Application Form
SD Space Grant Consortium Student Fellowship/Scholarship Stipend Program

Name Fehrman_____ Brian_____C. Birth Date 08/06/1986
Last First M.I.

Local Address _28 Cobalt Drive, Rapid City, SD, 57701_____ Phone 605-209-5443
Street, City, State, Zip

Permanent Address _28 Cobalt Drive, Rapid City, SD, 57701_____ Phone 605-209-5443
Street, City, State, Zip

Email address _____brian.fehrman@mines.sdsmt.edu_____

Student status during requested stipend period: □ □Freshman □Sophomore □Junior □Senior **X**Graduate Student (□MS, **X**PhD)

Application is for (select one):
□ Educational Stipend □ Undergraduate Research Fellowship **X**Graduate Research Fellowship

Undergraduate GPA/scale: __3.052 / 4.0__ Graduate GPA/scale: __3.692 / 4.0___

Degree Program/Major Currently Enrolled In _Mechanical Engineering, PhD_____ Expected Graduation Date _May 2014__

How did you hear about this opportunity? _____Advisor_____

Mark any that apply to your high school or college experiences:
□ I am a prior Space Grant award recipient
□ Participated in SD Space Days
□ Participated in Women in Science Conference
□ Participated in Space Camp
□ Participated in ACE Camp
X Participated in Robotics

Final Educational Degree Goal: □ Bachelors □ Masters **X** PhD □ Post-doc
Field of study for this degree goal: __Mechanical Engineering_____

Career Goals: **X** Higher Ed. **X** NASA □ Non-NASA federal agency □ State/Local Government
□ Nonprofit **X** Military □ Consulting □ Undecided □ K-12 teacher
X Industry
X Other _Research Oriented Career (could potentially be in any of the fields that I checked in this section)

Demographics (completion of this part of the application is voluntary, but is necessary if selected for an award)
Gender: **X** Male □ Female

Ethnicity: **X** Caucasian □ Pacific Islander □ Hispanic □ Native American
□ Asian □ African American □ Other □ Choose not to answer

□ I have a disability (Marking this indicates the applicant has a disability. Completion of this part is voluntary.)

By my signature or typed name below, I certify that I am a citizen of the United States, and I am or will be enrolled as an Undergraduate or Graduate student at _____South Dakota School of Mines and Technology____ during the award period.
(name of college or university)

__Brian Fehrman_____ ___5/12/2011____
Student signature or typed name Date

Introduction

Brian Fehrman has engineering research experience that is both rich and diverse. He received his B.S. in Computer Science with a Minor in Mathematics from the South Dakota School of Mines and Technology. Brian is currently pursuing a PhD in the field of Mechanical Engineering, also at the South Dakota School of Mines. He has worked for the Advanced Dynamics Lab (ADL) at the university for over four years. He has performed tasks spanning multiple disciplines for a variety of research projects with many great results. Some of the projects include Fast Steering Deformable Mirror Membranes Using Electrostatic Area Variation and Accelerated Crack Healing Using Focused Acoustic Energy via Time Reversal. He currently leads experimenting and research for both of these projects.

Brian's overall career goals involve a fulfilling life of research work. As may be evident by his choice of a broad science and engineering education, Brian has an extreme passion for learning in many of the STEM disciplines. Pursuing a career in research will enable him to continue this learning experience indefinitely. As co-founder of Engineering Today, he has also taken the first steps towards starting and running a technological based business here in South Dakota.

The current milestone which Brian needs to complete in order to accomplish his career goals is to conduct solid analysis and experiments pertaining to his doctoral thesis topic. Having a space grant would be extremely helpful towards him reaching this milestone. A grant would allow Brian to more strongly focus on this step as well as purchase materials that are needed through the course of testing.

Proposed Research: Requirements for Closed Loop Electrostatic Control of Mirror Membranes

Executive Summary

The broad, umbrella field of my studies will be electrostatic control of mirror membranes. This involves the use of both a mirror membrane and one or more electrostatic actuators. The actuators are placed underneath of the mirror membrane. A relatively small gap is left between the actuators and the membrane. If a voltage is applied to the electrostatic actuators, a force is created that will cause the mirror membrane to be attracted towards the underlying actuators. Deformation of the mirror membrane results from this. If directed energy, such as a laser, is pointed towards the front of the mirror membrane then a reflection occurs. When the mirror is deformed due to the actuators underneath of it, the energy will reflect at a different angle than if the mirror was in its non-deformed state. By using this concept we are able to “steer" the energy reflection by causing different deformations of the mirror membrane (i.e., exciting different modes of the mirror membrane). Deformable mirrors are also very useful in other cases where adaptive optics is needed. One such area is astronomy. Light is distorted as it enters our atmosphere. This distortion can be fixed if a telescope mirror is deformed to the correct shape which will provide a clearer image. Since mirror membranes are lightweight, low-cost, and deployable they are also attractive for space applications. My research work will look at the different requirements for stable control of mirror membranes.

Current State of the Art

In addition to the mode shapes, the amplitude at which the modes are excited will determine the reflection of the energy. There are various ways to control the amplitude of excitation, such as: varying the voltage applied, varying the gap between the mirror and the actuators, and by varying the amount of surface area that is used by the actuators. One of the biggest problems with controlling the mirror is that without closed loop control your mirror deflection cannot be greater than one-third the available gap size between it and the actuators beneath. After the mirror deflects past one-third of the gap, the restoring force of the mirror is less than the electrostatic force produced by the actuators and the mirror membrane will “snap-down” against the actuators. “Snap-down” can cause extreme damage to both the mirror and the actuator equipment. Increasing the gap size to increase allowable deflection will in turn increase the voltage requirements that are needed versus being able to use the full gap. Since the dynamics of the system are highly nonlinear, the control is also nonlinear which greatly increases the difficulty of the problem. One idea that has been worked on is closed loop control using variable voltage by Zhu et al and was performed on segmented MEMS mirror. Our work deals with closed loop control of continuous mirror membranes using area variation and gap variation which seeks to have improved performance over the voltage control. We wish to answer questions which will enable easier design and a better understanding of deformable mirror systems. Having this understanding can help make this technology widely available for everyone to use. (1; 2; 3; 4)

Specific Goals and Outcomes

My studies will focus on aspects of this overall concept and the goal will be to answer the following questions that are posed. The first portion of this that will be looked at deals with a multiple mode (multiple actuators) membrane mirror and the number of actuators that are used for controlling the mirror deformation. Two potential problems arise that pertain to the actuators. The first problem is the fact that in a boundary actuated system one actuator will influence every single point on the mirror. This means that every one of the many actuators being used (to generate many modes) will also affect every other actuator that is used. This could lead to instability in the system and a very complex (if existent) control algorithm. It is in then necessary to answer this question: Is there a limit on how many actuators can be used if a stable system is to be maintained? The second actuator problem is somewhat opposite of the first. Multiple actuators are required to excite multiple modes of the mirror membrane. The question that arises is this: For a desired bandwidth, accuracy and sensitivity, is there a minimum number of actuators that are required? There is also another question that comes up when dealing with the multiple mode mirror membrane. The closed-loop control uses a single variable for feedback; the change in position of the reflected energy. The question is then this: Is there a point at which given bandwidth, accuracy and sensitivity requirements for a given number of modes will require an inner-loop feedback in which the actual membrane deflection information is needed?

The other portion that will be looked at involves using gap control to vary the amplitude of excitation. There are also two problems with this. The first is the fact that the gap variation can really only provide a single variable for controlling the system. The first question to answer then is this: Is there an inherent performance limit, assuming infinite mechanical precision, to using gap variation as an independent control? The second question is somewhat of an extension, and possibly a sub question, of the first problem dealing with gap variation. This question pertains to the fact that the gap variation is achieved through mechanical motion. Because of this fact, this is the question we also wish to answer: Is there a limit to the resolution of control using gap variation?

Research Activities

There will be a good balance between analytical and experimental work in order to accomplish the goals that have been laid out. Analysis based on physical principles and engineering concepts will be used to develop the ridged theory which will help answer our questions. This analysis will come from a broad range of STEM fields involving: electrical engineering, mathematics, mechanical engineering, physics, and others. Laboratory experiments will be run concurrently in order to verify that the theory being developed is correct. These experiments will include use of deformable mirror membranes for beam steering and adaptive optics purposes. Performance of the mirrors will be compared to the expected performance generated by the analysis.

Success Metrics

Success will be determined on whether or not the following questions have been answered at the end of my studies.

- Is there a limit on how many actuators can be used if a stable system is to be maintained?
- For a desired bandwidth, accuracy and sensitivity, is there a minimum number of actuators that are required?
- Is there a point at which given bandwidth, accuracy and sensitivity requirements for a given number of modes will require an inner-loop feedback in which the actual membrane-deflection information is needed?
- Is there an inherent performance limit, assuming infinite mechanical precision, to using gap variation as an independent control?
- Is there a limit to the resolution of control using gap variation?

Activity Timline

- Setup basic experiments involving laser, deformable mirror, quad cell feedback, area variation, and custom FPGA software to test closed loop control of a mirror membrane.
    - Done (See setup below).
- Simultaneously perform the analysis on the minimum/maximum number of actuators needed/allowed for the desired control. Concurrently verify the analysis experimentally.
    - May 2011 – January 2012

- Determine at what point an inner loop feedback providing the membrane-deflection information is needed and confirm via experiments.
    - February 2012 – October 2012
- Find whether or not there is a performance limit using gap variation as an independent control. Conduct experiments at the same time to see that the theory is correct.
    - November 2012 – June 2013
- Perform analysis and experiments to determine the resolution limit (if any) of control using gap variation.
    - July 2013 – May 2014

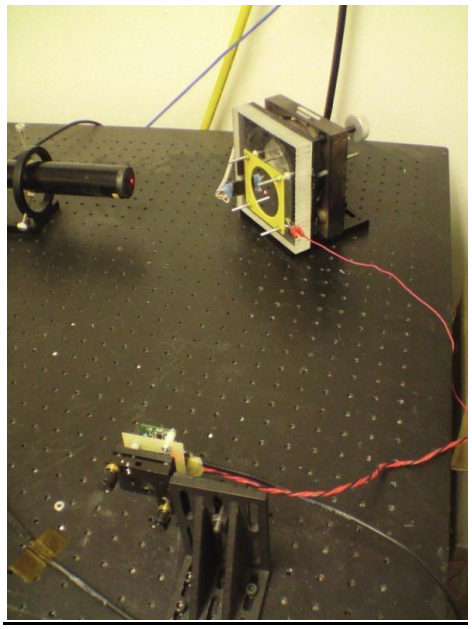

Figure 1 Overview of current mirror test setup. Pictured is Laser (Top Left), Mirror with Actuator Board Underneath (Top Right) and the Quad Cell Feed Back Device (Bottom)

The Proposed Project and SDSGC

In broad terms, this project will directly address the vision of the SDSGC. I will gain a large amount of education and experience dealing with many STEM disciplines. The successful completion of this work would also mean a great chance of running a successful technological business in South Dakota which could further help the SDSGC to reach some of their objectives pertaining to the collaboration between industry and universities.

One of the specific SDSGC objectives that will be met by the project will be Objective B.2.2 which is to support new and developing research, especially multidisciplinary and collaborative projects, in fields aligned with NASA's mission. Since our project is geared toward space technology it would be very useful to NASA. All of the strategies under this objective would be addressed. Objective C.2.2 as well as its strategy, C.2.2.1, will also be met since this grant would help me enter into the STEM workforce.

Works Cited

1. *Robust Control of an Electrostatic Microelectromechanical Actuator.* **Karkoub, M. and Zribi, M.** s.l. : The Open Mechanics Journal, 2008, The Open Mechanics Journal, Vol. 2, pp. 12-20.

2. *Electrostatic Micromechanical Actuator with Extended Range of Travel.* **Chan, Edward K.** s.l. : Journal of Microelectromechanical Systems , 2000.

3. *Modeling and Control of Electrostatically Actuated MEMS in the Presence of Parasitics and Parametric Uncertainties.* **Zhu, Guchuan and Penet, Julien and Lahcen, Saydy.** s.l. : Transactions of the ASME, 2007, Vol. 129.

4. *Large-displacement Closed-loop Control of Variable Area Electrostatic Actuation for Membrane Reflectors.* **Korde, Umesh A.** s.l. : Journal of Intelligent Material Systems and Structures OnlineFirst, 2008. doi:10.1177/1045389X08096258.

SOUTH DAKOTA
SCHOOL OF MINES
& TECHNOLOGY

DEPARTMENT OF MECHANICAL ENGINEERING

(605) 394-2401 FAX: (605) 394-2405 www.sdsmt.edu

South Dakota Space Grant Consortium

May 13, 2011

To whom it may concern,

I write this to request consideration on behalf of Brian Fehrman, who recently completed his first year as one of our first PhD students in mechanical engineering. I give my reasons below for putting my strongest support behind Brian in his request for NASA Space Grant funding.

Brian's doctoral research concerns real-time electrostatic control of lightweight flexible mirrors. His research will provide a lightweight and economical way to perform real-time, high-quality, aberration-free (i.e., corrected for atmospheric, vibration, or alignment-related distortions) astronomical imaging; precise real-time manipulation (focusing, steering, and aberration correction) of laser beams; as well as high-quality imaging of atmospheric, oceanic, and geological phenomena from low-orbit earth-observation satellites. As such, it contributes directly to NASA's space exploration, space utilization, and earth science missions.

Specifically, Brian's work focuses on closed-loop nonlinear control of boundary-located variable-area electrostatic actuators that would produce a real-time controlled deformation profile over a metal or metal-coated reflector. Variable-area, constant voltage and gap-controlled electrostatic actuation are new technique being developed by our group, and Brian is spearheading these developments. He uses a nonlinear controller that provides accurate deformation control at 500 Hz bandwidth with photo-diode feedback. Brian has tested new designs for focus/defocus and tip/tilt mirrors based on this method, and is now working on larger, 12-mode mirrors using variable area and electrode gap control techniques.

As part of his research, Brian is in the process of adapting a 12-mode deformable mirror to serve as a secondary reflector on a 1-m astronomical telescope being developed at the Orion Observatory in Oregon. For his doctoral dissertation, Brian aims to understand and quantify the relationship between actuator cross-coupling and controller stability, which is an important issue for lightweight, multiple-mode mirrors. He is in the process of incorporating a 2-layer feedback structure to provide the necessary deflection resolution and accuracy at each point while compensating for extraneous errors due to platform vibrations or atmospheric distortions. Space grant support would be of vital importance to Brian's research, and enable him to focus solely on the many experimental and numerical developments we need to have in place before a multi-mode closed-loop mirror can be produced and tested in the field.

Brian has been working with me for over 4 years now, and during this time has met every standard of excellence, dedication, perseverance one can think of in a research environment. He is an extremely talented and resourceful researcher and one looks forward to a long and productive research career for him. For the reasons stated above, I support Brian's application in the strongest terms, and look forward to working closely with him as he continues to advance his research further. Thank you very much for your consideration of this request. I would be happy to answer any questions and to provide additional information as needed.

Sincerely,

Umesh A. Korde
Pearson Professor for Sustainable Energy
Phone: (605) 355-3731, E-mail: Umesh.Korde@sdsmt.edu
501 E. Saint Joseph Street • Rapid City, SD 57701-3995
"An Equal Opportunity and Affirmative Action Institution"

Brian Fehrman

28 Cobalt Drive, Rapid City, SD 57701

Brian.fehrman@mines.sdsmt.edu

Work History:

- Co-founder of Engineering Today, Rapid City, South Dakota (2010 – present)
- Research Engineer, SDSMT Advanced Dynamics Lab, Rapid City, South Dakota (2007 – present)
- Retail Associate, Sam's Club, Rapid City, South Dakota, (2002 – 2007)

Education:

- Ph.D. M.E. South Dakota School of Mines and Technology, Rapid City, SD 2014
- B.Sc. CSC South Dakota School of Mines and Technology, Rapid City, SD 2010
- Minor Math South Dakota School of Mines and Technology, Rapid City, SD 2010

Background:

- **Time Reversal Acoustics**: Successfully performed time reversal focusing of acoustic stress waves using multiple methods.
- **FGPA Data Acquisition**: Has written many programs that efficiently harness the speed and reliability of FPGA data acquisition cards.
- **Circuit Boards**: Personally designed and milled circuit boards with many hours logged on the CNC milling machine which cuts down costs of outsourcing fabrication.
- **Extensive Programming**: Possesses programming knowledge that is both broad and deep which allows for using the right software tool for the job and converting code between different languages.
- **Electrostatics**: Performed many different tests on electrostatic mirror membranes using variable area actuators.
- **Custom Animation**: Created a variety of computer animation programs to better help convey concepts and ideas about different lab projects.

Recognition / Honors:

- 3rd Place, South Dakota School of Mines Student Research Competition, May 2010, topic of *Self-Healing and Acoustic Time Reversal Focusing*

Professional:

- Member of Association for Computing Machinery 2008-present
- Member of American Institute of Aeronautics and Astronautics 2009-present
- Member of SPIE 2009-Present
- Member of Triangle Fraternity 2008-Present

Selected Publications:

- **First Author -** *Time Reversed Focusing in Finite-Length Rods with Defects.* Accepted for publication by AIAA and was presented at the 2011 AIAA 52nd Structures, Structural Dynamics, and Materials Conference.
- **Co-Author -** *Experiments on the focusing and use of acoustic energy to enhance the rate of polymer healing*. Accepted for publication by SPIE and was presented at SPIE 2011 Smart Structures Conference.
- **First Author -** *Using Focused Acoustic Excitation to Accelerate Crack Healing.* Published by AIAA and was presented at the 2010 AIAA 51st Structures, Structural Dynamics, and Materials Conference.
- **Co-Author –** *Electrostatic control with discrete area variation for beam steering and focusing using membrane mirrors.* Accepted for publication by SPIE and was presented at SPIE 2010 Smart Structures Conference.

Undergraduate Transcript
Course Listing

If there is a letter following the course number, it indicates the university where the course was taken.
B = Black Hills State University, D = Dakota State University, M = SD School of Mines & Technology,
N = Northern State University, S = South Dakota State University, U = the University of South Dakota.

Name Fehrman, Brian C.

Address 28 Cobalt Dr

Rapid City, SD 57701

Course/Section and Title	Grade	Credits	Repeat	Term
CSC-317 M001 Computer Organiz & Architectur	B	4.00		2010SP
CSC-317L M051 Computer Organization/Arch Lab	LR	0.00		2010SP
CSC-467 M001 Senior Design II	B	2.00		2010SP
MATH-315 M001 Linear Algebra	B	3.00		2010SP
MATH-321 M002 Differential Equations	B	4.00		2010SP
MATH-381 M002 Intro to Prob and Stats	B	3.00		2010SP
CSC-421 M001 Graphical User Interfaces	A	3.00		2009FA
CSC-465 M001 Senior Design I	A	2.00		2009FA
CSC-492 M082 TP: SOFTWARE ENGINEERING	A	3.00		2009FA
MATH-423 M001 Advanced Calculus I	C	4.00		2009FA
PHYS-213 M001 University Physics II	B	3.00		2009FA
PHYS-213L M052 University Physics II Lab	A	1.00		2009FA
HUM-375 M001 Computers in Society	A	3.00		2009SU
CSC-410 M001 Parallel Computing	A	3.00		2009SP
CSC-447 M001 Artificial Intelligence	B	3.00		2009SP
CSC-461 M001 Programming Languages	A	4.00		2009SP
ENGL-289 M007 Technical Communications II	A	3.00		2009SP
PE-100 M001 Activity Courses-Weight Train	A	1.00		2009SP
CHEM-114 M001 General Chemistry II	B	3.00		2008FA
CSC-372 M001 Analysis of Algorithms	A	3.00		2008FA
CSC-484 M001 Database Management Systems	B	3.00		2008FA
ENGL-279 M003 Technical Communications I	A	3.00		2008FA
PHYS-211 M001 University Physics I	A	3.00		2008FA
PHYS-211A M012 University Phys I Recitation	LR	0.00		2008FA
CENG-244 M001 Intro to Digital Systems	A	4.00		2008SP
CENG-244L M052 Intro to Digital Systems Lab	LR	0.00		2008SP
CSC-433 M001 Computer Graphics	C	3.00		2008SP
CSC-456 M001 Operating Systems	B	4.00		2008SP
CSC-456L M051 Operating Systems Lab	LR	0.00		2008SP
SPAN-102 M021 Introductory Spanish II	A	4.00		2008SP
PE-118 M001 Beginning Swimming	A	1.00		2007FA
BIOL-121 M001 Basic Anatomy	B	3.00		2007FA
MATH-225 M004 Calculus III	B	4.00		2007FA
SOC-100 M003 Introduction to Sociology	B	3.00		2007FA
SPAN-101 M021 Introductory Spanish I	A	4.00		2007FA
CSC-300 M001 Data Structures	C	4.00		2007SP
CSC-314 M001 Assembly Language	D	4.00		2007SP
CSC-314L M051 Assembly Language Lab	LR	0.00		2007SP
MATH-225 M003 Calculus III	W	0.00		2007SP
PHIL-200 M001 Introduction to Logic	A	3.00		2007SP
CHEM-112 M001 General Chemistry I	D	3.00		2006FA
CHEM-112L M053 General Chemistry I Lab	B	1.00		2006FA
CSC-250 M001 Computer Science II	B	4.00		2006FA
CSC-251 M001 Finite Structures	D	4.00		2006FA
MATH-125 M002 Calculus II	C	4.00		2006FA

CSC-150 M004 Computer Science I	B	3.00		2006SP
CSC-150L M052 Computer Science I Lab	LR	0.00		2006SP
ENGL-101 M004 Composition I	B	3.00		2006SP
MATH-123 M004 Calculus I	C	4.00		2006SP
PSYC-101 M002 General Psychology	B	3.00		2006SP

Total Earned Credits 134.00

Total Grade Points 409.00

Cumulative GPA 3.052

Graduate Transcript
Course Listing

If there is a letter following the course number, it indicates the university where the course was taken.
B = Black Hills State University, D = Dakota State University, M = SD School of Mines & Technology,
N = Northern State University, S = South Dakota State University, U = the University of South Dakota.

Name Fehrman, Brian C.

Address 28 Colbalt Dr

Rapid City, SD 57701

Course/Section and Title	Grade	Credits	Repeat	Term
ME-625 M001 Smart Structures				2011FA
PHYS-521 M001 Electromagnetism				2011FA
ME-773 M001 Applied Engineering Anal II	A	3.00		2011SP
ME-798 M086 Master's Thesis	NP	0.00		2011SP
PHYS-551 M001 Classical Mechanics	B	4.00		2011SP
EE-505 M001 Survey of Circuits & Systems	A	3.00		2010FA
EE-505L M051 Survey of Circuits/Systems Lab	LR	0.00		2010FA
ME-673 M001 Applied Engineering Analysis I	A	3.00		2010FA
ME-798 M085 Master's Thesis	NP	0.00		2010FA
ME-798 M081 Master's Thesis	NP	0.00		2010SU

Total Earned Credits 13.00

Total Grade Points 48.00

Cumulative GPA 3.692