The Sensor Signal and Information Processing REU Site

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"I received my B.S degree in Electronics and Communications from the National Institute of Engineering, India in 2011. I am currently pursuing my Master's and PhD program in Electrical Engineering at Arizona State University(ASU). I am advised by Dr. Andreas Spanias. I joined Sensor, Signal and Information Processing Center (SenSIP) at ASU in Jan 2016. My research interests lie at the overlap of sensors and Machine learning and Big Data including, but not limited to Pattern recognition and Anomaly detection. In summer 2016, I did a summer internship at NXP Semiconductors where I worked on sensor data analytics for anomaly detection. I worked on integrating machine learning algorithms on an embedded sensor systems for Internet of Things applications, which can identify anomalies in real time. Before joining ASU, I worked as Systems engineer for 4 years at Hewlett Packard Research and Development, Bangalore, India."

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The Sensor Signal and Information Processing REU Site

Abstract – A unique Research Experiences for Undergraduates (REU) site was established at our University to address education and research problems in integrated sensor device and DSP algorithm design. The site will recruit and train nine undergraduate students each summer and engage them in research endeavors on the design of sensors including student training in mathematical methods for extracting information from sensor systems. The program was launched in 2017, and nine undergraduate research projects advised by a team of faculty advisors started in the summer. The projects embedded REU students in tasks whose focus was to design sensors and interpret their data by studying and programming appropriate machine learning algorithms. The paper describes the technical details of the research activities and summarizes an independent assessment of the projects and learning experiences.

1. Introduction

Undergraduate research projects, assessments and outcomes were reported in several recent papers [1-5]. A Research Experiences for Undergraduates (REU) on sensors and machine learning was initiated at our University in the summer of 2017. The program recruited a group of nine students from several programs across the country. Of the nine REU participants, five (56%) were male and four (44%) were female. The participants represented a diverse racial and ethnic group with three (33%) reporting they were Asian, one (11%) reporting they were Black/African American, 2 (22%) reporting they were Hispanic/Latino, 2 (22%) reporting they were White/Caucasian, and one (11%) reporting they were mixed race (African American and Caucasian). While five (56%) of the participants reported that they had participated in undergraduate research, only one (11%) reported they have participated in an REU program. REU participants stated that they heard about the program through faculty members (44%), the website (22%), an academic advisor (22%), and through a friend or colleague (11%). REU participants were from a variety of majors including: Biochemistry, Biomedical Engineering, Computer Engineering, Computer Information Technology, Computer Science. and Electrical Engineering. The titles of the REU projects are given below and abstracts are given in [6-14]:

- Photoplethysmogram Sensor Array;
- Nanopore Sensors and Signal Processing;
- Development of CO_2 analyzer for Health Monitoring;
- Fluorescent-based POC detection of cervical cancer biomarkers;
- Exercise Routine Optimization Via Sensor Fusion;
- Crowd Sourced Environmental Monitoring;
- Managing Respiratory Disease with Wearable Devices;
- Physiological Monitoring for Childhood Asthma;
- Mobile Applications for Health Monitoring.

Unique aspects of the REU program are: a) integration of sensor hardware and machine learning algorithm research experiences, b) development of video streamed discipline-specific and cross cutting modules, c) requirements to produce and present reports in IEEE style, and d) training in preparation of pre-disclosures.
Assessment and evaluation was completed by ASU's College Research and Evaluation Services Team (CREST) in the Institute for the Science of Teaching and Learning. CREST conducted both formative and outcome assessment. Formative assessment, or implementation evaluation, analyzed the activities delivered, participation in activities, and participant satisfaction. Outcome assessment, or impact evaluation, analyzed changes in participants' knowledge, perceptions, and skills as a result of the summer program.

1.1 Recruitment

The REU plan for recruitment that was stated in our proposal was executed. Electronic forms were uploaded on our REU web site and on the NSF web site. Although our grant was approved in late January of 2017, we had more than 80 applicants. In our evaluations, we have focused on past performance, statement of purpose documents, providing research opportunities to community college students, and we emphasize diversity. Our recruitment of nine students included veterans, community college students, and URM participants. Upon recruitment, students were placed in different labs and in most cases students were co-advised by two faculty; one on devices and one on software. Our assessment results were compiled after the end of the program and are described later in this paper.

Fig. 1 REU class of nine students recruited along with the Co-PIs on campus in June 2017.

2. REU Integrated Sensor Device and Algorithm Projects

REU projects were chosen to include an integrative sensor hardware and software experience. All projects associated with health-related applications. The training experience objective was to bridge the gap between sensor device design and sensor signal processing algorithm/software. For this reason, both hardware and software aspects of sensors were included in video streamed modules and in the projects. The projects and a brief summary for each one is listed below.

2.1 Photoplethysmogram Sensor Arrays for the Detection of Early Signs of Cardiac Disease [6]

Photoplethysmogram (PPG) sensor arrays (Fig. 2) are devices used to measure the volume of blood flowing through an organ. The device uses OLEDs to create an AC-Modulated light signal and then captures the signal data from beneath the skin non-intrusively. Using inexpensive flat panel screens bonded to a flexible backing, the device can be miniaturized and attached to the user's skin so that it is not cumbersome. Data will then be used in machine learning algorithms to detect age related cardiac issues.

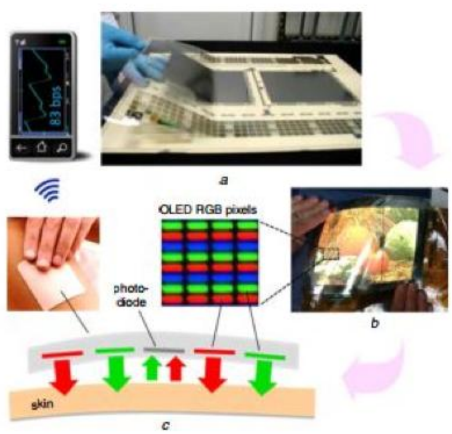


Fig. 2 Flexible sensor array used as a patch on the patient's skin [27].

2.2 Nanopore Sensors and Signal Processing [7]

Nanopore sensors (Fig. 3) and the associated signal processing have been used in several applications including: DNA analysis, sensing of analytes at the molecule level, biothreads and medicine. One challenging problem is the very low currents transmitted from the sensors which are susceptible to noise. The REU experience here consisted of characterizing ion channel currents and applying wavelet transformations to reduce noise. More specifically the REU project studied ion channel signatures [26], denoising of ion-channel signals using various filtering methods, and wavelet signal representations. The REU student applied wavelets to demonstrate that appropriate selection of the basis leads to improved signal to noise ratios and improved event detection.

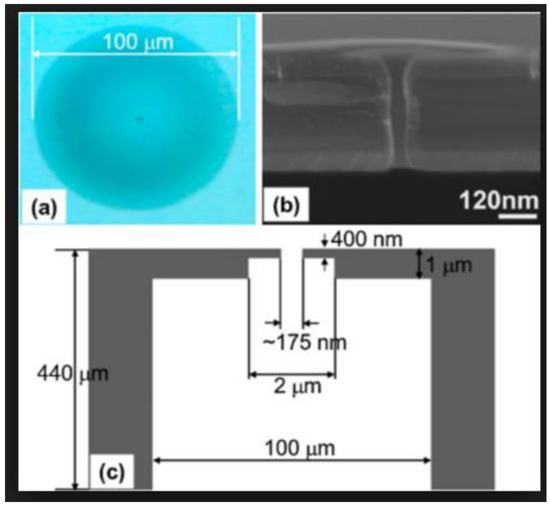


Fig. 3 Nanopore sensor design [25].

2.3 Fluorescent-based lateral flow point-of-care detection of cervical cancer biomarkers in serum [8,16]

Point-of-care (POC) diagnostics tools (Fig. 4) provide low cost methods of disease detection in low resource settings. Our POC device, shown in Figure 4, was developed to detect antibodies in serum to HPV16 biomarkers (E2, E6, E7) for cervical and head and neck cancers. The current POC model has been optimized for detecting antibodies in serum to recombinant biomarkers immobilized on a glass substrate. The POC device uses cheap green LEDs and optical filters to semi-quantitatively measure the fluorescence of captured and labeled antibodies. The project investigates nitrocellulose as an optimal substrate for enabling fluid handling and serum filtration while keeping the same or similar sensitivity for our POC test.

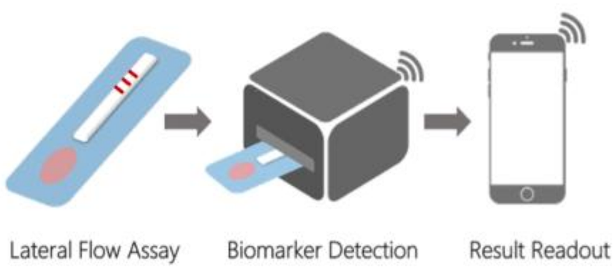


Figure 4. Biomarker detector based on a Florence based sensor.

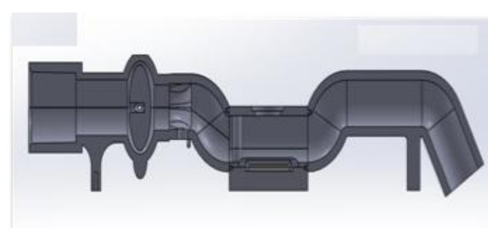


Fig. 5 The colorimetric sensor used for measurements.

2.4 Development of a CO_2 Analyzer [9]

The development of a CO_2 analyzer for health monitoring purposes is studied in this project. Of interest were analysis of signatures associated with Cardiovascular disease, Asthma, and COPD.

The analyzer used in this study was chosen to be low-cost consisting of colorimetric sensing technology. The colorimetric sensor (Fig. 5) used a pH dye and base coated on a Teflon membrane. Research experiments dealt with the robustness of flow in the sensor relative to temperature change. MATLAB was used to study the signal behavior and analyze noise sources. The system involved a breathing tube with a sensor whose signal was processed and displayed via a smartphone application.

2.5 Activity Detection and Exercise Routine Optimization via Sensor Fusion [10,17]

Internet of Things (IoT) has enabled a plethora of applications related to data analytics. In this REU project, an intuitive method for optimizing exercise routine data, and then providing feedback for future workout routines is presented. This method utilizes various Microcontroller Units (MCUs) with a variety of embedded sensors (Fig. 6) for activity detection Additionally, this method also incorporates supervised and unsupervised learning algorithms, including multi-class Gaussian Support Vector Machine (SVM) and K-Means algorithms.

Fig. 6. Sensors used for experiments on activity monitoring and classification [21,22].

2.6 Crowd Source Environmental Monitoring [11]

Respiratory disease patients that have our wearable devices to monitor their health, they can also monitor their current environment for temperature, ozone, and particulates. Inexpensive sensors will be used to collect the data, larger numbers of the sensors will ensure reliability. With constant collecting of sizable amounts of environmental data we propose to investigate a proper algorithm to gather and correlate the spatial and temporal data of the outdoor.

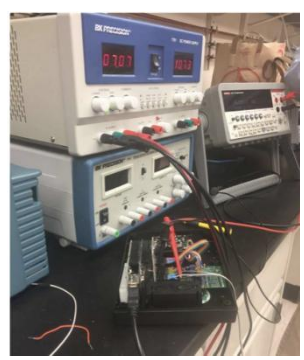


Figure 7. Environmental Monitoring Sensor.

2.7 Managing Respiratory Disease with Wearable Devices [12]

Pollutants such as dust particles and ozone are known to distress patients with respiratory disease. Currently, the one pollutant map available gives only a single value for the entire greater Phoenix (Arizona) area. The goal of this REU project is to develop wearable devices from small, inexpensive microprocessors and sensors that will measure these pollutants and compile the data into a real time, publicly available pollutant map.

2.8 Physiological Monitoring for Childhood Asthma [13]

Asthma is the leading chronic childhood disease that affects seven million children in the United States. Currently, there is not a simple scientific method of continuous monitoring of physiological or environmental conditions of asthma patients. The purpose of his REU project is to create a wearable device to connect human patients and the environment. This will be done by creating a Human-in-the-loop Cyber Physical System. These COTS-sensors will be used to create a pilot system. The pilot device will provide valuable data that will help implement the goal of an integrated health care device that enables patients to identify stressors and manage treatment. The data collected by the device will enable correlation of symptoms.

2.9 Human Factors Engineering for Mobile Health Applications [14,15]

Childhood asthma has effectively doubled since 1980 and currently affects about 8% of the U.S. childhood population. Efficiently analyzing quality of air data, which would ultimately improve the information available to parents with children suffering from asthma is crucial to reduce the likelihood of a serious attack. In order to accomplish this task, the use of low-cost, wearable, environmental sensors with appropriate data processing is necessary.

3. REU Training Modules.

The Co-PIs developed several modules which were prerecorded, and video streamed through a blackboard site. The modules included: Introduction to the REU Logistics and Research, Signal processing essentials, sensor device design and introduction to machine learning basics [19]. The modules were accompanied by hands on sessions in the SenSIP labs where students worked on filtering synthetic and real life sensor signals, and on obtaining and interpreting spectra of such signals. Students were also exposed to adaptive filtering [32] and linear prediction [18, 28-31] as these methods can be used to denoise and parameterize signals. Training continued with students learning the basics of feature extraction using principal component analysis and other methods. The training was done using MATLAB examples and J-DSP [20,23,24] training exercises. Each module was assessed with a pre- and post-quiz.

3.1 Hands-on Training Sessions in Signal Processing Software

During the first week, students were trained in using signal processing software tools for sensor signal analysis. The sessions were supervised by graduate students and the Co-PIs. Students learn how to acquire, process a signal frame by frame, take Fourier transforms and visualize spectra and spectrograms. Students were first exposed to an object-oriented program called Java-DSP (Fig. 8) and then they were asked to program several functions in MATLAB.

Fig. 8. Training in the J-DSP Lab. Graduate students advising REU students.

3.2 Additional Details on the Modules

Modules started immediately in the summer program. The first module was introductory and consisted of explaining the program structures, policy, lab safety, information handling, and publications. The second module was about 3 hours of video introduction on signal processing and more specifically the theory and practice of sampling, filters and spectra. The third module addressed hardware and flexible sensors and the properties of different types of circuits and transducers. The fourth module went into the details of machine learning and clustering. The signal processing and machine learning modules were accompanied by computer laboratories. The fifth and sixth modules were crosscutting addressing patent development, proposal preparation and conference paper writing. The fifth and sixth modules had writing exercises which were assessed by the module instructors and the Co-PIs.

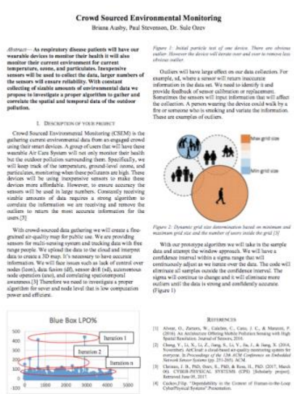
4. Dissemination and Feedback

We have organized several dissemination activities and we embedded the REU students and their projects in industry meetings. The PI of the grant heads an I/UCRC site that ran a meeting in June 2017. Each student participated in the meeting with a one-minute elevator pitch and a poster (Fig. 9). Students were asked to develop proposal posters which were first critiqued by the Co-PIs and graduate mentors. After two iterations on the poster design, the students presented those to an industry audience and obtained feedback.

Fig. 9. REU Poster Session at Industry-University Meeting.

4.1 Journal Style Proposals and Final Reports

To train the students to develop or participate in scientific research papers we established a process where two-column journal style proposals (Fig. 10) and reports had to be submitted. The reports included properly cited and formatted reference sections. The students submitted drafts which were then discussed in the weekly meetings. The Co-PIs, the faculty and graduate advisors provided feedback to the students and enabled them to improve their submissions.



Crowd Sourced Environmental Monitoring

Briana Ausby, Paul Stevenson, Dr. Sule Ozev

Human Factors Engineering for Mobile Health Applications

Chad Snyder, Advisor: Dr. Heather Ross, SenSIP Center, School of ECEE, Arizona State University

Fig. 10. Samples of two column journal style 1-page summaries of projects submitted by REU students within 10 days of their REU experience. Extended final reports with similar formats were submitted at the end of the program.

4.2 Weekly Review Meetings

The students met with the Co-PIs once a week for nearly 4 hours. In the meetings, all students gave presentations of their progress and obtained feedback from the Co-PIs. The meetings also included an informal session where issues in research labs were discussed. The evaluator also had individual sessions with the students to obtain information on the program, the research progress and discuss any advising problems. These sessions were accompanied by a social meeting. The social meetings strengthened the cohort.

5. Preliminary Assessment

Students were given surveys at the end of the program and asked to rate their satisfaction with the program. All participants completed a survey (100% response rate) so these results are representative of all students' perceptions of the program. As indicated in the chart below (Fig. 11), participants reported high levels of satisfaction. One hundred percent reported being satisfied or highly satisfied with the overall program in general, the schedule of the program, and communication with the REU program prior to arrival. Only one student reported that living arrangements were unsatisfactory, all other students reported being satisfied or highly satisfied.

Satisfaction with the Program

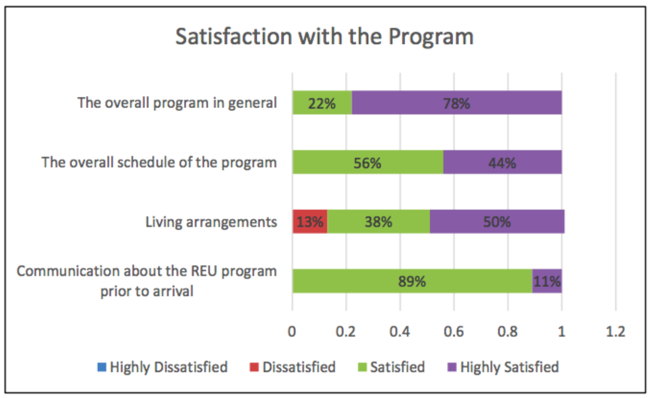


Fig. 11. REU Students' assessment of the overall program, schedule, and living arrangements.

5.1 More Details on Assessments

Formative assessment used document review to confirm that planned REU activities were implemented. Data were collected on satisfaction and perceptions of activities. These data were shared with the Principal Investigators and grant staff to make data-driven decisions on program activities. Further, through the use of pre- and post-program surveys, observations, interviews, and document review, outcome evaluation was completed. Survey data were used to examine changes over time in knowledge of sensor circuit device design issues and algorithm functional operation concepts and perceived skill in these areas. Further, surveys examined changes in problem solving, communication, creativity, collaboration, and research skills. Modules were also assessed with pre- and post quizzes and interviews. The assessment will be carried again for Year 2 and results will be compared. Data and graphs summarizing results from these assessments are being compiled and will be presented at the conference.

6. Conclusion

The sensor devices and algorithms REU program was described along with its assessments. The program recruited a group of culturally, race and gender diverse students coming from community colleges and research universities. The program included both structured training organized in video streamed modules, software and algorithm training that included classroom and computer lab training, and research lab experiences. The research lab experiences are where students spent most of their time. An independent evaluator assessed all facets of the program and provided a report that will be presented at the conference. Three of the students have published their work with one of them being a finalist for a student paper award. We have followed up with the students through social media. More details including specific references to projects, students, related publications and assessments are given in [8-36].

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