The Just-In-Time Adaptive Artificial Augmentation Capstone Project

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***Abstract*—Interest in assistive technologies (AT) and artificial intelligence (AI) supporting decision making and the performing difficult or dangerous tasks is experiencing continued and rapid growth. Systems of this nature have a wide range of use-cases spanning defense and commercial domains, such as aviation, air traffic control, decision support systems, emergency management, command and control, threat assessment, route planning, autonomous multi-vehicle mission oversight, power grid operations, and machine and heavy-machine operations. In line with our ongoing efforts to integrate applied, experiential learning programs into post-secondary undergraduate STEM curriculum, we propose a capstone program whereby undergraduate engineering and computer science seniors can gain valuable insight and skills by contributing to the creation of a just-in-time adaptive artificial augmentation (JIT-A3) system. The purpose of this program is to provide undergraduate senior students with a real-world, project-based experience that encompasses the complexities and realities they are likely to encounter in demanding commercial and government jobs.**

***Index Terms*—Adaptive Artificial Augmentation, UAV, Autonomous Systems, AI, Machine Learning, BCI, Computer Science Education, Assistive Technologies, Experiential Learning**

I. Introduction

Undergraduate internships contribute to students' preparedness for industry, and yet only 60% of undergraduate students in the United States participate in some form of internship program [12]. A recent study with 536 multi-institutional computer science (CS) students confirms this trend, showing that 57.5% of undergraduates completed an internship prior to graduation [4]. There is little measurable difference in academic performance between students who intern and those who do not; however, those graduating without experiencing an internship invariably discover that they have significantly more challenges finding employment. We've come to understand that this is due to the lack of practical experience, good technical/interpersonal skills, and the ability to work effectively in teams [4], [8]. We are continuing our efforts in addressing these issues for computer science (CS) undergraduate majors by designing programs that focus on applied and experiential learning approaches [8], [9]. Herein we propose a two-semester capstone designed to allow undergraduate students the opportunity to contribute towards the creation of a modular system and underlying pipeline that can be applied to many future systems designed for just-in-time adaptive artificial augmentation (JIT-A3) to human performance.

Just-in-time artificial augmentation systems will have a wide range of use-cases that span across defense and commercial domains, such as aviation, air traffic control, decision support systems, emergency management, command and control, threat assessment, route planning, autonomous multi-vehicle mission oversight, power grid operations, and machine and heavy-machine operations [2], [7], [6], [10], [5], [14], [11], [13]. A robust JIT-A3 system must be able to operate at a constant high level of "in readiness" state between the user and user interface of a an application or machine. Such a system requires 1) constant real-time physiological data streaming from the user, 2) one or more efficient AI models capable of transforming physiological data and assessing the resultant indicators in latent space, 3) the ability to assess user performance related to specific tasks and metrics, and 4) the ability to determine the level of introduced assistive augmentation to the system. Each of these operations should cooperate through a standardized communications pipeline so that system hardware and software components can be arranged into an end-to-end solution towards a particular application.

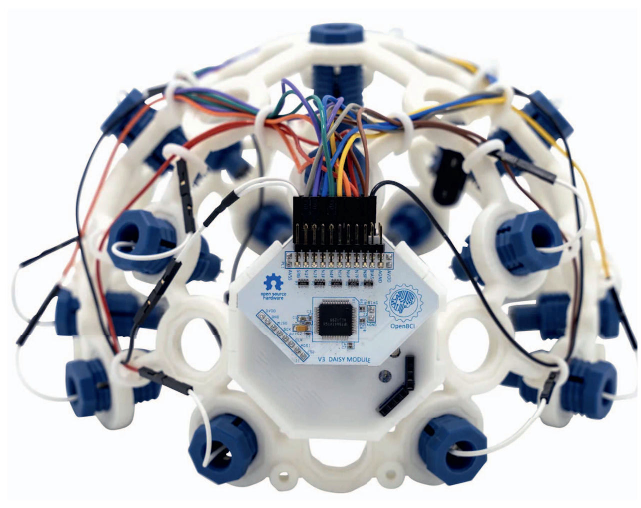

Fig. 1. 3D printed "Ultracortex M4" EEG Headset by OpenBCI

Our program aims to approach JIT-A3 by having students develop and deliver a flexible, open, end-to-end framework that allows the creation of specialized JIT-A3 appli-

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cations. This framework may support decision support systems, human-machine teaming, threat assessment, or any other application that may require real-time, in-line AI assistance and augmentation. An envisioned pipeline for this system is shown in Figure 2; however, the immediate goal for the pilot capstone program will address a specific use case involving scalp-based, electroencephalographic (EEG) brain-computer interface (BCI) [3] and RC skid steer and/or multicopter drone systems running on the same technology stack.

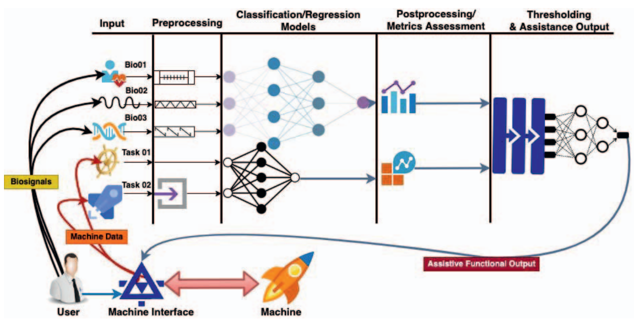

Fig. 2. Diagram depicting major components of the JIT-A3 pipeline.

II. Objectives and Initial Approach

The overall objective is to involve advanced undergraduate STEM students in a real-world project with many of the complexities and realities they are likely to encounter in well-paying jobs in engineering fields in both commercial and government domains. We will do this by introducing them to an interesting and unique project that involves working with subject matter experts, cross-team collaboration, open hardware, advanced Python programming, advanced machine learning, signal processing, advanced data collection and conditioning, and advanced software engineering - all under a single capstone program. The initial capstone effort will accommodate up to 6 students that make up 3 teams. Teams will be be assigned tasks that align with members' overall areas of expertise. Teams will then be coordinated to work in parallel on their respective tasks, integrating their artifacts into the overall JIT-A3 system as they become operational. There can be up to 3 subject matter experts/mentors. The students will be assigned mentors who have expertise in one of several topics, including BCI systems, software systems & development, data science & deep learning, and autonomous systems integration (robotics, drones or related subject matter).

A. Program Progression

The program will consist of 8, 4-week sprints. This approach will ensure teams make progress during every sprint in order to achieve the project's objectives by the end of the program. To support good initial momentum, we will provide a number of bootstrapped elements to the students that are cobbled artifacts from a variety of previously successful efforts and programs designed and lead by the authors of this abstract. These items are: (1) an API in Python that consist of all base classes, pipeline backbone, and interfaces that support module communications and data propagation, (2) Python libraries that provide abstracted interfaces to all hardware communications for drone and BCI hardware, (3) initial deep learning models to begin experimentation and perform advanced model build-out for predicting actions from EEG, (4) access to system SDKs, including OpenBCI and DroneKit, (5) references and reading material that covers relevant subject matter, (6) mini lectures and labs that provide orientation for each phase of the project, (7) all hardware and sensors, including dry electrodes, 3D printers for producing wearable apparatus, cameras, drones, and repair kits, (8) virtual environments for initial testing, (9) dedicated area for conducting physical drone operations, (10) development environments, git repositories, and configured NVIDIA Xavier NX systems with Jetpack 5.1 and Ubuntu 20.04. All hardware, firmware, and software used in the capstone program will be open and open source. The BCI equipment and SDK come from Arduino-based OpenBCI [1].

B. Project Deliverables

The final product will allow a user to place a BCI device on one's head and control basic drone operations via a console and streaming video. The console will be designed to take advantage of a user's evoked brain responses (e.g., P300 or motor imagery) while allowing the user to receive status and real time feedback via video coming from a multicopter drone. The user should be able to perform basic, hands-free operations via EEG: (1) arm/disarm, (2) takeoff/land, (3) climb/descend, (4) yaw, basic forward/backward/sideways movements, (5) latch operation for picking up or dropping objects. Augmentation will be introduced when certain thresholds have triggered the need for assistance. This will most likely be based on the drone's onboard distance sensors, gyros, and accelerometers. Assistance will take the form of throttled movement or emergency maneuvers, such as object avoidance, immediate land, timed loiter, or return to home. The deliverables will be in the form of an end-to-end proof of concept or prototype. The application of this specific deliverable may be limited, but it lends credence to the system's potential to host more complex system operations based on multimodal input, including additional biosignal information, such as eye movement, galvanic skin response, or heart rate. Each team will be required to keep and deliver a detailed log of their experiments, successes, failures, challenges, and overall approaches towards solutions.

III. Performance and Assessment

Each team will receive regular evaluations heavily weighted on the assessment of their project mentor at the end of every sprint. In addition, there will be cross evaluation from the mentors of every other project team. Final grading will include evaluations by outside faculty members and subject matter experts twice each semester, based on team presentations and demonstrations. Artifacts and journals will be evaluated for quality as well as teams' overall approach towards problem solving, project management, teamwork, and on-time deliverables.

IV. Conclusion

Our goal is to afford undergraduate STEM students real-world experience through our post-secondary curriculum by offering interesting projects that cover current interests in industry, with many of the complexities and realities they are likely to encounter in demanding jobs in engineering fields in both commercial and government domains. This particular program focuses on an interesting and unique project that involves working with advanced subject matter, cross-team collaboration, open hardware, advanced programming, advanced machine learning, signal processing, advanced data collection and conditioning. It is our most aggressive attempt to date to bring quality challenges to our students, yet it is backed by experience and artifacts from previously successful efforts. We have adequate resources, experience, and expertise to implement, simplify, template, and document this program so as to extend this learning opportunity to instructors and students in post-secondary STEM programs in other institutions. This program may be adapted to other robot modalities such as prosthetic limbs, ground-based rovers, and legged pack drones. Future plans include incorporating additional sensors and providing more interesting bolt-on capabilities based on additional sensor modalities. We plan to publish our collective findings after the first year of the program, covering detailed teaching materials, resources, final product deliverables, along with student assessments and feedback.

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