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Program Income Reporting
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Administration
Look Up NSF ID

Preview of Award 1827565 - Annual Project Report

Cover |
Accomplishments |
Products |
Participants/Organizations |
Impacts |
Changes/Problems
| Special Requirements

Cover

Federal Agency and Organization Element to Which Report is Submitted:	4900
Federal Grant or Other Identifying Number Assigned by Agency:	1827565
Project Title:	PFI-TT: Software for Automated Real-time Electroencephalogram Seizure Detection in Intensive Care Units
PD/PI Name:	Iyad Obeid, Principal Investigator Joseph Picone, Co-Principal Investigator
Recipient Organization:	Temple University
Project/Grant Period:	08/01/2018 - 09/30/2021
Reporting Period:	08/01/2020 - 07/31/2021
Submitting Official (if other than PD\PI):	N/A
Submission Date:	N/A
Signature of Submitting Official (signature shall be submitted in accordance with agency specific instructions)	N/A

Accomplishments

*** What are the major goals of the project?**

There are three main goals of this project: **(1) technology hardening:** create a real-time system that is capable of being deployed into clinical environments and support clinical testing, **(2) technology enhancement:** close the gap on performance between our state of the art system and clinically acceptable performance, and **(3) technology evaluation:** evaluate the system on a previously unseen data set to demonstrate that performance translates to a broad range of clinical operating conditions. The expected impact of these three goals is that the research system developed previously under SBIR funding should be transformed into a commercially viable product.

*** What was accomplished under these goals and objectives (you must provide information for at least one of the 4 categories below)?**

Major Activities:

There are three major activities associated with this project: (1) improve the performance of our seizure detection system to meet clinical targets; (2) create a real-time implementation of our best research system that has low latency and is acceptable for clinical use; and (3) continue our attempts to validate and commercialize the technology.

With respect to the first activity, our best research system, which we refer to as the baseline system for this grant, is fully described in Vinit Shah's PhD dissertation (Shah, 2021), which was successfully defended in May 2021. This dissertation represents the cumulative work of one of our two students who initiated our work in automatic seizure detection. The central thesis of his work is that separation of the seizure detection problem into a two-phase problem – epileptiform activity detection followed by seizure detection – should improve our ability to detect and localize seizure events. In the first phase, we used a sequential neural network algorithm known as a long short-term memory (LSTM) network to identify channel-specific epileptiform discharges associated with seizures. In the second phase, the feature vector is augmented with posteriors that represent the onset and offset of ictal activities. These augmented features are applied to a multichannel convolutional neural network (CNN) followed by an LSTM network.

The multiphase model was evaluated on a blind evaluation set and was shown to detect 106 segment boundaries within a 2-second margin of error. Our previous best system, which delivers state-of-the-art performance on this task, correctly detected only 9 segment boundaries. Our multiphase system was also shown to be robust by performing well on two blind evaluation sets. Seizure detection performance on the TU Seizure Detection (TUSZ) Corpus development set is 41.60% sensitivity with 5.63 false alarms/ hours (FAs/24 hrs). Performance on the corresponding evaluation set is 48.21% sensitivity with 16.54 FAs/24 hrs. Performance on a previously unseen corpus, the Duke University Seizure (DUSZ) Corpus is 46.62% sensitivity with 7.86 FAs/24 hrs. Our previous best system yields 30.83% sensitivity with 6.74 FAs/24 hrs on the TUSZ development set, 33.1% sensitivity with 19.89 FAs/24 hrs on the TUSZ evaluation set, and 33.71% sensitivity with 40.40 FAs/24 hrs on DUSZ.

Our second student, Meysam Golmohammadi, who pioneered our work on applying deep learning to seizure detection and was the Chief Technical Officer of our start-up, Biosignal Analytics Inc., also successfully defended his dissertation (Golmohammadi, 2021) in June 2021. This dissertation represents a summary of our initial work understanding the problem and addressing it by leveraging our years of experience with other applications such as speech recognition. Automatic analysis of clinical EEGs is a very difficult machine learning problem due to the low fidelity of a scalp EEG signal. Deep learning approaches can be viewed as a broad family of neural network algorithms that use many layers of nonlinear processing units to learn a mapping between inputs and outputs. Deep learning-based systems have generated significant improvements in performance for sequence recognitions tasks for temporal signals such as speech and for image analysis applications that can exploit spatial correlations, and for which large amounts of training data exist. The primary goal of this research was to develop deep learning-based architectures that capture spatial and temporal correlations in an EEG signal. We applied these architectures to the problem of automated seizure detection for adult EEGs. The main contribution of this work is the development of a high-performance automated EEG analysis system based on principles of machine learning and big data that approaches levels of performance required for clinical acceptance of the technology.

With respect to the second goal of developing a real-time system, the process of engineering the system to be amenable to a real-time implementation is discussed in Khalkhali et al. (2021). Scalp electroencephalogram (EEG) signals inherently have a low signal-to-noise ratio due to the way the signal is electrically transduced. Temporal and spatial information must be exploited to achieve accurate detection of seizure events. Most popular approaches to seizure detection using deep learning focus on modeling temporal or spatial information but do not jointly model this information. We exploit both simultaneously by converting the multichannel signal to a grayscale image and using transfer learning approaches to achieve high performance. The proposed system is trained end-to-end with only very simple pre- and post-processing operations which are

computationally lightweight and have low latency, making them conducive to clinical applications that require real-time processing. We demonstrate the efficacy of this approach We have achieved a performance of 42.05% sensitivity with 5.78 FAs/24 hours on the development dataset of v1.5.2 of the Temple University Hospital Seizure Detection Corpus. The system can run easily run in real-time using a single-core CPU, operating at 0.58 xRT on a 1.7 GHz processor in 16 Gbytes of memory with a latency of 300 msec.

With respect to the third major activity, in Golmohammadi's study, we used the Temple University EEG (TUEG) Corpus, supplemented with data from Duke University and Emory University, to evaluate the performance of these hybrid deep structures. We demonstrated that the performance of a system trained only on Temple University Seizure Corpus (TUSZ) data transfers to a blind evaluation set consisting of the Duke University Seizure Corpus (DUSZ) and the Emory University Seizure Corpus (EUSZ). This type of generalization is very important since complex high-dimensional deep learning systems tend to overtrain.

We also investigated the robustness of this system to mismatched conditions (e.g., train on TUSZ, evaluate on EUSZ). We train a model on one of three available datasets and evaluate the trained model on the other two datasets. These datasets are recorded from different hospitals, using a variety of devices and electrodes, under different circumstances and annotated by different neurologists and experts. Therefore, these experiments help us to evaluate the impact of the dataset on our training process and validate our manual annotation process.

Further, we introduced methods to improve generalization. We analyzed performance to gain additional insight into what aspects of the signal are being modeled adequately and where the models fail. The best results for automatic seizure detection achieved in this study are 45.59% with 12.24 FAs/24 hrs on TUSZ, 45.91% with 11.86 FAs/24 hrs on DUSZ, and 62.56% with 11.26 FAs/24 hrs on EUSZ. We demonstrate that the performance of our deep recurrent convolutional structure is statistically comparable to the human performance on the same dataset.

Finally, in Golmohammadi's work, we also developed some effective visualization tools to understand exactly what the network is learning. We believe these tools will be relevant to a larger class of deep learning systems.

References

Shah, V. (2021). *Improved Segmentation for Automated Seizure Detection Using Channel-Dependent Posteriors* [Temple University]. *https://www.isip.piconepress.com/publications/phd_dissertations/2021/seizure_segmentation/*

Golmohammadi, M. (2021). *Deep Architectures for Spatio-Temporal Sequence Recognition With Applications in Automatic Seizure Detection* [Temple University]. https://doi.org/https://www.isip.piconepress.com/publications/phd_dissertations/2021/seizure_detection

Khalkhali, V., Shawki, N., Shah, V., Golmohammadi, M., Obeid, I., & Picone, J. (2021). Low Latency Real-Time Seizure Detection Using Transfer Deep Learning. In I. Obeid, I. Selesnick, & J. Picone (Eds.), *Proceedings of the IEEE Signal Processing in Medicine and Biology Symposium (SPMB)* (pp. 1–7). IEEE.

Specific Objectives:

Regarding the first goal, we were focused on making the system run faster than real-time on a 1.7 GHz processor with a latency less than 30 secs.

Regarding the second goal, our performance goal has always been 75% sensitivity at an FA rate of 1/24 hours. We made substantial progress towards this goal, but also believe we might have reached some sort of limit given the amount of training data available.

Regarding the third goal, we were focused on demonstrating that the models we developed could be used on data collected from different EEG systems. We also wanted

to collect feedback on how acceptable the current level of performance would be to clinicians.

Significant Results: Regarding EEG performance, we established our best result to date on the TU Seizure Detection Corpus (TUSZ) - 41.60% sensitivity with 5.63 FAs/24 hrs. The real-time version of this system gives performance of 45.59% sensitivity with 12.24 FAs/24 hrs. This is competitive with the best research systems presented at the open source Neureka Epilepsy Challenge and is the only one of these systems that operate in real-time with low latency.

We have also released v1.5.2 of the TUSZ Corpus and will release v1.5.3 by the end of the 2021 calendar year (we are running behind schedule on this due to some unexpected staffing issues). v1.5.3 will include a new eval, dev, and training set definition. All annotations in v1.5.2 have been carefully reviewed by a new team of annotators.

Regarding generalization and robustness, a system that achieves 45.59% sensitivity with 12.24 FAs/24 hrs on the TUSZ dev set achieves 45.91% sensitivity with 11.86 FAs/24 hrs on the Duke University Seizure Corpus (DUSZ), and 62.56% sensitivity with 11.26 FAs/24 hrs on the Emory University SEizure Corpus (EUSZ). The performance of our deep recurrent convolutional structure is statistically comparable to the human performance on the same dataset. The system was only trained on TUSZ and did not need to be retrained to deliver good performance on the other datasets.

Key outcomes or Other achievements: We have released v1.5.2 of the TUSZ Corpus and will release v1.5.3 by the end of the calendar year. v1.5.3 contains a significant increase in the amount of training data. We also completed a review of all of the /dev and /eval data to make sure the annotations were accurate.

*** What opportunities for training and professional development has the project provided?**

Students involved in this project often enter the project will little or no software experience. We provide extensive training on Linux-based computing, software development in C++ and Python, and a variety of project management tools. We also encourage our students to publish at our annual conference. The skills they develop allow them to transition into summer internships in industry, where they gain even more valuable skills relevant to their careers. We spend a lot of time assisting these students in their job searches.

*** Have the results been disseminated to communities of interest? If so, please provide details.**

In addition to distributing information through our very active listserv, we maintain a project web site and disseminate data, resources, and software through our well-known EEG web site: https://www.isip.piconepress.com/projects/tuh_eeg/. We also host an annual conference at which we publish our EEG-related research. Both our graduate students and undergraduates participate in this conference by presenting papers and posters on our EEG research. The archives of the conference are indexed in IEEE Xplore.

*** What do you plan to do during the next reporting period to accomplish the goals?**

We are at the conclusion of the project. We will provide an expanded version of this report as the final project report.

Supporting Files

Filename	Description	Uploaded By	Uploaded On
roc.pdf	Receiver Operating Characteristics (ROC) comparing the three significant EEG seizure detection systems we have developed.	Joseph Picone	09/30/2021
table.pdf	A comparison of our EEG seizure detection system to several competitive systems that participated in our open source challenge. Our system is the only one of these that can be implemented in real-time and used in clinical applications.	Joseph Picone	09/30/2021

Products

Books

Obeid, Iyad; Selesnick, Ivan; Picone, Joseph (2021). *Biomedical Signal Processing: Innovation and Applications 1.* 1. Obeid, Iyad; Selesnick, Ivan; Picone, Joseph. Springer. New York, New York, USA. Status = PUBLISHED; Acknowledgment of Federal Support = No ; Peer Reviewed = Yes ; OTHER: Not Yet Available

Book Chapters

Shah, Vinit; Golmohammadi, Meysam; Obeid, Iyad; Picone, Joseph (2021). Objective Evaluation Metrics for Automatic Classification of EEG Events. *Biomedical Signal Processing: Innovation and Applications 1.* 1. Obeid, Iyad; Selesnick, Ivan; Picone, Joseph. Springer-Verlag. New York, New York, USA. 1. Status = PUBLISHED; Acknowledgement of Federal Support = Yes ; Peer Reviewed = Yes ; OTHER: https://www.isip.piconepress.com/publications/unpublished/book_sections/2021/springer/metrics/.

Inventions

Journals or Juried Conference Papers

View all journal publications currently available in the NSF Public Access Repository for this award.

The results in the NSF Public Access Repository will include a comprehensive listing of all journal publications recorded to date that are associated with this award.

Roy, Subhrajit and Kiral, Isabell and Mirmomeni, Mahtab and Mummert, Todd and Braz, Alan and Tsay, Jason and Tang, Jianbin and Asif, Umar and Schaffter, Thomas and Ahsen, Mehmet Eren and Iwamori, Toshiya and Yanagisawa, Hiroki and Poonawala, Hasan and Madan, Piyush and Qin, Yong and Picone, Joseph and Obeid, Iyad and Marques, Bruno De and Maetschke, Stefan and Khalaf, Rania and Rosen-Zvi, Michal and Stolovitzky, Gustavo and Harrer, Stefan. (2021). Evaluation of artificial intelligence systems for assisting neurologists with fast and accurate annotations of scalp electroencephalography data. *EBioMedicine*. 66 (C) 103275. Status = Deposited in NSF-PAR doi:https://doi.org/10.1016/j.ebiom.2021.103275 ; Federal Government's License = Acknowledged. (Completed by Picone, null on 09/30/2021) Full text Citation details

Ferrell, Sean and Mathew, Vineetha and Refford, Matthew and Tchiong, Vincent and Ahsan, Tameem and Obeid, Iyad and Picone, Joseph. (2020). The Temple University Hospital EEG Corpus: Electrode Location and Channel Labels. *Institute for Signal and Information Processing Report*. 1 (1) 1-9. Status = Deposited in NSF-PAR doi:https://doi.org/ ; Federal Government's License = Acknowledged. (Completed by Picone, Joseph on 10/29/2020) Full text Citation details

Shawki, Nabila and Elseify, Tarek and Cap, Thao and Shah, Vinit and Obeid, Iyad and Picone, Joseph. (2020). A Deep Learning-Based Real-time Seizure Detection System. *IEEE Signal Processing in Medicine and Biology Symposium SPMB*. 1 (1) 1-4. Status = Deposited in NSF-PAR doi:https://doi.org/ ; Federal Government's License = Acknowledged. (Completed by Picone, Joseph on 10/29/2020) Full text Citation details

Shah, Vinit and Golmohammadi, Meysam and Obeid, Iyad and Picone, Joseph. (2021). Objective Evaluation Metrics for Automatic Classification of EEG Events. *Biomedical Signal Processing: Innovation and Applications*. 1 (1) 1-26. Status = Deposited in NSF-PAR doi:https://doi.org/ ; Federal Government's License = Acknowledged. (Completed by Picone, Joseph on 10/29/2020) Full text Citation details

Jean-Paul, S. and Elseify, T. and Obeid, I. and Picone, J.. (2019). Issues in the Reproducibility of Deep Learning Results. *IEEE Signal Processing in Medicine and Biology Symposium (SPMB)*. 1 (1) 1 to 4. Status = Deposited in NSF-PAR doi:https://doi.org/10.1109/SPMB47826.2019.9037840 ; Federal Government's License = Acknowledged. (Completed by Picone, Joseph on 10/29/2020) Full text Citation details

Ochal, Domenic and Rahman, Safwanur and Ferrell, Sean and Elseify, Tarek and Obeid, Iyad and Picone, Joseph. (2020). The Temple University Hospital EEG Corpus: Annotation Guidelines. *Institute for Signal and Information Processing Report*. 1 (1) 1-28. Status = Deposited in NSF-PAR doi:https://doi.org/ ; Federal Government's License = Acknowledged. (Completed by Picone, Joseph on 10/29/2020) Full text Citation details

Rahman, Safwanur Hamid. (2020). Improving the Quality of the TUSZ Corpus. *IEEE Signal Processing in Medicine and Biology Symposium (SPMB)*. 1 (1) 1-5. Status = Deposited in NSF-PAR doi:https://doi.org/ ; Federal Government's License = Acknowledged. (Completed by Picone, Joseph on 10/29/2020) Full text Citation details

Shah, Vinit and Obeid, Iyad and Picone, Joseph and Ekladious, George and Iskander, Ray and Roy, Yannick. (2020). Validation of Temporal Scoring Metrics for Automatic Seizure Detection. *Proceedings of the IEEE Signal Processing in Medicine and*

Biology Symposium (SPMB). 1 (1) 1-5. Status = Deposited in NSF-PAR doi:https://doi.org/ ; Federal Government's License = Acknowledged. (Completed by Picone, Joseph on 10/29/2020) Full text Citation details

Hamid, Ahmed and Gagliano, Katherine and Rahman, Safwanur and Tulin, Nikita and Tchiong, Vincent and Obeid, Iyad and Picone, Joseph. (2020). The Temple University Artifact Corpus: An Annotated Corpus of EEG Artifacts. *IEEE Signal Processing in Medicine and Biology Symposium SPMB*. 1 (1) 1. Status = Deposited in NSF-PAR doi:https://doi.org/ ; Federal Government's License = Acknowledged. (Completed by Picone, Joseph on 10/29/2020) Full text Citation details

Rahman, S. and Miranda, M. and Obeid, I. and Picone, J.. (2019). Software and Data Resources to Advance Machine Learning Research in Electroencephalography. *IEEE Signal Processing in Medicine and Biology Symposium (SPMB)*. 1 (1) 1 to 4. Status = Deposited in NSF-PAR doi:https://doi.org/10.1109/SPMB47826.2019.9037851 ; Federal Government's License = Acknowledged. (Completed by Picone, Joseph on 10/29/2020) Full text Citation details

Golmohammadi, Meysam and Shah, Vinit and Obeid, Iyad and Picone, Joseph. (2020). Deep Learning Approaches for Automatic Seizure Detection from Scalp Electroencephalograms. *Signal Processing in Medicine and Biology: Emerging Trends in Research and Applications*. 1 (1) 233-274. Status = Deposited in NSF-PAR doi:https://doi.org/10.1007/978-3-030-36844-9 ; Federal Government's License = Acknowledged. (Completed by Picone, Joseph on 10/29/2020) Full text Citation details

Kiral, Isabell and Roy, Subhrajit and Mummert, Todd and Braz, Alan and Tsay, Jason and Tang, Jianbin and Asif, Umar and Schaffter, Thomas and Mehmet, Eren and Picone, Joseph and Obeid, Iyad and Marques, Bruno De and Maetschke, Stefan and Khalaf, Rania and Rosen-Zvi, Michal and Stolovitzky, Gustavo and Mirmomeni, Mahtab and Harrer, Stefan and Yanagisawa, Hirki and Iwamori, Toshiya and Madan, Piyush and Qin, Yong and Ma, Li and Ti, Wei Lian and Liu, Wen and Mei, Jing and Hensley, Sharon and Chandra, Rachita and Hake, Paul and Henessy, Richard and Babaali, Parisa and Yuenreed, Gigi and Kather, Ryan and Arcos-Diaz, Dario and Cherner, Michael. (2019). The Deep Learning Epilepsy Detection Challenge: Design, Implementation, and Test of a New Crowd-Sourced AI Challenge Ecosystem. *Challenges in Machine Learning Competitions for All (CiML)*. 1 (1) 1-3. Status = Deposited in NSF-PAR doi:https://doi.org/ ; Federal Government's License = Acknowledged. (Completed by Picone, Joseph on 10/29/2020) Full text Citation details

Lin, Rebecca and Marquez, Destiny and Jacobson, Mercedes and Castaldi, Hannah and Buckman, Samuel and Shah, Vinit and Picone, Joseph. (2020). Accuracy of Automated Machine Learning Software in Identifying EEGs with Prolonged Seizures. *Annual Meeting of the American Academy of Neurology (AAN)*. 1 (1) 1. Status = Deposited in NSF-PAR doi:https://doi.org/ ; Federal Government's License = Acknowledged. (Completed by Picone, Joseph on 10/29/2020) Full text Citation details

Shah, V., Obeid, I., Picone, J., Iskander, R., & Roy, Y. (2020). Validation of Temporal Scoring Metrics for Automated Seizure Detection. Proceedings of the IEEE Signal Processing in Medicine and Biology Symposium. https://www.isip.piconepress.com/publications/unpublished/conferences/2020/ieee_spmb/scoring/. Status = PUBLISHED.

Khalkhali, V., Shawki, N., Shah, V., Golmohammadi, M., Obeid, I., & Picone, J. (2021). Low Latency Real-Time Seizure Detection Using Transfer Deep Learning. In I. Obeid, I. Selesnick, & J. Picone (Eds.), Proceedings of the IEEE Signal Processing in Medicine and Biology Symposium (SPMB) (pp. 1–7). Philadelphia, Pennsylvania, USA.. Status = ACCEPTED.

Buckwalter, G., Chhin, S., Rahman, S., Obeid, I., & Picone, J. (2021). Recent Advances in the TUH EEG Corpus: Improving the Interrater Agreement for Artifacts and Epileptiform Events. In I. Obeid, I. Selesnick, & J. Picone (Eds.), Proceedings of the IEEE Signal Processing in Medicine and Biology Symposium (SPMB) (pp. 1–3). Philadelphia, Pennsylvania, USA.. Status = ACCEPTED.

Licenses

Other Conference Presentations / Papers

Shawki, Nabila; Elseify, Tarek; Cap, Thao; Shah, Vinit; Obeid, Iyad; Picone, Joseph (2020). *A Deep Learning-Based Real-time Seizure Detection System*. IEEE Signal Processing in Medicine and Biology Symposium (SPMB). Philadelphia, Pennsylvania, USA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Rahman, S. Hamid, A.; Ochal, D.; Obeid, I.; Picone, J. (2020). *Improving the Quality of the TUSZ Corpus*. Proceedings of the IEEE Signal Processing in Medicine and Biology Symposium (SPMB). Philadelphia, Pennsylvania, USA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Hamid, Ahmed; Gagliano, Katherine; Rahman, Safwanur; Tulin, Nikita; Tchiong, Vincent; Obeid, Iyad Picone, Joseph (2020). *The Temple University Artifact Corpus: An Annotated Corpus of EEG Artifacts*. IEEE Signal Processing in Medicine and Biology Symposium (SPMB). Philadelphia, Pennsylvania, USA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Other Products

Other Publications

Patent Applications

Technologies or Techniques

Thesis/Dissertations

Golmohammadi, Meysam. *Deep Architectures for Spatio-Temporal Sequence Recognition With Applications in Automatic Seizure Detection*. (2021). Temple University. Acknowledgement of Federal Support = Yes

Shah, Vinit. *Improved Segmentation for Automated Seizure Detection Using Channel-Dependent Posteriors*. (2021). Temple University. Acknowledgement of Federal Support = Yes

Websites or Other Internet Sites

Participants/Organizations

Research Experience for Undergraduates (REU) funding

Form of REU funding support:	REU supplement
How many REU applications were received during this reporting period?	12
How many REU applicants were selected and agreed to participate during this reporting period?	4
REU Comments:	The REU funding had a substantial impact on this project because it allowed us to produce and release a large amount of new data as well as providing students a transformative experience.

What individuals have worked on the project?

Name	Most Senior Project Role	Nearest Person Month Worked
Obeid, Iyad	PD/PI	2
Picone, Joseph	Co PD/PI	2
Shah, Vinit	Graduate Student (research assistant)	9
Shawki, Nabila	Graduate Student (research assistant)	3
Alexander, Carmel	Undergraduate Student	1
Buckwalter, Grace	Undergraduate Student	1

Name	Most Senior Project Role	Nearest Person Month Worked
Cap, Thao	Undergraduate Student	2
Chhin, Sidney	Undergraduate Student	1
Elseify, Tarek	Undergraduate Student	3
Liang, Shu (Dennis)	Undergraduate Student	1
Miranda, Matthew	Undergraduate Student	1
Nguyen, Sarah	Undergraduate Student	1
Rahman, Safwanur	Undergraduate Student	1
Tchiong, Vincent	Undergraduate Student	1
Temory, Mir Muzamil	Undergraduate Student	1
Tulin, Nikita	Undergraduate Student	1
Vorwick, Lynn	Undergraduate Student	1

Full details of individuals who have worked on the project:

Iyad Obeid
Email: iobeid@temple.edu
Most Senior Project Role: PD/PI
Nearest Person Month Worked: 2

Contribution to the Project: Subject matter expert in bioengineering; leader of our commercialization strategy.

Funding Support: N/A

Change in active other support: No

International Collaboration: No
International Travel: No

Joseph Picone
Email: joseph.picone@gmail.com
Most Senior Project Role: Co PD/PI
Nearest Person Month Worked: 2

Contribution to the Project: Machine learning expert and real-time system development. Responsible for improving the performance of the research system and delivering a real-time version of the system.

Funding Support: N/A

Change in active other support: No

International Collaboration: No
International Travel: No

Vinit Shah
Email: tug14467@temple.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 9

Contribution to the Project: Lead algorithm designer. Artifact reduction. Deep learning architectures.

Funding Support: No additional funding. Transferred from another externally funded project for Summer 2019.

International Collaboration: No
International Travel: No

Nabila Shawki
Email: tuk02200@temple.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 3

Contribution to the Project: Real-time implementation. Feature extraction development using augmented information.

Funding Support: Worked 9 months as a department teaching assistant prior to Summer 2019.

International Collaboration: No
International Travel: No

Carmel Alexander
Email: carmel.alexander@temple.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 1

Contribution to the Project: Data Annotator

Funding Support: None other than this grant.

International Collaboration: No
International Travel: No

Grace Buckwalter
Email: grace.buckwalter@temple.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 1

Contribution to the Project: Data Annotator

Funding Support: None other than this grant.

International Collaboration: No
International Travel: No

Thao Cap
Email: tuj64267@temple.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 2

Contribution to the Project: Software engineer. Supports the development of some of software and infrastructure.

Funding Support: Nothing other than this grant.

International Collaboration: No
International Travel: No

Sidney Chhin
Email: sidney.chhin@temple.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 1

Contribution to the Project: Data Annotator

Funding Support: None other than this grant.

International Collaboration: No
International Travel: No

Tarek Elseify
Email: tug35668@temple.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 3

Contribution to the Project: Web developer and software engineer. Tarek helped develop the user interface for the real-time demo and addressed issues with Python efficiency.

Funding Support: None

International Collaboration: No
International Travel: No

Shu (Dennis) Liang
Email: tul14986@temple.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 1

Contribution to the Project: Web developer and content creator.

Funding Support: N/A

International Collaboration: No
International Travel: No

Matthew Miranda
Email: tuj66769@temple.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 1

Contribution to the Project: Software engineer responsible for the development of the real-time system.

Funding Support: None.

International Collaboration: No
International Travel: No

Sarah Nguyen
Email: sarah.nguyen0005@temple.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 1

Contribution to the Project: Data Annotator

Funding Support: None other than this grant.

International Collaboration: No
International Travel: No

Safwanur Rahman
Email: tuh01696@temple.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 1

Contribution to the Project: Data Annotator and Release Coordinator

Funding Support: None

International Collaboration: No
International Travel: No

Vincent Tchiong
Email: tug94380@temple.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 1

Contribution to the Project: Data Annotator

Funding Support: None other than this grant.

International Collaboration: No
International Travel: No

Mir Muzamil Temory
Email: mirmuzamil_temory@temple.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 1

Contribution to the Project: Data Annotator

Funding Support: None other than this grant.

International Collaboration: No
International Travel: No

Nikita Tulin
Email: tug47034@temple.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 1

Contribution to the Project: Data Annotator and Release Manager

Funding Support: None other than this grant.

International Collaboration: No
International Travel: No

Lynn Vorwick
Email: tug70217@temple.edu

Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 1

Contribution to the Project: Software engineer responsible for design and testing of our Python code. Manages the released software and makes sure it conforms to our standards.

Funding Support: None other than this grant.

International Collaboration: No
International Travel: No

What other organizations have been involved as partners?
Nothing to report.

Were other collaborators or contacts involved? If so, please provide details.
Nothing to report

Impacts

What is the impact on the development of the principal discipline(s) of the project?

The listserv we maintain, which users sign up for, now has 4,954 members. We average one support request per day, typically from users needing help with understanding the data or searching for resources relevant to their project.

The databases we provide are now used extensively throughout the EEG community to support their research. Customers are very appreciative of the resources we provide.

The software we provide also helps these users learn how to process the data and how to implement their research efficiently.

What is the impact on other disciplines?

We host an annual conference, the IEEE Signal Processing in Medicine and Biology Symposium. We now regularly see papers submitted that report results on our data. We also regularly answer support requests from researchers outside our immediate discipline looking to use our data for their research.

What is the impact on the development of human resources?

It is difficult to underestimate the impact the opportunity to work on this project has on our undergraduates. Many of these students would not get an opportunity to work on this type of research if it wasn't for our group. Once exposed to this research, students often get summer internships and full-time employment based on the skills they develop in this group. Also, since we often employ students from departments outside engineering, such as neuroscience, we often help these students find new career directions. Many of these students enter Temple thinking they want to go into traditional disciplines like medicine, but after their experiences in our group, they become much more interested in data science and software.

What was the impact on teaching and educational experiences?

The data and resources we develop are used in a wide range of classes including: Engineering Computation I (ECE 1111), Engineering Computation IV (ECE 4822), Senior Design (ENGR 4196/4296) and Introduction to Machine Learning and Pattern Recognition (ECE 8527). Students often use our data to test data-intensive programs, or conduct machine learning experiments on data sets we prepare for educational purposes.

What is the impact on physical resources that form infrastructure?

We have developed a state of the art small computing cluster to host our data and resources. This cluster is used for our research, but also, to support upper-level and graduate-level education. We have published information about configurations and often support other research groups in their attempts to replicate our computing environment.

What is the impact on institutional resources that form infrastructure?

We are regularly consulted by our campus Information Technology group, and our Library Services Division, on how we maintain data integrity and how we support the dissemination of our research. We have been helping them implement better infrastructure to support campus research.

What is the impact on information resources that form infrastructure?
Nothing to report.

What is the impact on technology transfer?

We have been actively trying to commercialize the technology through our commercial spinoff, Biosignal Analytics, Inc., and by directly marketing the technology to leading EEG equipment providers.

What is the impact on society beyond science and technology?
Nothing to report.

What percentage of the award's budget was spent in a foreign country?
Nothing to report.

Changes/Problems

Changes in approach and reason for change
Nothing to report.

Actual or Anticipated problems or delays and actions or plans to resolve them

Obviously COVID has had a big impact on many research projects. We were able to return to collecting data at Temple Hospital this year. Starting with the fall semester, students were able to spend time in the lab in person. This is particularly helpful for the data annotation portions of our work, where communication between annotators becomes important.

Changes that have a significant impact on expenditures

We had received a one-year extension due to the delays caused by COVID. We managed to get back on track this year and have spent all the remaining funds.

Significant changes in use or care of human subjects
Nothing to report.

Significant changes in use or care of vertebrate animals
Nothing to report.

Significant changes in use or care of biohazards
Nothing to report.

Change in primary performance site location
Nothing to report.

Special Requirements

Responses to any special reporting requirements specified in the award terms and conditions, as well as any award specific reporting requirements.
Nothing to report.