MRI: Acquisition of an Immersive Virtual Reality System for the South Jersey Technology Park at Rowan University

Results from Prior NSF Support


Both projects involved extensive collaboration between Rowan University and University of South Florida. The primary objective of the Rowan University team is the design, development and validation of automated image processing algorithms that can estimate three-dimensional shape-descriptors for particle aggregates, which can then be used in discrete element modeling.

The principal accomplishments in this research work are:

- The design and development of automated algorithms that can estimate three-dimensional shape-descriptors for particle aggregates using a statistical combination of two-dimensional shape-descriptors from multiple two-dimensional projections.
- The design and development of automated 3-D tomography reconstruction algorithms applied to shape characterization of particle aggregates.
- The demonstration of the algorithm’s ability to accurately and repeatedly reconstruct composite 3-D shapes from 2-D projections of multiple particles and their corresponding 2-D shape-descriptors.
- The development of experimental protocols and a database of results obtained by optical and X-ray tomography of a varying set of particle aggregate mixtures.
- The demonstration of the consistency, separability and uniqueness of the 3-D shape-descriptor algorithm by exercising the method on a varying set of particle aggregate mixtures.
- Numerical validation of the reconstruction method by comparing with 3-D reconstructions obtained from multiple projections of a single particle generated using optical (OT) and X-ray methods.
- Numerical validation of the reconstruction method using Optimized Optical Microscopy Images by comparing with 3-D reconstructions obtained from multiple projections of a single particle generated using optical (OT) and X-ray methods.

Dissemination to date:


The objective of this project was to purchase a semi-immersive portable virtual reality (VR) display system for providing interactive displays of results obtained from the nondestructive evaluation of gas pipelines. This research work conducted in this project was complemented by concurrent projects funded by the US Department of Energy and ExxonMobil Corporation for developing multi-sensor data fusion techniques for inspecting underground gas transmission pipelines. The principal accomplishments of this research project are:

- Development of a framework for multi-sensor data visualization in VR. An immersive data fusion environment was defined and created, consisting of (a) graphical data, (b) measurement data, and (c) functional data. Incorporating user-defined inputs allowed the user to interact and navigate in the environment. The framework was demonstrated using multi-sensor data obtained during the in-line inspection of a section of a gas transmission pipeline. Graphical models of the pipeline components were displayed in addition to magnetic and ultrasonic inspection signals, neural network predictions of pipeline condition, and the geographic location of the pipeline network.

- Development of time-evolutionary models for 1-D, 2-D, 3-D, and N-D VR evolutionary simulations. Four candidate algorithms were implemented – deterministic modeling, autoregressive moving average modeling, genetic algorithm modeling, and hidden Markov modeling. The results of these evolutionary techniques were demonstrated using the growth of a stress-corrosion crack on a pipeline section.

- Comparison of the evolutionary algorithms for scenario development. The following evaluation criteria were identified – versatility, model I/O, speed, memory, interaction with the user, and software specific features. A prioritization matrix technique was used to rate the candidate algorithms and identify strengths, weaknesses, and trade-offs.
Since the purchase of the equipment in Fall 2002, there has been an annual involvement of 10 undergraduate students and 2 graduate students (from Electrical & Computer, Mechanical and Civil & Environmental engineering students), a total of 4-faculty and six external (industrial collaborators) associated with this acquisition. Furthermore, this acquisition has resulted in 4 follow-on research grants from NASA-Stennis Space Center and the US Navy.

Dissemination to date:


The VR system has also seen extensive media coverage – television (The History Channel, Channel 6-ABC, New Jersey Network) and local newspapers (Courier-Post, Philadelphia Inquirer, Gloucester County Times, Star Ledger).

A. Research Activities

Background: The Rowan Imaging & Nondestructive Evaluation Laboratory

Over the previous 10-years, the Imaging & Nondestructive Evaluation Laboratory (NDE Lab) in the College of Engineering at Rowan University has pioneered the application of a variety of imaging, image-processing and advanced scientific visualization techniques for a variety of applications. Faculty, students and industrial collaborators have addressed a wide range of practical problems such as –

- Multi-sensor data fusion (using magnetic, acoustic emission, ultrasonic and thermal imaging) techniques for assuring the integrity of underground natural gas transmission pipelines;
- X-ray CT and optical tomography imaging techniques for the numerical characterization of 3-D shapes in geomaterial particle aggregate mixtures;
- Development of integrated awareness platforms using virtual reality (VR) for supporting the integrated systems health management of NASA rocket-engine test-stands;
- Development of virtual prototyping techniques for simulating ship-board engine systems for US Navy vessels.
Figure 1 illustrates the existing capabilities in the Rowan Imaging and NDE lab. A common approach that has been employed in arriving at the problem solution most of our previous research projects includes –

- The design, development or acquisition of an imaging platform (including the fabrication of test specimens);
- The application of digital image processing and/or artificial neural networks for characterization (component/system integrity, geometrical shape, etc.);
- The use of VR-based advanced scientific visualization for an interactive, navigable and immersive display of analysis results.

**Background: Immersive Virtual Reality for Advanced Scientific Visualization**

Advanced scientific visualization (ASV) is the use of visual techniques to aid in problem solving and data analysis [1]. ASV is usually employed for handling problems with large or complex multi-dimensional data sets, which are understood better when the data is visualized [2]. Meteorologists use ASV to study weather phenomena, archeologists use ASV to study excavations, political analysts use ASV to study political trends, mathematicians use ASV to study complex equations, astrophysicists use ASV to study the cosmos, and so on [3].
Immersion refers to the blocking of real world sensory inputs from interfering with the virtual world. A sense of immersion is usually created through the ability of the visual display system to minimize contradictions between the real world and the virtual world [5]. Navigation is the ability of the user to move within the virtual world; navigation includes manipulation of the orientation of the data being represented. Finally, interaction is the tracking of the user inside the virtual world, and the ability of the world to react to movements and commands initiated by the user [6].

Van Dam [2], in a seminal paper that reviewed the use of immersive VR, opined that the technology “holds great promise for scientists, mathematicians, and engineers who rely on scientific visualization to grapple with increasingly complex problems that produce correspondingly larger and more complex models and data sets.”

Research Activity Proposed with the Immersive VR System Acquisition

As shown in Figure 1, our present VR capability consists of a semi-immersive (single wall) Fakespace ImmersaDesk® system. This proposal seeks support to augment our advanced scientific visualization capabilities to a fully-immersive, navigable and interactive VR system, commonly known as a “CAVE”.

We now describe two ongoing research projects that demonstrate the need for the proposed acquisition and the research activities that will be conducted.

(i) Evolutionary Virtual Reality Platforms for Integrated Systems Health Management (ISMH)

Complex structures, such as those used in monitoring and testing space-craft components require a multitude of sensors to determine any irregularities or malfunctions. Intelligent sensors have become critical components of complex test systems [7]. These sensors have the capability not only to provide raw data, but also indicate the data’s reliability and its effect on system health at a component or higher level, resulting in a voluminous increase in total data. Integrated Systems Health Management (ISMH) algorithms consist of processes that must identify and manage anomalous conditions that such systems may encounter during routine operation. ISHM offers the potential to move space systems operations and space platforms closer to their ultimate performance boundaries, which will be needed to undertake lunar and planetary missions under stringent performance and cost goals [8]. An ISHM provides real-time assessment of component health and a determination of their contribution to aggregate system health using a combination of modeling,
reasoning, and experience. However, current ISHM development work has not sufficiently developed the sensor fusion and integration to the degree required to achieve the benefits required to support next-generation space exploration missions. In particular, there are insufficient tools available to perform the “what if” scenario developments at a level above the ISHM.

We have proposed the use of VR visualization platforms for managing the vast amount of multi-sensor data collected in an ISHM environment that is deployed in a complex large-scale system. Figure 3 shows a typical ISHM architecture for a rocket engine test stand. VR platforms allow for complete and spatially accurate three-dimensional models of systems (and subsystems) to be displayed in real time. VR environments are ideal for integrating data containing different attributes. These include graphical data that consist of CAD models of the physical environment, measurement data that is obtained from multiple smart-sensors that collect operational information and functional data that pertain to the contextual analysis of sensor measurements. A VR environment for data integration is shown in Figure 4. VR provides a medium for improved information assimilation and analysis through its core capabilities of immersion, interaction and navigation. This allows the operator to rapidly sift through large amounts of (presumably) benign indications and identify anomalous occurrences for subsequent analyses. Furthermore, VR environments provide the capability to develop subsequent risk-analysis modules, enabling the operator to simulate various “What if?” scenarios.

In our ongoing work, supported by NASA, we have developed a VR environment for monitoring the performance of a rocket engine test stand, specifically the Methane Thrust Transfer Protocol (MTTP) portable engine test stand at NASA-Stennis Space Center’s E-3 test facility [9]. Typically, measurement data from rocket engine tests are recorded and stored as spreadsheets. We demonstrate the potential of VR for analyzing sensor data meaningfully in an integrated and immersive manner, either synchronously or asynchronously. Figure 5 shows the development protocol required for creating an immersive VR environment and Figure 6 shows a screen capture of the 3-D environment.

![Figure 3: ISHM for a rocket engine test stand.](image-url)
The proposed work will mature previously developed evolutionary VR environments for supporting the ISHM platform that is being developed at SSC for the A-3 test facility. This facility is intended to support the testing of the new Constellation rocket systems that will be launched for the upcoming Moon (and subsequently, Mars) missions. The ISHM system consists of networked intelligent elements including smart sensors, other components (e.g., pumps, valves), and processes (e.g., tank pressurization, valve opening). The ISHM architecture is intended to support intelligent integration of system health management functions and will address management of information and knowledge (storage, distribution, maintenance, evolution) so as to determine condition for each element in the system in context and in a timely fashion. Specific project tasks include:

1. Developing a graphical database of specific ISHM components that can be used to create the virtual ISHM environment.
2. Developing artificial neural network models that include information and knowledge of system elements to predict system health at multiple hierarchical levels.
3. Adaptation of previously developed evolutionary algorithms for virtual scenario development, as the system health evolves with new sensor inputs [10].
4. Validation of the VR environment using a laboratory ISHM implementation and a corresponding test stand implementation.

The proposed project requires the development of novel data fusion capabilities such as those requiring the integration of heterogeneous sensor data – time-domain signals, spatial-domain images, time-histories and qualitative descriptors of sensor behavior. In addition, the real-time generation of an immersive, interactive and navigable display of the evolutionary scenario inside the VR. 

**Figure 4:** VR environment for data integration.
environment requires the adaptive generation of model and data files – most commercial VR software are ill-suited for this purpose. A significant challenge of this proposed project is the development of a software framework that is portable and scalable for deployment in other environments.

Figure 5: VR environment development protocol.
(ii) Synthesis of Particle Aggregate Mixtures from their Numerical 3-D Shape Descriptors

The research activity in this project was funded by the National Science Foundation.

There is a strong dependence of shear strength and deformation characteristics of granular materials on particle shape [11, 12]. Quantitative description and realistic modeling of particle shape can immensely improve our understanding of the mechanisms controlling natural phenomena such as liquefaction susceptibility, shear flow, soil-structure and soil-geosynthetic interaction, design of geotechnical interfaces, and selection of suitable materials for construction. However, little progress has been made toward quantitative characterization of particle morphology, and its direct effect on the response of geomaterials. Conventional methods available to define particle shape and angularity are often subjective and do not necessarily render quantitative information. Despite the tremendous progress in computer imaging and object reconstruction, the vast majority of the resources and technologies currently available to the geotechnical community are limited to two-dimensional modeling and characterization, with little or no progress in the three-dimensional domain.

In a previous project, we have addressed the following two specific questions [13-24]:

- How can the 3-D shape of natural sand and gravel particles be measured and digitized?
- Can a link be established between the 3-D particle shapes and their corresponding 2-D projections?

We developed a database of sand particle images from various mixes (Ottawa #45, standard-melt, #1-dry, etc.) using the following three imaging platforms:
• An optical microscope with a digital camera for imaging multiple particles from distinct mixtures (the least expensive method);
• An optical tomography system for imaging single particles from distinct mixtures;
• An X-Ray CT scanner (the “Gold-standard”) for imaging single particles from distinct mixtures (the most expensive method).

We have developed a computationally efficient 3-D model for the representation and recognition of a large number of similar granular particle-shapes using a combination of 2-D shape representation techniques and random variable models. A significant advantage of using such a combination of 2-D shape descriptors and random variable models is that the 3-D granular particle shape can be reconstructed from the 3-D shape descriptor set. We have shown that statistical 2-D shape descriptors that can be obtained from cheaper, optical microscopy or tomography systems can be used to represent the 3-D shapes of aggregates in a geomaterial mixture, with accuracies similar to that obtainable using an X-ray CT system. These 2-D statistical descriptions have been shown to be similar for similarly shaped particles and separable for dissimilarly shaped particles.

Furthermore, we have attempted to use the algebraic reconstruction technique (ART) algorithm to synthesize the 3-D shapes of the geomaterial aggregates from their optical microscopy and tomography projections. However, when we attempted to reconstruct 3-D shapes representative of the entire mixtures from the optical systems, we discovered that the optical tomography system was more accurate than the microscopy system. These results are illustrated in Figure 7.

Figure 7: ART synthesis of geomaterial shapes for Daytona beach sand. (a) X-ray CT; (b) Optical tomography and (c) Optical microscopy.

The proposed project intends to use the benefits of an immersive VR environment for analyzing the cost-accuracy trade-off in using the different imaging methods for synthesizing multiple 3-D shapes in a particle aggregate mixture. The primary objective of such accurate synthesis is its use inside a discrete element model, which is described next.

In the recent past, Discrete Element Method (DEM) has gained momentum in the field of micromechanical modeling. With the advancement of DEM, particle shape modeling in two and three dimensions has become increasingly relevant. Discrete element method is a numerical technique which allows modeling of a system of discontinuous material as an assembly of discrete elements interacting with each other. The main advantage of DEM lies in its ability to capture the mechanical interaction between different discrete bodies that cannot be solved by traditional continuum-based techniques such as the Finite Element Method. Although the two-dimensional DEM framework has seen considerable development in the area of particle shape characterization, however, three dimensional characterizations and modeling of non-spherical particles is still in the early stage of development. This study will model irregular sand particle geometries within discrete element modeling software PFC$^{3D}$ [26].
Modeling irregular particles in DEM is a challenging task and will utilize techniques used by Ashmawy et al. [27] and Das [28]. After characterizing the grain shape using either data obtained from an X-ray Computed Tomography system or using an Optical Tomography system, three-dimensional coordinates of each and every voxel of the particle surface are obtained. A skeletonization algorithm is then used to obtain the skeleton of the three-dimensional particle. Skeletonization is often called Medial Axis Transformation which is defined as the locus of centers of maximally inscribed discs. In 3-D, the medial surface is the locus of centers of all maximally inscribed spheres. An Overlapping Discrete Element Cluster (ODEC) technique is then used for implementation in three-dimensional discrete element modeling software PFC$^{3D}$. In the ODEC technique, three-dimensional particle surface is covered by clumping a number of overlapping spherical discrete elements so that the simulated particle surface resembles the surface of an actual particle. To reduce the number of overlapping spheres within the clump, the biggest sphere covering maximum volume is inscribed first. The next sphere to be added is the sphere that covers the maximum uncovered volume and so on. The process is demonstrated in Figure 8.

![Figure 8:](image)

(a) Three-Dimensional Particle Geometry Obtained from the XCT  
(b) Skeleton of the particle obtained from the skeletonization algorithm  
(c) The geometry of the particle is then recreated in PFC3D using ODEC technique [28]

The importance of DEM to the study of the influence of inherent particle characteristics such as particle morphology on the fabric that develops has been documented earlier [29]. Figure 9 shows DEM of angular particles, where the particles have been deposited in a box under gravity. The dark gray clusters in the figure show regions of high density and the light gray clusters show regions of low density [30]. This is especially relevant because even with the same depositional characteristics, local variations in density are highly likely as seen in Figure 9 with Daytona Beach sand having more pockets of higher density than less angular Fraser river sand. Studies like this will shed light on how particle size and shape distribution influences depositional characteristics and the differences in fabric that develops, which in turn influences granular shear behavior.

![Figure 9:](image)

Figure 9: Channelization in angular particles when deposited in a box under gravity for a) Daytona beach sand and b) less angular Fraser river sand [29, 30]
This problem is especially suitable for study in an immersive VR environment enabling researchers in distant locations, especially collaborators in Australia with whom the research team has been working on this problem previously.

B. Description of Research Instrumentation and Needs

This proposal seeks support to acquire a Fakespace SSVR™ Immersive Display System, and its associated components that include –

- Stereographic emitters and eyewear (for immersive 3-D displays)
- A wireless tracking system (for user navigation and interaction)
- 4-PC computer cluster (for object rendering in the VR environment).

Figure 10 illustrates the proposed system, also known as a CAVE® (an acronym for “CAVE Automatic Virtual Environment”) is a room-sized advanced visualization solution that combines high-resolution, stereoscopic projection and 3D computer graphics to create the illusion of complete sense of presence in a virtual environment [32]. The system we propose to acquire consists of 10'h x 10'w x 10'd tracked virtual environment with three individual vertical 10' x 10' soft screens for a four-surface projection (3 walls and floor). There are 4-projectors with 12,000 lumen digital projection capacity. The approximate footprint of the system is 11.6'h x 30'w x 22'd.

The software to drive the proposed fully-immersive VR system has already been acquired by Rowan University and is currently being used for the existing semi-immersive system. This includes VGeo [33] and Vizard [34] for developing the virtual environment; Autodesk 3Ds Max and Maya [35] for developing the 3-D models.

The entire system will be installed in a designated laboratory in the Samuel Jones Innovation Center at the South Jersey Technology Park (the facility will be described in Section D: Management Plan). It is anticipated that the Imaging & NDE laboratory shown in Figure 1, will be moved to a room alongside – this allows for maximum interaction between research project teams involved with various aspects of imaging, image-processing and advanced scientific visualization.

Figure 10: A fully-immersive VR system CAVE® [32].
The CAVE® is the most widely installed fully immersive system in the world, and is owned by numerous universities, federal research laboratories and industrial prototyping facilities. The South Jersey Technology Park is the only such research park in the Southern New Jersey area and would therefore be the only facility to acquire this VR system. Rowan University is a member of the NJ Edge Consortium of Universities, which allows it a dedicated bandwidth to the high-bandwidth Abilene Internet2 network – therefore, a CAVE® installed at Rowan allows for collaborative immersion with CAVE®s anywhere in the United States that are similarly connected.

C. Impact of Infrastructure Projects

(i) Intellectual merit of the proposed activity

The acquisition and use of a fully-immersive VR system has a direct impact on the conduct of several on-going projects in the Imaging & NDE laboratory at Rowan University. We have described two specific application areas for the proposed acquisition; the intellectual merit associated with each is listed below –

(a) Development of VR platforms for the integrated systems health management of NASA’s rocket-engine test stands: The proposed project requires the development of novel data fusion capabilities such as those requiring the integration of heterogeneous sensor data. Furthermore, the real-time generation of an immersive, interactive and navigable display of the evolutionary scenario inside the VR environment requires the adaptive generation of model and data files – most commercial VR software are ill-suited for this purpose. A significant challenge of this proposed project is the development of a software framework that is portable and scalable for deployment in other environments. The results of this effort will be VR technology adapted to support the ISHM environment to provide a more useful framework for both ground operations and in-flight space systems. The proposed project has the potential to contribute to further evolution of on-going ISHM developments to higher technical and functional maturity levels to better meet NASA’s Human & Robotic Technology missions.

(b) Synthesis of particle aggregate mixtures from numerical 3-D shape descriptors: The use of advanced visualization in an immersive and interactive virtual environment will significantly enable the development of computationally efficient numerical shape descriptors of granular soil mixtures to be employed in developing realistic discrete element models that capture the actual soil morphology. This will allow the researcher to study the interaction between soil grains at the particulate level and improve the understanding from a micro-geomechanical viewpoint. The modeling effort will help verify the influence of particle shape on dilatancy, steady state shear strength of sands, cyclic behavior and liquefaction potential. This is important from a practical viewpoint because a fundamental understanding of soil behavior governs design of foundation elements for any type of infrastructure project.

As part of the supplementary documentation for this proposal, we have included letters from our collaborators at NASA Stennis Space Center in Mississippi and The University of Sydney in Australia.

(ii) Broader impacts of the proposed activity

The proposed immersive VR system is planned to be installed in the newly constructed South Jersey Technology Park [31], into which the Imaging & NDE lab facility that was described earlier in this proposal, will move. The Imaging & NDE Lab in the Rowan University College of Engineering is a multi-disciplinary, collaborative research and teaching laboratory that supports the R&D efforts faculty, students (both graduate and undergraduate) and industrial partners. To date, the funded research activity in the Lab exceeds $2.4 million. The Lab has also seen extensive media coverage – television (Channel 6-ABC, The History Channel, New Jersey Network), local newspapers (Courier-
Post, Phila. Inquirer, Gloucester County Times, Star Ledger) and national magazines (ASEE Prism, Pipeline & Gas Journal, ASCE Civil Engineering Magazine etc).

Previously funded research projects in the Imaging & NDE Lab have had significant educational impact. To date, the Lab has employed over 40 undergraduate research assistants and 14 graduate research assistants. The Lab has supported an average of three multi-disciplinary Engineering Clinic projects every semester since Fall 1999, impacting approximately 150 students. So far, 9 Faculty from three engineering disciplines (ECE, ME, CEE) have collaborated on research and education projects. We anticipate that 10 undergraduate students and 2 graduate students will use the proposed system every semester.

The Engineering Clinic is a series of courses taken each semester by every engineering student. In the Engineering Clinic, which is based on the medical school model (and adapted from Harvey Mudd’s implementation), undergraduate & graduate students and faculty from all four engineering departments work side-by-side on multidisciplinary laboratory experiments, design projects, applied research, and product development. Incorporating the use of the proposed VR system into the Senior Engineering Clinic will satisfy both technical and educational objectives. From a technical standpoint, the Engineering Clinic will provide the project with a competent, experienced, multidisciplinary workforce of students and faculty from all four disciplines within the College of Engineering. From an educational standpoint, the project will provide senior undergraduate students the opportunity to take part in a complex, multifaceted project with real-world applications.

The South Jersey Technology Park is a collaborative effort between the State of New Jersey and Rowan University to revitalize the economic development of the Southern New Jersey region. In 2001, the Rowan University was awarded a grant of $5.8-million by the New Jersey Economic Development Authority to establish the South Jersey Technology Park. Additional grants from the Delaware River Bay Authority and a $1-million gift from a local entrepreneur, Samuel H. Jones, provided for $11-million of total funding. The goal of the SJTP is to lead the economic revitalization of southern New Jersey through an integrated strategy of science and technology initiatives. The mission of the SJTP is to:

- Expand and strengthen the unique research and learning environment of Rowan University,
- Establish a technology-based entrepreneurial economy, and
- Create value for its surrounding communities in their economic, physical and social development.

The acquisition of an advanced VR facility such as the CAVE® has the potential to attract anchor tenants to this facility and will have a significant economic impact in the region in terms of the development of a high-technology enabled workforce.

D. Project Management Plans

(i) Facility

The proposed VR system will be installed in a laboratory in the Samuel Jones Innovation Center at the South Jersey Technology Park. The approximate footprint of the system is 11.6’h x 30’w x 22’d. The lab modules in the Innovation Center are 12’h x 32’w x 24’d. We have consulted with the architect and have arranged for the removal of the dividing wall between the VR lab and the adjacent Imaging & NDE lab, to enable maximum interaction and improved traffic flow. As part of the supplementary documentation for this proposal, we have included a letters of institutional commitment both from the Rowan University administration and the South Jersey Technology Park.

(ii) Personnel

Faculty and technicians: The PI and co-PI will share in the oversight of the proposed project. Although the entire system will be professionally installed by the manufacturer, the engineering
technicians (Electronics, Computer and Civil) will be available to provide system support during the course of the project.

**Dr. Shreekanth Mandayam** (PI) is graduate from Iowa State University’s NDE group, and has been extensively involved in the design and development of imaging and nondestructive evaluation systems, both as part of his graduate work and as a faculty member at Rowan University. He directs the research activities at the Imaging & NDE laboratory at Rowan, with sponsorship from NSF, NASA, DoE, NIH, US Navy, ExxonMobil, US Army TACOM, Water Environment Research Foundation, etc. He is a Senior Member of the IEEE, Chair of IEEE Student Activities for IEEE Region-2 and serves on the Administrative Committee of the IEEE Instrumentation & Measurement Society.

**Dr. Beena Sukumaran’s** (Co-PI) research interests include evaluating the performance of suction caissons in different soil conditions, investigating the feasibility of using fly ash for construction, effect of inherent particle characteristics on liquefaction potential, fuzzy set applications in geotechnical engineering and use of the discrete element method to investigate the interaction forces acting on particles. She has been involved with several pre-engineering programs for middle school and high school students. Through the AWE (Attracting Women into Engineering) program for middle school girls, she has focused on informing students about engineering careers and stimulating their enthusiasm for engineering education.

**Students:** Together, the investigators will oversee a team of 5 – 10 undergraduates in this Junior/Senior Clinic project and approximately 2 graduate students each semester. The students will be assigned, in a “Project Fair” at the beginning of each, by the discipline managers (faculty members) from each of the four engineering departments. Vertical integration across the graduate (Master’s level) and undergraduate curriculum is expected. Each year, the College of Engineering at Rowan University provides full stipend and tuition for 8 graduate students among the 4-departments in engineering. Since this is a multidisciplinary project proposal from two engineering departments, it is anticipated that at least 2-graduate students will be supported on this project, at no cost to NSF. These two students will be primarily responsible for the day-to-day operation of the VR system.

**(iii) Timeline**

The project is expected to be completed in three phases, divided equally over three years. During Year 1, the VR system will be purchased, installed and calibrated. The research team will familiarize themselves with the operation of the system and begin developing procedures for integrating this added capability into existing projects in the Imaging and NDE laboratory. During Year 2, we will specifically address the use of the VR system in the two research projects described in this proposal. In Year 3, we will begin efforts on attracting external constituents (industrial collaborators) to use this facility at the South Jersey Technology Park. The intent is to develop the VR facility as a “cost-center” so that future upgrades and maintenance of the system are self-sustaining.

**(iv) Dissemination activity**

The main venues for the dissemination of research activity related to new contributions to Integrated Systems Health Management will be at the following annual conferences: *International Instrumentation and Technology (I2MTC)* and *IEEE Sensors Applications Symposium*, both leading to publications in the *IEEE Transactions on Instrumentation and Measurement*. New software methods developed for interactive data visualization will be submitted for publication in *IEEE Transactions on Visualization & Computer Graphics*. The particle characterization findings will be published in refereed geotechnical journals such as *Géotechnique*, ASCE.’s *Journal of Geotech. & Geoenv. Engrg.*, the *Int. Journal of Num. and Analytical Methods in Geomech.*, and *Computers and Geotechnics*. In addition, the PIs will target refereed journals across other disciplines, where particle characterization are of interest to the respective audiences. Examples of such journals include *Sedimentology, Engineering Computations, Powder Technology*, and *Granular Matter*. Experiences in educational scholarship activity as a result of involving undergraduate students in research will be disseminated at the annual conference of the *American Society for Engineering Education* and the *Frontiers in Engineering Education* conference.

15