HANDS-ON ENGINEERING AND SCIENCE: DISCOVERING COSMIC RAYS USING RADAR-BASED TECHNIQUES AND MOBILE TECHNOLOGY

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ABSTRACT

This paper reports on the latest efforts of the MARIACHI[1] program at Stony Brook University, a unique endeavor that detects and studies ultra-high-energy cosmic rays. This is done by using a novel detection technique based on radar-like technology and traditional scintillator ground detectors. Using the phenomena of cosmic rays and meteors as vehicles to motivate research and educational activities, innovative hands-on modules in physics, engineering and cyberinfrastructure based on a learning by doing philosophy are offered to high school teachers and students. Participants at all levels are engaged in research projects, seminars, and workshops, where they will learn to use tools needed in MARIACHI by means of mobile technology.

Index Terms— MARIACHI, ultra-high-energy cosmic rays, multidisciplinary education, radar-based techniques, scintillator ground detector, mobile technology.

1. INTRODUCTION

Education in science and engineering is optimally achieved in the challenging research environment. Providing students of all ages with intensive hands-on research experiences while working side by side with engineers, scientists and educators, is the key component of this project. It builds upon the creative framework of the MARIACHI [8] program at Stony Brook University, a unique endeavor that integrates research at the frontier of human knowledge with a broad discovery-based educational program. Driven by the quest to develop a new technology for the detection of ultra high energy cosmic rays [3, 4], this project motivates teachers and students to experience cutting edge technology and learn forefront science. The novel detection technique is radar-based and leads naturally to the implementation of strong educational and research programs in engineering, and in particular signal processing.

MARIACHI propagates the philosophy of *learning by doing* to students at all levels by means of research projects and classroom activities using a knowledge propagation chain [1]. At the top, graduate and undergraduate students help faculty with the development and delivery of research projects and workshops that are administered to teachers and high school students. Teachers lead the development of classroom curriculum with the aid of scientists and graduate students. In the process of implementing this educational structure, we have spawned workshops for educators, regular courses, and seminars for a wide audience on various topics related to the project including cyberinfrastructure, data analysis, radar technology, and cosmic ray science. To broaden the impact of the project we have implemented classroom activities to a broader audience with particular emphasis on traditionally underrepresented groups. To that end we have partnered with the CESAME (Center for Science and Mathematics Education) [2] and the WISE (Women in Science and Engineering) [7] programs at Stony Brook University.

During the past academic year, our program has been effectively modernized and streamlined in both research and educational aspects with the implementation of mobile technologies and wireless data collection systems. At the MARIACHI home, the exploitation of mobile computing by use of Tablet PCs has allowed students to perform analysis while interacting with each other in class or remotely to other classrooms and participants elsewhere.

In this paper we describe in some detail the latest efforts related to this multidisciplinary project. We report on a summer workshop for high-school students and teachers as well as for new college faculty interested in replicating the activities at their home institutions; and on the use of mobile computing for enhanced teaching and learning. The remainder of the paper is as follows. The next section describes the science and engineering challenges related to the project. In Section 3 the educational activities are explained in detail. Section 4 addresses the inclusion of mobile technologies in the classroom, and finally, Section 5

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[1]Mixed Apparatus for Radar Investigation of Cosmic-rays of High Ionization.

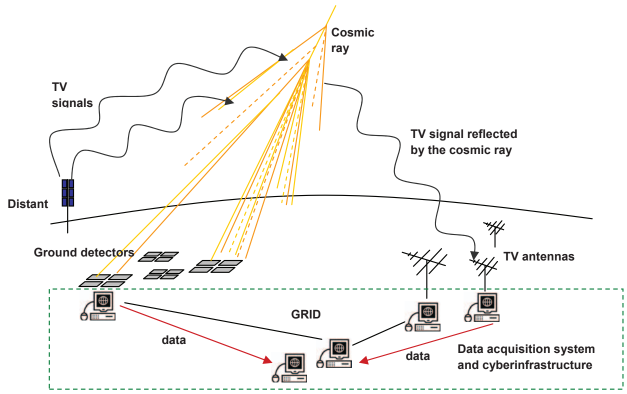

Fig. 1. Pictorial description of the MARIACHI experiment.

includes some concluding remarks and future plans.

2. RESEARCH ACTIVITIES

The research from this project adds to the efforts of scientists throughout the world to collect information about ultra high energy cosmic rays, that is, the rate of their occurrence and the location where they are detected. The scientific objective is to exploit the potential of forward-scattering techniques [5, 6] for detecting and analyzing signals that are set off by cosmic rays. These methods are based on similar principles as those of radar and allow for building inexpensive stations that can easily cover very large geographical areas.

Figure 1 depicts the basic components of the MARIACHI experiment:

- Radar: MARIACHI uses TV antennas connected to wideband and computer-controlled radio receivers. The received signals are analyzed in order to find echoes from distant TV stations. Most of the echoes are from airplanes, meteors evaporating and ionizing very high in the atmosphere, lightning, and some sporadic ionization phenomena.

- Scintillator ground detectors: To confirm possible cosmic ray radar signals we place ground detectors in selected locations (mostly high schools). These scintillators detect debris from cosmic ray cascades and record the time of occurrence using a GPS clock. The times are compared to the times of occurrence of radar echoes.

- Cyberinfrastructure: In order to capture and analyze the data from the geographically separated radar and detectors, MARIACHI implements a sophisticated data acquisition, analysis, and communication system based on the emerging technology of the grid. GPS time-stamped events detected at each site are transmitted via the internet securely to a central server that only accepts data from a grid-certified computer within MARIACHI. There are three data streams to be collected: radar data, cosmic ray scintillator data, and environmental parameters.

The research program focuses on the processing and analysis of the data acquired by the experimental setup. To that end, the MARIACHI program has already installed conventional particle detectors at thirteen sites (mostly high schools) and radar setups at four locations (Stony Brook University, Suffolk County Community College, Brookhaven National Laboratory and Custer Institute).

3. EDUCATIONAL ACTIVITIES

The educational program flows from the inspired concept to teach high school teachers and students to build and operate the scintillator ground detector sites and to help analyze the data taken by both radar and ground detectors. The MARIACHI home is equipped with scintillator detectors, electronic logic, TV antennas and receivers, and computers. Using this facility, we introduce MARIACHI science, technology, and cyberinfrastructure topics to the high school participants. The range and variety of activities is large and comprises from understanding concepts like frequency or cosmic rays to calibration of antennas (which are outside the laboratory) used for data collection, counting of events with ground detectors, collection and analysis of data, or reporting of results.

3.1. Building the detectors

The MARIACHI detector concept was developed through a series of one-day workshops for high school teachers and students. The first cosmic ray ground detector building workshop took place at CESAME, where teams of teachers and students from Brentwood High School and Rocky Point High School assembled and tested their detectors. As schools take ownership of their equipment, they must understand in great detail the functioning of each detector component; thus these workshops are essential. Demonstrations that illustrate the experimental setup and the underlying science have been developed by MARIACHI participants, complement the material offered in the school curriculum, and are accessible on our website.

Once the setup is properly running in the classroom, students are assigned various data analysis tasks including evaluating the number of events per time interval, which is used to check if the data are truly random (Poisson Distribution); counting the number of events per hour, which allows for verification if there are day/night differences (Student's T test); or calculation of cosmic ray rates as function of barometric pressure, which seeks to find a

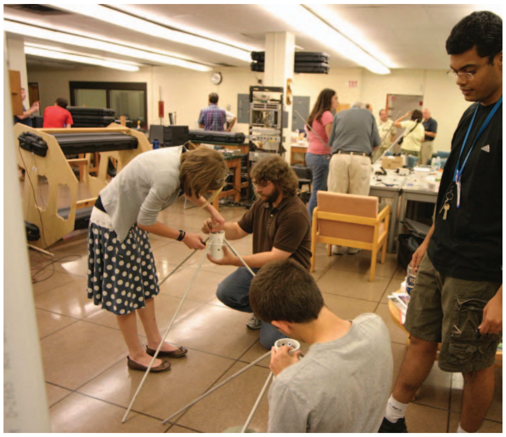

Fig. 2. Building antennas during the MARIACHI summer workshop.

correlation with atmospheric pressure and the number of cosmic ray events detected.

3.2. Summer workshop

A one-week summer workshop comprising all the elements of MARIACHI, i.e., radio processing, scintillator ground detectors and cyberinsfrastructure has been implemented and offered in a novel way. The workshop has been designed for physics and research teachers, as well as high school students interested in pursuing research projects. It is a combination of training, brainstorming, and hands-on sessions where we review the science reach of the experiment, the equipment that is available to schools, the experiment's cyberinfrastructure, and the data collected. The instructors of the workshop are MARIACHI participants and include faculty, technicians, postdoctoral students, graduate students and high school teachers. The use of a secure wiki[2] and email, and other cyber-communication tools are exploited. Through brainstorming sessions the goal of the workshop is to catalyze groups around common research interests and establish tracking mechanisms to monitor progress. Students should come away from the workshop with a research plan and the beginnings of a project.

Unlike previous years, this summer many of the activities were focused on radar technology with the long-term objective of introducing radar sites at high schools. Some of these activities included experiments using radar elements like characterization of MARIACHI antennas (Figure 2), radar location or clock synchronization; and exercises related to the analysis and acquisition of radar data like measuring received signals at Stony Brook using spectrum analyzer or processing of data files using software packages like Octave. We describe in detail two of the radar-like activities:

- Measuring the speed of sound: The speed of sound was measured using an experimental setup consisting of a speaker and two microphones. The speaker generated a pulse waveform, which was recorded on each of the microphones. The time delay between the arrivals of the waveform at the microphones was measured using a PC-based software oscilloscope and the sound card. Based on the known distance between the microphones, and the measured delay, the students calculated the speed of sound.

- Object localization: This activity introduced the students to the ideas of trilateration and multilateration. The students calculated the algebraic solution for the location of an object using trilateration in a noise-free case. The data for this case came either from oscilloscope measurements performed by the students (in which case there was some small error) or synthesized data. The students also developed a method for solving the multilateration problem with noisy measurements using the computer (using Excel or in a programming language like Matlab, depending on the background of the students).

It is important to mention that this year we also hosted faculty from other institutions (Wright State University - Dayton Ohio, Messiah College - Hershey PA, York College - Queens NY, IDCAST - Dayton Ohio) who were interested in replicating our activities at their home institutions. Overall, the response of the participants to the course was very positive as evidenced by their comments on surveys and the wiki.

3.3. Research projects at high schools

As result of the previous activities, some students have developed their Intel projects[3] under the supervision of MARIACHI researchers. Two of the students at Wellington Mepham High School were 2007-2008 Intel semi-finalist. One of them developed a pattern recognition software to identify meteors, lightning and airplanes in signals seen by a MARIACHI radar.

MARIACHI has also offered the opportunity for teachers to participate in the ongoing research experiments with many possibilities for personal as well as professional growth. As result of these collaborations some of them have developed new materials for their classes and have spent six weeks in the summer at Brookhaven National Laboratory as research associates.

4. MOBILE TECHNOLOGY

Due to the physical separation of the experiment resources, the offered courses and workshops needed a well defined

[2] A wiki is software that allows to create, edit, and link web pages easily.

[3] The Intel Science Talent Search is a US pre-college science competition.

Fig. 3. Use of TabletPCs during the MARIACHI summer workshop.

set of activities that could not be properly combined and developed to full extent. The exploitation of portable computing technology in the class introduced this summer for the high school workshop has provided with many opportunities for students to move from activity to activity writing notes easily, storing data, sharing results, asking questions, or presenting results. It has enhanced the teaching and collaborative learning by providing multimedia support for friendly explanations and presentations and by facilitating communication between the instructor and the students and among students as they move from setup to setup. Besides, we were be able to program parallel activities so students could share the work load and participate in various experiments at the same time. The new delivery has increased the quality of the student learning, the curiosity and the rapid absorption of new concepts and ideas.

The use of Tablet PCs (Figure 3) have provided the means for successful integration of the theoretical and practical components of the course deliveries in only one classroom. All the needed resources were available to perform theoretical explanations, programming experiments, or research activities. Students and instructors were able to communicate even if they were carrying out different activities in different locations. By connecting the Tablet PC to a projector and Smartboard, we had a fully interactive presentation system that allowed for delivery of highly visual and dynamic lectures with multimedia presentations and demos. Besides all the notes, students exercises and live elements of the discussion sessions were saved, which facilitated keeping more accurate records of students progress. It also allowed for a more individualized attention to the students.

5. CONCLUSIONS AND FUTURE WORK

MARIACHI's goal of bringing science and engineering research to classroom is achieved while students are exposed to cutting edge technology. The workshops and educational activities are motivated from the science of detecting ultra high energy cosmic rays using radar-based methods. Current efforts include implementation of full wireless data transmission which will allow for the installation of detectors in sites with poor land based network services.

In the past year the experiment has attracted interest by some faculty from other institutions. To facilitate their participation in our effort the interested institutions have taken part in the 2008 summer workshop to get acquainted with the aspects of MARIACHI. As a result, we plan on seeding similar infrastructures at some selected colleges outside Long Island.

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