APPLICATION CHECKLIST
Presidential Faculty/Student Collaboration and Publication Grant

Deadline February 15th (or following Monday if a weekend)

Please print and complete this checklist and attach it as the cover page of your grant application. For more information about Presidential Faculty/Student Collaboration and Publication grants, please see http://gustavus.edu/facdev/GrantOpportunities/PresidentialGrant.php.

Faculty information

Name: Steve Mellema Dept: Physics

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Student Information

Name: Chen-Yu Yang Year: First year

Email: cyang2@gustavus.edu Major: Physics

Checklist

Project Details

- ☑ Brief description of the proposed project including its collaborative nature
- ☑ Clear statement of anticipated outcomes
- ☑ Likely placement for publication or performances
- ☑ Anticipated research completion date

Participant Details

- ☑ Names and brief biographies of all participants
- ☑ Explanation of how this project fits into the career of the faculty
- ☑ Explanation of how this project fits into the educational trajectory of the student (include year of graduation; student eligibility is limited to full-time returning students)

☑ **Presidential Budget Proposal Form attached as last page of application**

☑ **Eight copies of completed application (including this checklist) to be submitted to the John S. Kendall Center for Engaged Learning (SSC 119)**

If successful, my proposal can be used as an example to assist future faculty applications. This decision will not in any way influence the evaluation of my application.

[✓ Yes] / No (please circle one)

Study of Optical Imaging by Reflection through Random Media

A Proposal to the Presidential Faculty/Student Collaboration

Steven Mellema Chen-Yu Yang
Professor of Physics Class of 2011
Gustavus Adolphus College
February 15, 2008

I. Description of the Proposed Project

A. Background

For medical imaging, the use of visible light would be vastly preferable to ionizing radiation (i.e. x-rays). Potential cell damage from ionizing radiation may lead to subsequent cancers or birth defects. Thus, the use of ionizing radiation as a diagnostic tool always involves a risk *vs.* benefit analysis. Of course, in the century since Roentgen discovered the penetrability of x-rays, they have become the primary tool of medical imaging, developed today to the point of Computer Automated Tomography (CAT) scans. Nevertheless, the risk to the patient due to the ionizing nature of the radiation must always be a consideration.

While visible (or near-visible) light does not pose a potential for ionizing cell damage, the obvious disadvantage of such light as an imaging tool is that the human body is not highly transparent to visible light. Nevertheless, the surface layers of human skin, while dense enough to rapidly attenuate visible light by scattering, do permit a tiny fraction of incident light to penetrate unscattered. If that tiny fraction of the light can be isolated and tracked, it may be used to image objects below the skin's surface. The most obvious application of this technique, if it can be developed, would be early detection of melanoma (skin cancers).

In previous work, our colleague Paul Saulnier and several Gustavus students have studied imaging in random media through the use of short coherence-length lasers[1]. The so-called "random media" are liquids which, like the skin layers, are highly scattering. (Their optical behavior is qualitatively like that of ordinary milk.) Through the use of dilute solutions of monodisperse polystyrene spheres, the density and size of the scatterers may be controlled experimentally. The imaging techniques which are beginning to develop, and which we propose to extend, involve the unique property of *coherence*, possessed by light emitted from a laser. The instrument we will build is called an *interferometer.* Basically, if coherent light from a single source is split and subsequently sent along two different paths before being recombined, the light which remains coherent can be isolated (or identified) upon recombination of the two beams. If one of the two beams passes through the sample (milk, skin, etc.), most of the light will, of course, scatter and be lost. However the tiny fraction of light that passes unscattered through the sample, strikes a reflective object within that sample, and then travels back unscattered, can be recombined with the other beam and then identified and used to create an image of the object.

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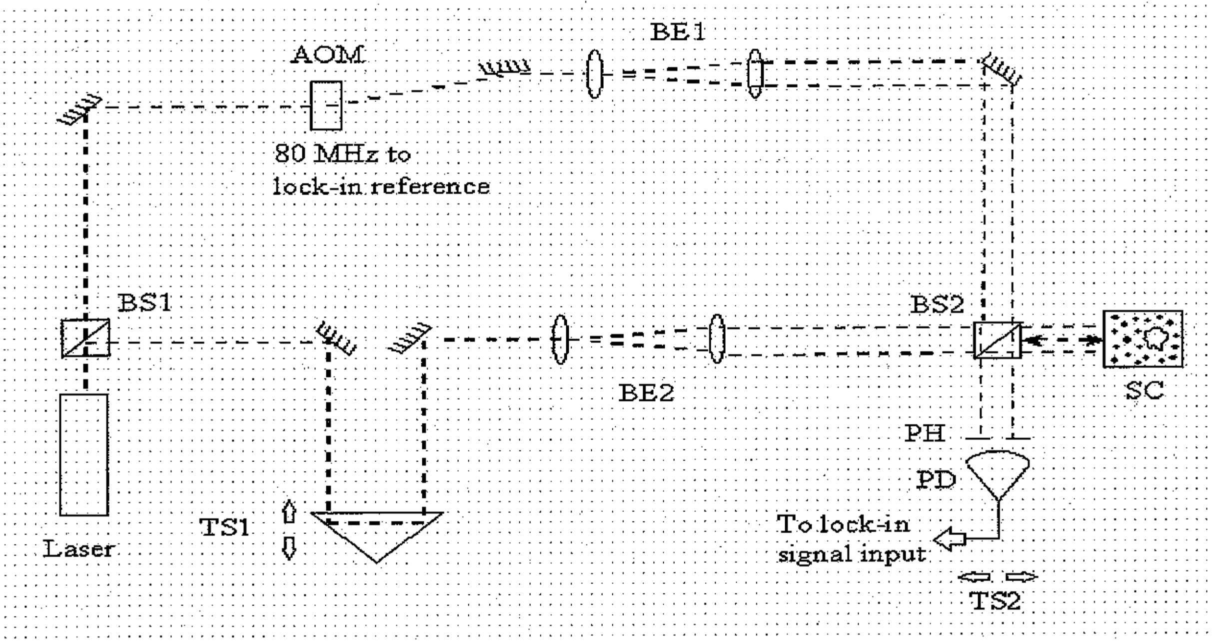
[1] A. Schmidt, R. Corey and P. Saulnier, Optics Letters, **20** (1995) 404

B. Technical Description of the Research

We propose an experiment involving low-coherence reflectometry measurements in random media. We will attempt the imaging of reflective objects immersed in such media. The media will be monodisperse dilutions of polystyrene spheres. The medium will be altered by varying both the size and concentration of scatterers within the dilution. The technique applied will be low-coherence reflectometry utilizing a near-IR diode laser with a coherence length on the order of 50-300 μm. Optical heterodyning will be accomplished through the use of an 80 MHz acousto-optic modulator (AOM) in the reference arm of an interferometer. When the path lengths of the two arms of the interferometer are matched to within the coherence length of the laser, the resulting interference pattern will "beat" at the frequency of the AOM. A high-frequency lock-in amplifier will then be used to analyze the signal from a photodiode detector.

This optical heterodyning technique is very similar to the one used successfully in the experiments on imaging by transmission through random media carried out by Paul Saulnier and his students. Those experiments detect ballistic photons that pass completely through the sample. (Scattered photons are not coherent with the reference arm and thus are not detected by the lock-in.) By sweeping the beam across the sample cell, one can reconstruct, pixel-by-pixel, an image (shadowgram) of an object immersed in the random medium.

For reflectometry measurements, however, the optical path length of the sample arm of the interferometer will depend upon the depth within the sample at which the reflection occurs.



Thus, by changing the length of the delay arm of the interferometer (see the figure above), images may be formed for different depths within the sample. The photons detected would be those that traveled ballistically to the object, reflected back, and traveled ballistically to the detector. Depth resolution will be limited primarily by the coherence length of the laser. And, the ability to image three-dimensionally by probing at different depths in the medium will be an enhancement over any previously reported work.

The experimental arrangement for low-coherence reflectometry experiments is shown in the figure above. It is a modified Mach-Zender interferometer using a near infrared diode laser, acousto-optic modulator (AOM), photodiode detector (PD) and high-frequency lock-in amplifier. The samples to be studied will be reflective objects inside a sample cell (SC) filled with an aqueous suspension of polystyrene spheres. The first translation stage (TS1) and retroreflection arrangement allow the optical path length of the lower arm (delay arm) of the interferometer to be adjusted. This will essentially determine the depth within the sample from which the image would be obtained. The pinhole (PH) and second translation stage (TS2) permit sweeping the beam across the sample to reconstruct each image pixel by pixel.

C. Previous Work on the Project

An NSF-MRI grant eight years ago led to the purchase of all of the equipment necessary for the performance of this work. The project thus far has involved two distinct experimental problems, the first being the need for computer hardware interfacing and software programming to allow for experimental control and data acquisition. Much of that problem was solved by Chris Holstrom (Class of 2000) and me under the auspices of a previous Presidential Faculty/Student Collaboration. Unfortunately, a computer hard disk "crash" a few years ago has left us with only printed copies of all of the programs Chris originally wrote.

A second problem is the construction of an optical interferometer (as in the figure above) in which a stable signal is obtained in the interference between the reflected light and the reference light. The technical difficulties of building a working reflectometer have been manifest in the intervening years, as I and a half dozen research students have attempted to overcome problems of radio-frequency interference, low signal, and faulty acousto-optic modulators.

Under the auspices of a second Presidential Collaboration grant in 2005, Sharon Jaffe and I produced, for, the first time, a stable signal from our AOM. Sharon and I also successfully constructed, collimated and tested a new, more powerful infrared laser, which should give us sufficient signal power (bright enough light) to perform the scattering measurements.

The project is now ready to move to the final stage. The basic pieces of the apparatus are all assembled and tested. We are excited to continue the work this summer and to finally obtain images from the system.

II. Anticipated Outcomes/Publications

The work described here will, hopefully, lead to the completion of this very time-consuming and difficult project. The outcome of this summer's work is expected to be the actual detection of reflected images from objects embedded inside random scatterers. The eventual goal is a quantitative determination of the quality of the reflected image obtained as a function of the density and size of the scatterers in the embedding medium.

Chen-Yu and I have been working together on this project since early last fall semester, and using this coming summer's work we hope to move this project to a successful conclusion. He is a unique student who, while only a freshman at Gustavus, brings with him a broad background in both physics and computer programming from China. This background, coupled with his stellar performance in his first classes at Gustavus this past fall, has led to our department designing a "special track" through our major that will waive certain course prerequisites and accelerate his progress. He is, in terms of his background, motivation, skill level and absolutely tireless work ethic, the kind of student who only comes along perhaps once in decade.

The concentrated time and effort afforded by a summer research period is the only way to make the kind of progress necessary to complete the project. We need to re-create all of the computer software that Chris Holstrom wrote, while adapting it and enhancing it to fit our current needs. We need to construct the final reflectometer apparatus. We are hopeful that we will have a successful imaging system by the end of summer, and that we will continue to take data (images) through the fall semester of 2008, and to work on preparing presentations and publications for spring 2009. Besides a paper at next spring's Sigma Xi Research Symposium, the work carried out should lead to one or more contributed papers at American Physical Society (APS) and/or Optical Society of America (OSA) conferences. It is also expected to lead to at least one publication in a refereed journal, most likely the *Journal of the Optical Society of America*, *Optics Letters* or, possibly, the *American Journal of Physics.*

III. Participants' Statements

A. Steven H. Mellema, Professor of Physics

I have had a long career as an experimental research physicist (from 1980 until the present) and as a mentor for undergraduate research students (since coming to Gustavus in 1986). However, to be frank, a careful reading of my *curriculum vita* would reveal a recent paucity of pure-physics research publications.

My career as a physicist and a faculty member at Gustavus is evolving in new directions. Most of my recently published work has been in the area of physics education. But I have been involved in a pure-physics research collaboration in the area of scattering with my departmental colleagues Tom Huber, Chuck Niederriter, and Paul Saulnier. Together we applied to the National Science Foundation for a Major Research Instrumentation grant entitled *Acquisition of Equipment for Acoustical, Optical and Computational Scattering Studies*. The work we proposed, a portion of which is described in this proposal, combines interests and expertise we each have in the study of scattering. We were successful in obtaining $145,628 and used the money to equip the research labs in the basement of Olin Hall. We have, as mentioned above, purchased everything needed to perform the work in this proposal.

I have had six student research assistants working with me on this scattering research project over the past eight years. As is often true with experimental physics research, progress has been slowed by a number of factors, from faulty equipment to unanticipated sources of electronic noise. Perhaps most significant, however, is the need to re-train (from scratch) a new research assistant ever year or two because: (1) usually only a junior or senior physics major has the background to work in this area; and (2) they all graduate. I am excited because Chen-Yu, while only a first-year student, has the skills and energy to jump right into the project. This spring his experimental training will be much enhanced by completing our Electronics and Instrumentation I course. He brings with him from China the necessary computer programming skills. As a non-US citizen and first year student, he is very unlikely to be accepted in any off-campus summer research internship programs this summer. However, if he has the opportunity to successfully complete an internship here this summer, his chances of getting an off-campus internship in a subsequent year will be greatly enhanced.

In furthering my studies in optical scattering, it is my intention to seek (and to obtain) outside funding for faculty/student research through Research Corporation or the National Science Foundation RUI program. However, because I have no established "track record" of published research in this area, I need to establish some credibility in this new area before asking for outside funds. The opportunity afforded by Gustavus' funding of the Presidential Faculty/Student Collaboration and the refereed publication(s) of results which we anticipate from the work this summer would put us in a much more favorable position to obtain an external research grant in the following years.

B. Chen-Yu Yang, Class of 2011, Physics Major

I have been in Dr. Mellema's project ever since I began to study at Gustavus. Even though I am a first-year student, my previous experience in physics has qualified me for advanced courses and projects. Before I went to college, I achieved the first prize in National Physics Olympiad (province) in China. Throughout my upper years of high school, my physics courses had been more demanding than the Classical Physics sequence at Gustavus. As such, I was waived from almost all first and second year math and physics courses here. Seeking more academic challenges, I took one of the highest level math courses (a capstone course) this January, and delved deeper into this optical imaging project.

My previous exposure to experimental optics enables me to progress quickly. Tapping into the experience with the interferometer begun during the fall semester. I successfully built a Mach-Zender interferometer and measured its contrast this January. Even though this interferometer is not sufficiently stable for imaging because of the imperfect lenses and laser, I gained further insight into how to build an interferometer. As I read the previous lab books in the project, I found that building the interferometer was the most challenging part of the whole experiment. With more immersion in the project this spring, I will further sharpen my skills in overcoming this difficult core of the experiment.

Another advantage I have is that I will concentrate on optics. I have carefully read the previous lab books, and will study more papers related to the project. Since the underlying principles of the project are not theoretically complicated, good skills with the optical and electronic instruments are more important than theoretical knowledge. Last semester, I researched in the optical lab an average of ten hours a week, and twice that much during J-term.

Now I am no less experienced with the optical devices than an upperclassman. Also, my previous background in programming will be very helpful in reconstructing the code that controls the electronics in the experiment. After successfully constructing the Mach-Zender interferometer this J-term, I decided to concentrate on this project during my stay here. I will further increase my efforts in the project this spring and the following summer.

If I progress through the project with Dr. Mellema, I will have a great learning experience in real-world research. First, my task of reconstructing the computer code will enable me to put my programming skills to work. Second, undertaking the project will give me a lot of expertise in experimental optics. Half a year ago when I participated, I just wanted more academic challenges. As I was more involved, I realized that the project was not only demanding, but may also give rise to a cutting-edge application in the study of imaging. More importantly, I am qualified to undertake the project.

It is almost certain that I will go to a physics or engineering graduate school after Gustavus. Working with Dr. Mellema on optical imaging is the first of hundreds of research projects in the years to come. This project is the academic challenge I am seeking, and the start of scientific research I am pursuing.