Optimizing and automating electron accelerator data collection and processing

ENEE499L Proposal

University of Maryland, College Park

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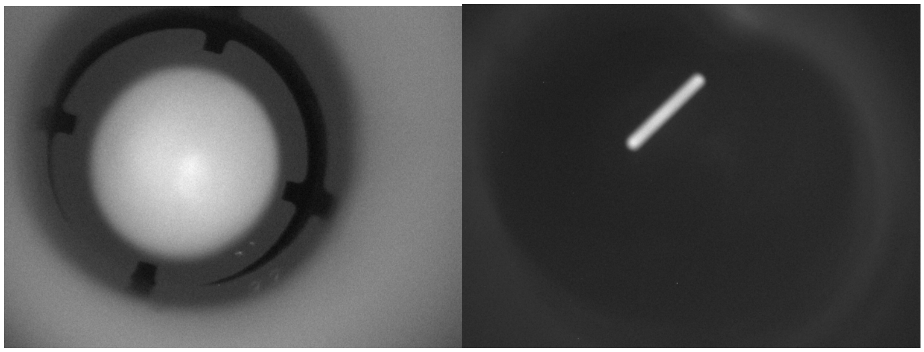
1 Overview

The University of Maryland Charged Particle Beam laboratory is housed within the Institute for Research in Electronics and Applied Physics (IREAP) at the University of Maryland. IREAP is a multidisciplinary institute that houses research from five Academic departments, including Physics and Electrical and Computer Engineering. The Bright Beams Collective (BBC) group is responsible for research in high energy accelerator physics within the institute.

The group's linear accelerator is the focus of a flat-to-round-to-flat experiment, where quadrupole magnets are used to manipulate the configuration space, among other profiles, of the beam to explore applications for beam cooling in larger circular accelerators. Theoretically, with improved beam cooling, circular accelerators can operate at MeV and TeV energies while taking the area of a moderately-size lab or shop room. Beam images are taken with a phosphor screen that takes advantage of the photoelectric effect to radiate photons that are then captured by a camera setup.

Peter Krepkiy is a fourth-year electrical engineering student, with primary interests in beam physics, wave propagation, antenna and applications to RF design, radar and sensors. He is focused on test automation and optimization for efficiency, ergonomics and volume, with multiple past experiences so. Peter is currently working with the BBC group on the linear accelerator experiment as an undergraduate research assistant. For supplementary information, Peter's CV can be found here.



(a) Round beam image (b) Flat (slit) beam image

Figure 1: Two separate phosphor captures demonstrating manipulation of the electron beam

2 Research Objectives

The project proposal is in response to a need for more efficient and voluminous data collection and processing in support of the flat-to-round, round-to-flat (FTRTF) linear accelerator project at the Institute for Research in Electronics and Applied Physics (IREAP) at the University of Maryland, College Park (UMD). Currently, the data collection process is manual, and contains many repetitive steps that present an opportunity for automation.

The project will be supervised by Patrick O'Shea (principal investigator), Brian Beaudoin, David Sutter, Santiago Bernal among others.

The program, written in Matlab and ImageJ scripting languages, is expected to replace manual scaling and cropping, and eye-ball data collection operations that strain overhead labor costs associated with the program, thus improving the rate of progress and cost-benefit, leading to faster turnaround time in results. Additionally, a standardized algorithm reduces variation in data accuracy due to human error, leading to increased confidence in novel observations.

With the added benefit of scaled operations that can process multiple photocaptures at the same time, or even creating 'moving images' that are processed for beam intensity profiles in real time as the phosphor-screen is moved, creates an opportunity for accelerated progress towards the goals defined in the renewal proposal.

2.1 Primary Objectives

- Create a system to process real data from images taken of the electron beam
- Develop an algorithm to resize image data and extract beam shape boundary from fiducial markings through edge detection
- Further extract beam shape profile with edge detection of relative intensity
- Extract intensity, variance raw data and automatically generate plots from beam image data in support of research efforts
- Create extensive documentation for the operation and use of the software and supporting systems for future reference

2.2 Secondary Objectives

- overhaul the camera support system to prevent variation in data precision due to instability
- Implement remote functionality through shared file directory access
- Package software to allow for scaled, i.e. concurrent processing operations
- Create a data path to allow for real-time processing as the position of beam imaging system is changed
- Collaborate with Physicists on the project for further needs of the software as necessary

3 Student Involvement

The Bright Beams Collective group is comprised of multiple Professors and guest researchers, as well as one PhD student. The primary purpose of the group is to investigate accelerator dynamics for beams with intense space charge.

Other than PI Patrick O'Shea, guest researchers Brian Bedouin, David Sutter, and Santiago Bernal are most present in the day-to-day operations in the lab. The guest researchers analyze beam data and make calculations for the adjustment of the various devices associated with the operation of the accelerator, such as quadrupoles.

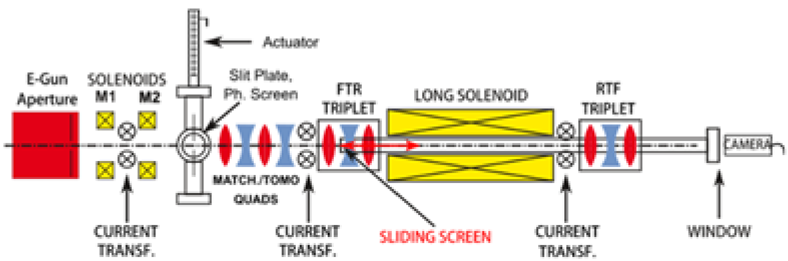


Figure 2: Schematic of the linear accelerator experiment with quadrupole sections. The sliding phosphor screen is designated and can move internally throughout the entire length of the interior space.

4 Methodology

The following tools, techniques and approaches will be used to complete the research project.

- The camera system software will be used to capture beam images
- The physical camera hardware will be manipulated and focused accordingly to capture precise beam images
- The moving Phosphor screen will be used during software development to test the software on various edge-case beam image profiles (The phosphor screen captures electrons in the beam and releases photons which are captured by the camera system, an application of the photoelectric effect)
- Tape measuring devices will be used to measure distances between the screen and camera system

An expected initial delay in implementing the aforementioned design is for calibration of the system to ensure accurate readings.

5 Project Learning Schedule

The project is expected to be active during the Spring 2024 semester.

January/February

- Create a database of existing data to find patterns in existing images
- Create a clear document for manual data processing
- Develop an outline ('pseudocode') for the approach

- Explore scripting capabilities in the ImageJ native software and its interaction with Matlab; evaluate an ImageJ-Matlab approach as opposed to a pure Matlab-based software

March

- Take measurements for camera focusing at various beam imaging distances
- Evaluate mathematical formulas to calculate image scaling given varying image distances and camera focusing
- Research appropriate edge detection algorithms
- Mid-semester report after Spring break (March 17-24)

April

- Finish bulk of software troubleshooting stages and bug fixes
- Begin research into camera support system overhaul as permitted
- Evaluate the opportunity for an automatic camera focusing system with a micro controller, position sensor and actuator system; Draw plans and schematics for a future project, time permitting

May

- Final report in the first week of May; Presentation to BBC group on software operation and background image processing algorithms

6 Student Learning Outcomes

- A deeper understanding of Matlab with respect to image processing
- Image processing kernels and Sobel operator algorithms
- Understand the intricacies of accelerator beam imaging and data collection
- ImageJ software, an important tool in data collection used in the real world
- Acquire a technical background of space-charge dominated beam propagation phenomena (For example, Bernal rings)
- Critically examine large datasets
- Further develop collaborative skills while apprenticing with Physicists

7 Advanced laboratory requirement

This project is expected to satisfy the Advanced Laboratory Requirement due to significant collection and processing of novel data from the linear accelerator beam images in support of research efforts.

8 References

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