Saint Vincent College

A.J. Palumbo Student Research Application

Student Name John Meneghini Graduation Date 5/24

Project Title Computational Modeling of X-ray Attenuation and Simulation of Medical Imaging

SVC P.O. Box 825 Major: Physics

E-Mail Address john.meneghini@stvincent.edu

Total Estimated Budget:

Your proposal narrative should clearly state how each of the items in your budget would support your project. An additional single page **must** be added to your proposal that itemizes the budget and explains how the costs were determined (for instance, how airfares and hotel costs were determined).

Supplies (itemize)	$ 285
Equipment (itemize)	$
Printing and duplicating	$
Travel	$
Lodging	$
Other (itemize)	$
Less funding from other sources (e.g., departmental funds)	$
Total funding requested	$ 285

Student Signature John Meneghini Date 3/15/23

Faculty Advisor:

As Faculty Advisor to the project I have reviewed the following research proposal and budget and agree to work with the student to support the completion of the project.

Faculty Advisor Signature Fr. Michael C Antonacci, OSB Date 15 March 2023

Faculty Project Advisor (please print) FR. MICHAEL ANTONACCI, OSB

Each application should include this page as a cover page, the proposal narrative (maximum 3 pages), and an additional page with an itemized budget and short budget narrative if needed. Applications should be completed and submitted to the Academic Affairs Office, second floor, Headmaster's Hall before 4:30pm on the application deadline for each semester.

Deadlines for Applications:

Fall Semester: November 15 (for projects during the upcoming Spring and Summer)
Spring Semester: February 15 and March 15 (for projects during the upcoming Summer and Fall)
(if a deadline falls on a weekend, then the deadline is extended to the following Monday)

(revised 09/18/2018)

1. I am requesting funding to cover the cost of phantom objects and materials, as well as the cost of using Google's Cloud Graphics Processing Units (GPUs) for the comparison of X-ray images to their simulated counterparts. My plan is to purchase polyethylene terephthalate to be used in our department's 3D printer in order to produce 3D objects. Polyethylene terephthalate has a known X-ray attenuation coefficient, which is a parameter that describes how strongly a material weakens or reduces the strength of X-rays as they pass through the material. With this known value, my code will be able to simulate X-ray attenuation through this type of plastic.

Using these materials, I will be able to simulate the x-ray image of a physiological model. Then, I will 3D print the object and image it using the cadaver lab C-Arm, a compact X-ray machine for use during surgery. By comparing a simulated image with its associated X-ray image, I will be able to demonstrate the efficiency and accuracy of my program in determining X-ray attenuation.

So far, I have developed my simulation to run on the average computer; however, exploiting the power of graphics cards can drastically increase the speed of the simulation. While my simulation runs quickly for the simple objects I have used so far, more complex objects will drastically reduce the speed of the simulation. With this in mind, I am requesting funding to purchase time to use Google's Cloud GPUs, which will allow me to take advantage of the power of graphics cards while avoiding the hefty price that comes with purchasing one.

This research project will take place in the physics department at Saint Vincent College, starting in the summer of 2023 and ending in the spring semester of 2024.

2. X-ray imaging is a critical diagnostic tool used by medical professionals to diagnose and treat various illnesses and injuries. While the use of X-rays is essential to provide immediate, life-saving results, the amount of radiation dosage patients receive can be more than medically necessary. This excessive radiation exposure can increase the risk of cancer, DNA damage, and other potential health risks, making it crucial to minimize the amount of radiation exposure patients receive during X-ray imaging.[1]

While one could minimize radiation dosage by adding shielding and/or changing the position of the target/x-ray source and obtain a reported dosage from the x-ray machine software, this approach has limitations. First, it is time-consuming in often urgent situations, and it still does not guarantee the optimal imaging parameters. Secondly, when it comes to resource-limited settings, the increased cost of imaging procedures due to this optimization procedure may not be financially viable.

To address these challenges, *my proposed project focuses on the development and validation of a computational modeling approach for X-ray attenuation and medical imaging simulation using ray tracing and GPU acceleration. This approach will be able to accurately simulate the image one might obtain from an X-ray machine, while also being able to approximate the associated dosage.* Accurate computer simulations enable the user to easily add shielding and change the X-ray source orientation, allowing one to optimize the imaging procedure by finding the best quality image that can be obtained with a minimal dosage of ionizing radiation.

In particular, my approach to X-ray simulation uses ray tracing, which is a common graphics technique that simulates particles of light traveling in a 3D environment. It is in this 3D environment that I will place models of objects and trace the path of the light particles through the objects. By using the objects' attenuation coefficients and the distance light travels through the object, I am able to calculate the attenuation of the X-ray and simulate the expected X-ray image.

To make this approach computationally feasible for more complex geometries, I will also use GPUs for acceleration. GPUs are specialized processors that are designed for the parallel processing of large amounts of data, which is ideal for the plentiful but simple calculations involved in ray tracing and X-ray simulation. By exploiting the power of GPUs, I will be able to perform these simulations much faster than would be possible with typical computer processors, allowing for more efficient optimization of X-ray imaging procedures.

In order to validate the accuracy of my simulation, I will use the cadaver lab C-Arm to obtain X-ray images of the objects and compare them with the simulated images. With the assistance of Dr. Gregory Bisignani and Ms. Krista Jobe, I have already taken images of very simple objects and have qualitatively compared them with simulations. Funding will allow for the simulation and imaging of more realistic geometries, as well as their quantitative comparison.

3. The method for this project will include the following tasks and timeline:

Starting in June, I plan to rewrite my simulation to utilize NVIDIA's OptiX SDK (Software Development Kit), which provides optimized ray tracing implementations that run parallel on GPUs. Using this SDK and Google's Cloud GPUs, I plan to accelerate my simulation, allowing for the rendering of more complex geometries. Additionally, I plan to order polyethylene terephthalate, along with various phantoms based on common physiological substances, including oil (fat), raw meat (muscle), and aluminum (bone).[2]

In July, I plan to simulate a model of a torus knot using both single-precision (less precise) and double-precision (more precise) calculations. I will then use different image-similarity classifiers to compare the two images; this will give me insight into what precision and classifier I should use when comparing a simulation to its X-ray image.[3] Once complete, I will simulate and take an x-ray image of the oil, raw meat, and aluminum and compare them to a simulation of fat, muscle, and bone, respectively.

In August, I plan to 3D print a hollow cylinder that will surround an aluminum cylinder. The empty space will be filled with water to represent a bone surrounded by skin. An associated simulation will be performed and compared to an X-ray image of the cylinder. Furthermore, I plan to go through the same process, replacing the water with oil, then with raw meat.

Throughout the fall semester, I will perform similar experiments, replacing the 3D-printed cylinder with models found in NIH's medical model database. This database is filled with thousands of physiologically accurate models, such as hands, feet, and skulls that I will be able to 3D print and fill/surround with oil, raw meat, and water to accurately represent human body parts.

Finally, in the spring semester, I plan to present my research in the form of a talk and poster at both the Saint Vincent College's Academic Conference and the Western Pennsylvania American Association of Physics Teachers. Furthermore, throughout the semester, I will be working on my thesis to document the methodology and findings of my research.

4. This research project coincides with my academic interest, which is studying computational physics and its numerous real-life applications. With Saint Vincent College not having a computational physics course, all of my knowledge has come from independent study. While I believe I am relatively proficient in the field for an undergrad, I have no true formal education in computational physics. This project will give me the opportunity to prove my interest and motivation in the field and gain invaluable experience that could potentially be used for a thesis. Furthermore, the research I produce in this project can be presented at conferences. Such accomplishments would make me stand out from other grad school applicants and would increase my chances of receiving an acceptance offer from a top graduate school, specifically Carnegie Mellon University. Overall, I'm requesting funding for my project in order to validate the accuracy of my simulation and demonstrate my passion and motivation for computational physics in my graduate school applications.

In conclusion, this project will not only give me the opportunity to demonstrate my knowledge in the field of computational physics but also grant me experience with topics such as medical imaging and GPU programming that I have never had the chance to explore. As such, this research project will be invaluable to me and my future goals. I am confident that this project will be successful and I look forward to all the opportunities it brings. Thank you for your consideration.

Table 1: Estimated Budget

Supplies	Quantity	Price	Total Price ($)
Google Cloud GPUs	50 hrs	$2.80/hr	140.00
Polyethylene Terephthalate	2 kg	$40.00/kg	80.00
Canola Oil	1 gal	$10.00/gal	10.00
Sirloin Steak	2 lbs	$15.00/lb	30.00
Aluminum Rod	1.25" diameter	$25.00 ea.	25.00
		Total Estimated Budget:	$285.00

References

[1] Radiation studies: Health effects depend on the dose (2015). URL `https://www.cdc.gov/nceh/radiation/dose.html`.

[2] Hubbell, J. H. & Seltzer, S. M. Tables of x-ray mass attenuation coefficients and mass energy-absorption coefficients 1 kev to 20 mev for elements z = 1 to 92 and 48 additional substances of dosimetry interest (1995).

[3] Wang, Z., Simoncelli, E. P. & Bovik, A. C. Multi-scale similarity for image quality assessment. *Proceedings of the 37th IEEE Asilomar Conference on Signals, Systems and Computers, Pacific Grove, CA, Nov. 9-12, 2003. ©IEEE* (2003).