. Omori, N. Shinno, H. Hara, Y. Mukai, T. Sugase, T. Takeoka, K. Asukai, T. Kanemura, N. Nakai, *et al.*, "Robotic total gastrectomy with thrombectomy and portal vein reconstruction for gastric cancer and portal vein tumor thrombus," *World Journal of Surgical Oncology*, vol. 20, no. 1, pp. 1–7, 2022.

G. A. Antoniou, C. V. Riga, E. K. Mayer, N. J. Cheshire, and C. D. Bicknell, "Clinical applications of robotic technology in vascular and endovascular surgery," *Journal of vascular surgery*, vol. 53, no. 2, pp. 493–499, 2011.

Thank You