

Tutorial on TensorFlow Spark for BCI Augmented Robotics

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Abstract

This work presents the current approach at SCSU for creating and offering a framework to give students a hands-on experience with Brain Robotics interfaces. The proposed work describes the overall steps in hardware architecture and system platform, thus providing valuable information for implementing an enterprise solution or a practical procedure for higher education institutions interested in starting development in the new technology field known as Brain-Computer Interaction and Interface.

Keywords: Avatar, Brain-Computer Interface, Hardware Architecture, Spark, TensorFlow.

1 Introduction

The field of HPC High-Performance Computing has been using the current trends in Cloud Computing with easy scalability. The creation of cluster computing has successfully led the way for advanced distributed systems. Ongoing trends in Brain-Computer Interface offer a cutting-edge approach to Human-Computer Interaction, using pattern identification techniques with real-time sensors to harvest brain wave control to perform brain system connectivity. For steering and control of real-time agents, as a UAS Unmanned Aerial System, the challenge is to build a reliable architecture platform to address low latency at low cost with high stability and load balance.

2 Motivation

Sci-Fi movies and literature have featured the concept of controlling devices, systems, and machines through the brain's thoughts for many years. In the early '80s, the scientific community presented initial prototypes for the Brain-Computer Interface. Back then, the first BCI devices were invasive until the end 1960s, meaning that EEG sensors needed to

be implanted in the person's head to allow precise reading of the neurons and brain signals. In the early 70s, through the BCI challenge initiative, the first version of EEG that was not invasive was presented. Despite that, initial EEG-BCI was still quite expensive, limiting the development of several systems based on this type of technology. However, in recent years the cost involved to such devices decreased significantly. Thus, we can observe many projects to integrate BCI more commercially towards developing market-oriented solutions that rely on BCI as the next generation of the Human-Computer Interaction and Interface paradigm. Several startup companies are currently developing many applications intended to work solely using BCI. In this race to commercialize the first wave of BCI applications, giant high-tech companies invest their resources and development teams towards this objective. Examples are Neuralink from Tesla and Facebook Meta.

Micro and nanoelectronics have continuously paved the way for a growing number of advanced devices at low cost with large-scale manufacturing and distribution [1]. That resulted in our society's ability to access complex sensors at a low price, with high precision and lower costs.

3 Methodology

The support received by the SCSU and the teamwork started with a faculty board discussing establishing a workspace for research and development in the Engineering and Computing Center building; after several meetings, the R&D committee member came out with naming the workspace Interdisciplinary Computer Hub. A few months later, the Dean's office administration approved a faculty start-up package to fund the initiative that we used to have a thing to start moving. The first most noticeable acquisition of 4 sets from the: OpenBCI All-in-one Biosensing R&D Bundle, followed by additional gears and gadgets. The next step was to reorganize the layout of the room used for project: ECC102E. Besides the infrastructure, the other important aspect of the approach is using open-source technologies, which comprise 100% of the project system implementation. The ability to use readily available libraries for cloud computing performance, automation, and machine learning algorithms with a framework for real-time data streaming is paramount for fast prototyping and implementation.

Last but not least, and most importantly, the teamwork and promotion: the Cloud Computing Club develops most activities remotely using a high-performance distributed cluster approach. For the development team coordination, we use Github and Atlassian Jira. While all contributors use Github, once a member becomes a more frequent contributor, if that member becomes a committer or one of the project administrators, then that implies also having access to the Atlassian Jira repository used for starting a new patch in tandem with Github, for such as fixing a bug or adding a new feature to the code base.

4 Hardware Architecture

The current development of low-cost mass production of electronics and components for integrating advanced architecture with hardware and software solutions is making possible the creation of immersive reality and telemetric control of avatars [2]. In our approach, we

establish a suitable platform that can effectively provide the application to various control and haptics interactions [3]. The user can apply his thoughts and activate the system (Figure 1). In the sequence, we describe each component's technical specification and how it integrates with our implemented solution.



Figure 1: Dataflow - connectivity and data streaming in real time for BCI drone augmented robotics.

4.1 EEG-BCI

The use of advanced electroencephalography (EEG) for Brain-Computer Interface (BCI) makes possible the implementation of a new framework to control systems and devices using machine learning to automate teleoperated robots with your mind (Figure 2). Initially, the development of EEG-BCI centered around partially impaired patients [4].

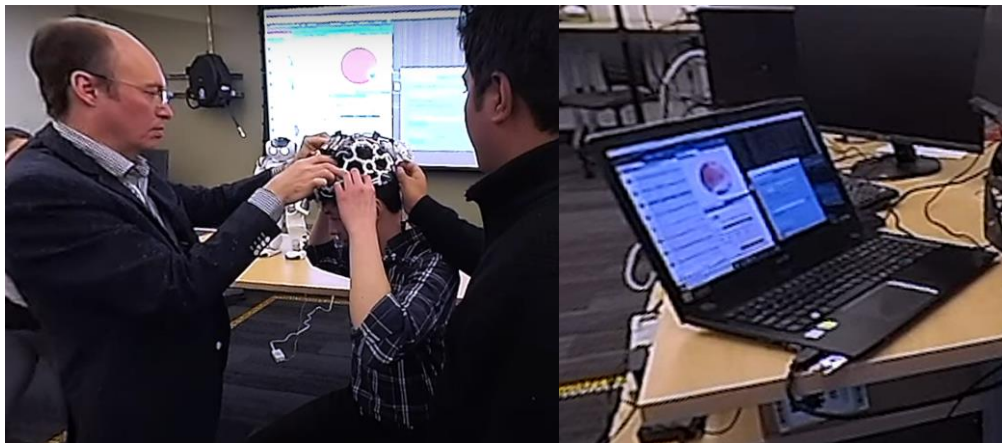


Figure 2: Calibrating to run a data collection with the BCI takes about a minute or two.

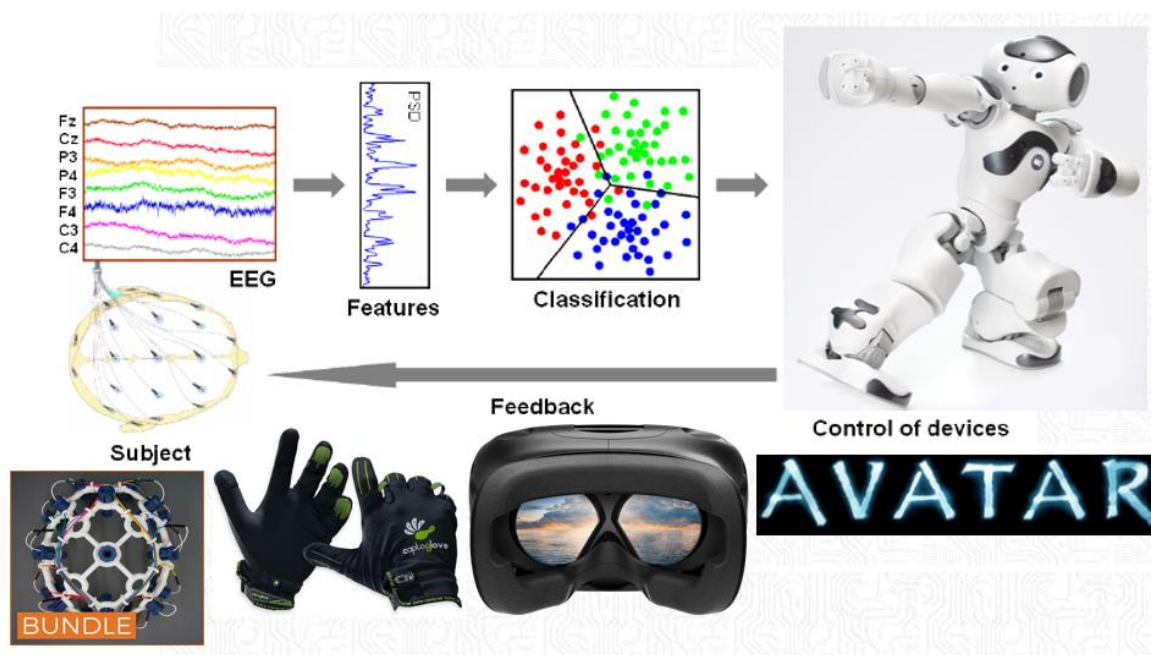


Figure 3: Dataflow with real-time connectivity and data streaming for BCI NAO6 augmented robotics.

With the fast-growing development of EEG-BCI, commercial applications for such technologies are expected to grow in the coming years (Figure 3). Several big tech companies are betting on this new technological frontier as the next step in Human-Computer Interaction. Some most known companies doing this kind of development include Meta Facebook, Tesla Neuralink, and some other 110 start-ups around the globe. The fact that the currently in development technologies allows the EEG-BCI to be non-invasive plays an essential role in making this technology for UI and UX more commonly accepted and desirable.

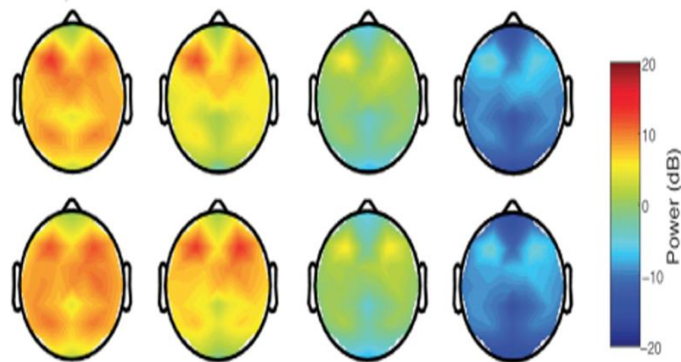


Figure 4: Brain activity - the EEG readings show the difference when certain parts of the brain might be more active than others.

Topographic EEG maps can read the brain wave activities from lower to highest frequencies (Figure 4). Typical brain wave frequencies are associated with specific types

of activities (Figure 5). As our framework and activities in the BCI Lab, we concentrate on brain reading frequencies, so we want your brain waves in our cloud database [5].

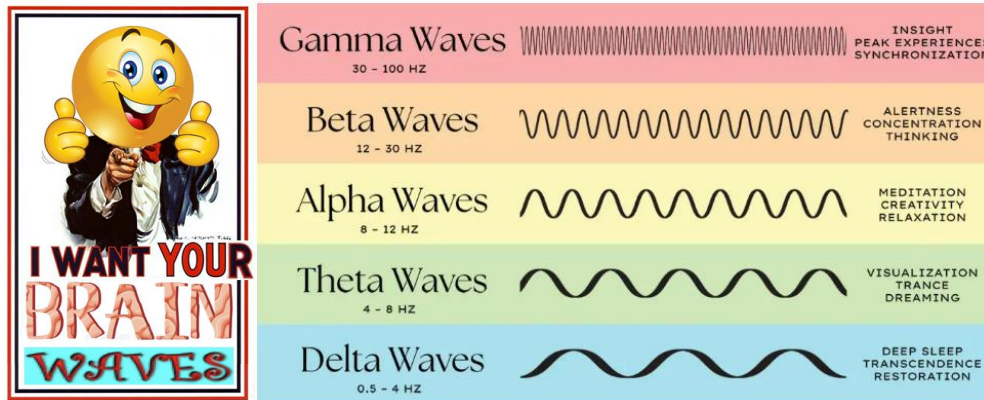


Figure 5: Brain waves - all the Cloud Computing and BCI Lab want.

Source code implemented in MATLAB is available as open source for computing BCI applications [6].

4.2 Drone

Ryze Tello Edu provides a programmable drone at a very accessible price (Figure 6). It has a broad connectivity capability and offers the option to program the device in Python [7]. In our case, we considered a compelling approach to have the bird's eye view of the footage captured by the drone and projected onto the smartphone inside the VR headset and simultaneously transmit the duplicate footage in the large screen ROKU TV. The Smart-TV just arrived this week in our lab.

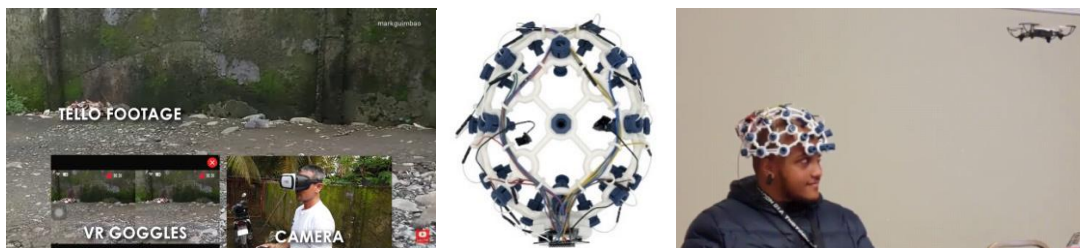


Figure 6: DJI Tello Edu Programmable Drone provides BCI and VR headsets with a mind-teleoperated flying avatar.

The current Tello EDU runs on version SDK 2.0 and is also compatible with Scratch or Swift programming. Brain-Computer Interface from OpenBCI Headset reads brain waves generated by thoughts that create related signal patterns for our machine learning platform [8].

4.3 Robotics

Currently, many robot models are available for implementing augmented platforms to facilitate avatar instrumentation. One interesting approach that our development considers besides using drones for flying avatars is to use a humanoid robot for evident reasons.

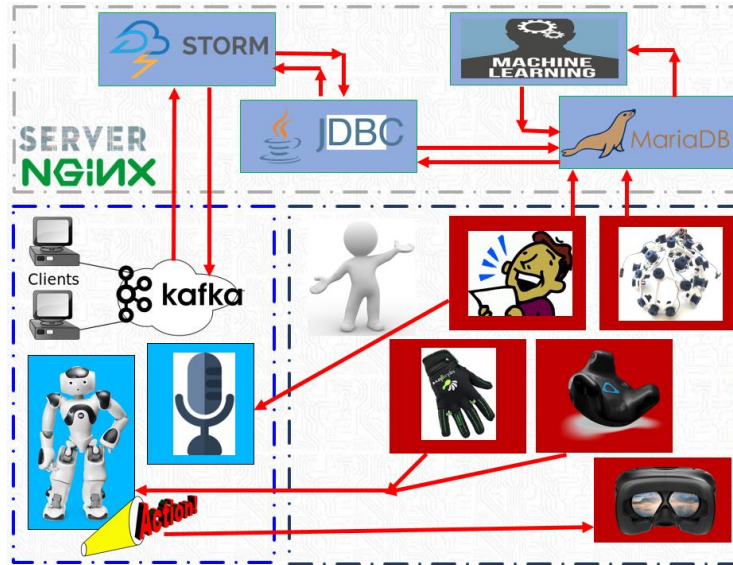


Figure 7: BCI-NAO6 Implementation done for a humanoid robot with alternative pathways for control.

It has many haptic sensors and a very similar human-like design. NAO6 is an option that we are considering acquiring soon to integrate into our current framework (Figure 7). The implementation types using a similar architecture can apply to connecting your mind to perform big data analytic queries to social media searches and much more.

4.4 Tablet

We got the Hotwav R5 Rugged Tablet 10-inch Tablet Android 12 2023, which is used for steering control of the drone (Figure 8). For the testing and programming of the drone, first, we define the type of steering actions using the Python SDK for the Ryze Tello Edu Quadricopter. Although the final goal is to control the drones solely with our minds, for the prototyping and testing phases, using the drone app helps define control strategies that best fit the BCI low latency and cloud-based machine learning processing steps.



Figure 8: Tablet with MediaTek MT6762 processor, 6GB RAM, 4GB+64GB (SD up to 1TB), Cortex A73 2.0GHZ×4+A53 2.0GHZ×4,12nm process technology.

4.5 Smartphone

The smartphone provides the Bird’s Eye view from the Tello Edu drone (Figure 9). Although we were initially planning to acquire rugged phones, we had to adjust our initial expectations and pick another phone model. The reason for the limitation is those rugged ones are more durable on the one side, and with long-lasting batteries, they are bulky and, therefore, cannot fit inside the FEEBZ headsets. Therefore, we switch to a smartphone that effectively fits within the specifications that work with the VR headset. The phone we purchased for our workstations was the Samsung Galaxy S10+ Plus (Dimensions 6.2 x 0.3 x 2.9 inches).



Figure 9: Smartphone with 128GB Storage, 8GB RAM, Up to 1TB microSD Card slot, Qualcomm SDM855 Snapdragon 855 (7 nm), CPU: Octa-core.

4.6 Augmented Reality Goggles

We have compared several VR headsets that would effectively fit the context of the type of application we are developing. After considering several factors, including cost-benefit, connectivity, and reviews, we decided on the FEEBZ VR headset that gives the augmented reality feeling when someone is flying the drone controlled by the pilot’s mind (Figure 10).



Figure 10: Augmented Reality - the Feebz VR headsets design fits almost any iPhone or Android phone with a screen size of up to 6.5".

4.7 Workstation

For development, we chose Chromebook compared to other options. Some objective motivations for this choice: ChromeOS is an open-source operating system based on Gentoo Linux (Figure 11). Gentoo Linux offers the flexibility of customizing the system source code, thus allowing optimized configuration for targeted computer hardware components and architecture. The model we got was the HP Chromebook X360 2-in-1 14.0" HD (1366 x 768).



Figure 11: ChromeOS - it uses Gentoo Linux as it offers a flexible range of customization, allowing optimized hardware adaptability and configuration.

There are several advantages to using a Chromebook (Figure 12). One of them, of course, is the price tag. Because the operating system is free and open source, you can get a better machine configuration for half price than if you get the same computer running on a proprietary closed-source operating system with the same hardware configuration. For our initial setup, instead of two workstations as laptop computers, we got four workstations for the same amount of available budget.

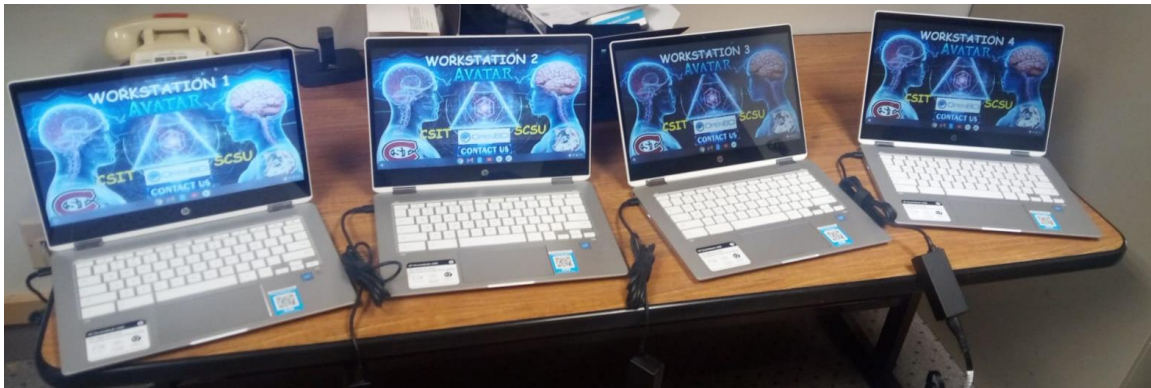


Figure 12: Chromebook with Intel Celeron N4000 (1.1 GHz base frequency, up to 2.6 GHz burst frequency, 4 MB L2 cache, 2 cores) & Intel UHD Graphics 600, 4GB LPDDR4-2400 MHz SDRAM, 32GB eMMC+32GB SD card.

4.8 Cloud Computing VPS

We have compared many options: Google Cloud, AWS, Azure, CloudSurph, and IONOS. After reaching and trying some of them, we ultimately used the IONOS. Our project currently has two VPS servers running on the cloud, plus a data repository integrated with Delta Lake. One server is located geographically in US CT; meanwhile, the second mirroring server is in Germany.

4.9 Budget and Funding

Our project received a faculty grant from the university as part of the called start-up fund. The department also provided additional support to help to complete some of the components and devices needed to integrate a set of 4 complete permanent workstations for Brain-Computer Interface. The Cloud Computing Club directly benefits from the opportunity to access a development framework environment on the edge of advanced technologies. The same infrastructure for development and programming is also helping the senior student and master students taking the course SE475/575 Brain Robotics Interface, which is a course entirely dedicated to teaching and offering the students the valuable skillset to aid their professional development with know-how currently considered the next step on Human-Computer Interaction interfaces. The students taking the SE413/513 Big Data Organization and Management Systems will also have Brain-Computer Interface technologies aided to their Big Data Analytics activities as a new way to query big data with your mind. And the student taking the class SE350 Software Engineering and Human-Computer Interaction are also equally offered the opportunity to integrate BCI into their Human Computer Interaction control applications.

Additionally, passed three months have since the equipment arrived, and we already have it set up and ready for an Open Lab event that is part of the Math Contest at the end of March 2023. We had the opportunity to see all students from High School exceedingly motivated after watching live the system running and the possibilities of control of systems

and devices with the power of their minds. For the Math Contest event, we expect to have at least 140 students visiting the Lab from 11 AM to Noon at the of the month. Undoubtedly, the most expensive part of the workstations is the OpenBCI combo, which costs around 3K each. But the investment is worth it. So far, we have been delighted with the support from OpenBCI and the quick post-sale response on any eventual needs in keeping our Lab running smoothly and homogeneously.

5 Learning and Development Workspace

Working as a team towards transforming the ECC102E into a development hub to strengthen the CSIT department has been excellent. All faculty and students can benefit from an R&D space for collaboration so that ideas and development can flourish. We use in-person, distributed, and virtual tools that help boost cooperation and speed development and integration. Among other technologies for collaboration, it is worth mentioning: Zoom, Atlassian Jira, Github, VPS, Spark, Dockers, and Kubernetes. These tools provide the ideal scalability, automation, and remote collaboration framework.

5.1 Interdisciplinary Computer Hub

Creating a physical space for uplifting creativity and collaboration is essential (Figure 13). Therefore, establishing an environment that supports students in a continued implementation practice significantly impacts students' engagement in teamwork development.



Figure 13: ECC102E - Interdisciplinary Computer Hub comprising the Brain Computer Interface Lab, and it also serves as the physical headquarters for the Cloud Computing Club.

For that, a committee comprising three faculties had several meetings last year to establish a clear and transparent policy about how a new workspace for research and development could follow guidelines that will bring together collaboration towards supporting our students' success. Thus, some guidelines were drafted and voted. It was afterward presented and approved by all faculty during our department meetings.

The term Interdisciplinary Computer Hub (ICH) is a name that encompasses all activities of all faculty that belong to the CSIT. Additionally, the reason to call it a Hub instead of a

Center is that the ECC102E locates in the Engineering and Computing Center building. This new workspace for development and research supports undergraduate and postgrad students in all areas of their computing-related creativity and imagination. The students have the opportunity to translate their ideas into applied systems.



Figure 14: Multimedia - the stand with a wheel holds the TV, making it easy to move around for open lab demos and events.

The Brain-Computer Interface Lab (Figure 14) received most of the equipment in January and early February this year, yet some other components arrived just recently. As one can see, we just assembled and mounted the smart TV to allow students to visualize the drone bird's eye view on the big screen [9].

5.2 Cloud Computing Club

The club brings together all students interested in implementing distributed high-performance cloud computing. The club started on March 2022, initially with about eight active members. Discussions about it started in November 2021, and it became an official student's club on 2/23/2022. The Cloud Computing Club (#3C) provides the following:

- A forum for discussion on the newest technologies and trends.
- Providing a bright space for joint development.
- Discussion on professional development strategies and mentoring.

For team communication and new members, we have the Cloud Computing Club online discord permanent link that allows anyone interested in the ongoing development and news to join in. Currently, the #3C Discord community counts 35 subscribed members, and the official #3C university member's registration log counts presently as having 18 students. Thus, #3C has 53 students participating in the club activities. Those activities include professional mentoring, participation in events like workshops and conferences, and hands-on development of cluster cloud computing technologies applied to high-performance distributed computing for brain-computer interface integration. One logical explanation for that remarkable growth is the fact that the students are interested and motivated in having the opportunity to have their technical skills and abilities tested in a practical approach. We

have patches, and only the best implementation is selected, tested, and approved to enter our source code base. Having a code peer-reviewed by a team and chosen as the best solution among several code version submissions is an astonishing thing to add to the student's Portfolio when going for a job interview.

5.3 Course Curriculum

The program proposed and approved the SE475 Brain Robotics Interface course. It provides a feasible approach to allow the students a comprehensive pathway into the Brain Computer Interface realm and technologies. The fact that we have been able to organize infrastructure in a relatively fast way, the created workspace was also of remarkable value, which indeed helped the students to start learning how the different brain wave bands work using machine learning to put into practice ways to implement direct control in real time of systems and devices through the power of your mind. After the concept and different hardware components and parts came together, we concluded that the created infrastructure could integrate as part of other course curricular activities, which we did as detailed further down in this article.

5.4 Security

The students learn the importance of taking the necessary steps to avoid hacking. They use the Discord Forum to collaborate with real-time remote development discussions. Usually, any broadly popular forum or app like Discord would be safe. However, Discord is not peer-to-peer encrypted. The students didn't check on that, so while discussing, one of them inadvertently texted the root password in the forum and deleted it a few minutes later. A week later, the VPS host informed us that our suspended server became a tool for DNS attacks as a zombie server. So, nobody got any losses or liability, as we quickly took the necessary actions to solve the problem. It was a real-life good lesson for the students about being extra careful. Since then, we have adopted many steps to ensure that our server stays safe, avoiding becoming targeted again. Actions taken, among other guidelines, include that data transmission from local BCI workstations to the VPS servers must be encrypted. The encryption methods adopted and recommended by #3C include Rsync, Tokio, SSH2, and Blockchain.

We were additionally setting up the server to be accessed only using SRA private and public keys instead of a simple remote connection with a password and user name. Noteworthy to mention that last year, we had just started creating our LAMP (Alma Linux, NGNIX, Apache SQL, Rust). So, there were no data britches. Besides the data security aspects of the distributed system implementation and data transmission, the other factor that we also aided in the security of the infrastructure had the place to be under 24-hour surveillance. We tried to find a reliable yet secure and easy-to-use camera recording monitoring system. After doing some search and several comparisons, we purchased the system: LaView 4MP 2K 4 Security Cameras Outdoor Indoor Wired, IP65, Starlight Sensor. This system addressed our needs for our ICH/BCI Lab workspace. For video recording storage, we have a remote Chromebook used as a machine dedicated to

monitoring and visualizing ongoing activities inside the laboratory. We also placed a sign at the entrance door advising that 24-hour surveillance cameras monitor the place.

5.5 Human Subject IRB

To collect and save brain waves as part of our dataset, we must abide by the Human Subject Regulations. Thus, we submitted a proposal to the Institutional Research Board with a detailed description of the challenges involved with current activities we are developing with the participation of the Cloud Computing Club and other students that use the ECC102E Interdisciplinary Computer Hub as part of the BCI Lab. The IRB asked us to have the Principal Investigator take a course on Human Subjects and take the test to demonstrate an understanding of the IRB Human Subject regulation. They also asked us to draft and submit the form: Informed Consent for approval. All volunteers wishing to participate and contribute to the project should sign this form, especially in donating their brain waves to our development framework database. All data collected remain unidentifiable and securely stored in the cloud.

6 System Platform Development

Many open-source packages and libraries are available for implementing distributed high-performance computing. The software industry has evolved into the current era, where companies want to optimize the development life cycle of any system. Thus, working towards open source and collaborative implementation is of paramount importance.

Spring 2023		
Category	Activity or Course name	# of students - capacity
#3C	Cloud Computing Club	50
SE475/575	Brain Robotics Interface	20
SE413/513	Big Data Management Systems	40
SE350	Human Computer Interaction	20
SE610	Operating Systems	20
	TOTAL	150

Table 1: Current student with access upon request to the Brain Computer Interface Lab activities and respective four workstations.

6.1 Open Source

The students can experience the development and the type of technologies currently being put together through various approaches. For example, as optional extra credit activities,

knowingly that their contributions will also have to be reviewed and approved by the Cloud Computing Club. Including all students from several courses that now have access to the activities related to the project that works to implement Flying Avatars with Brain Computer Interface, we can currently count on a broad engagement (Table 1).

The #3C does the code review and testing, then once the best patch is selected, that program or feature contribution done by the student interested in participating will enter the project code base. For the student, it also shows that his coding skills are peer-reviewed and that the student knows how to implement a high-quality code awarded as the best contribution for the specific feature implementation or bug that was published and up for fixing.

6.2 System Integration

The entire implementation uses open-source packages. The exciting aspect of our development framework and architecture is that the same architecture can be effortlessly reusable for another type of BCI application. From controlling drones to humanoid robots, the overall building blocks are the same (Figure 15). The critical thing that will only change is the dataset used to identify brain wave patterns associated with specific thought commands read by sensors for the avatar's control.

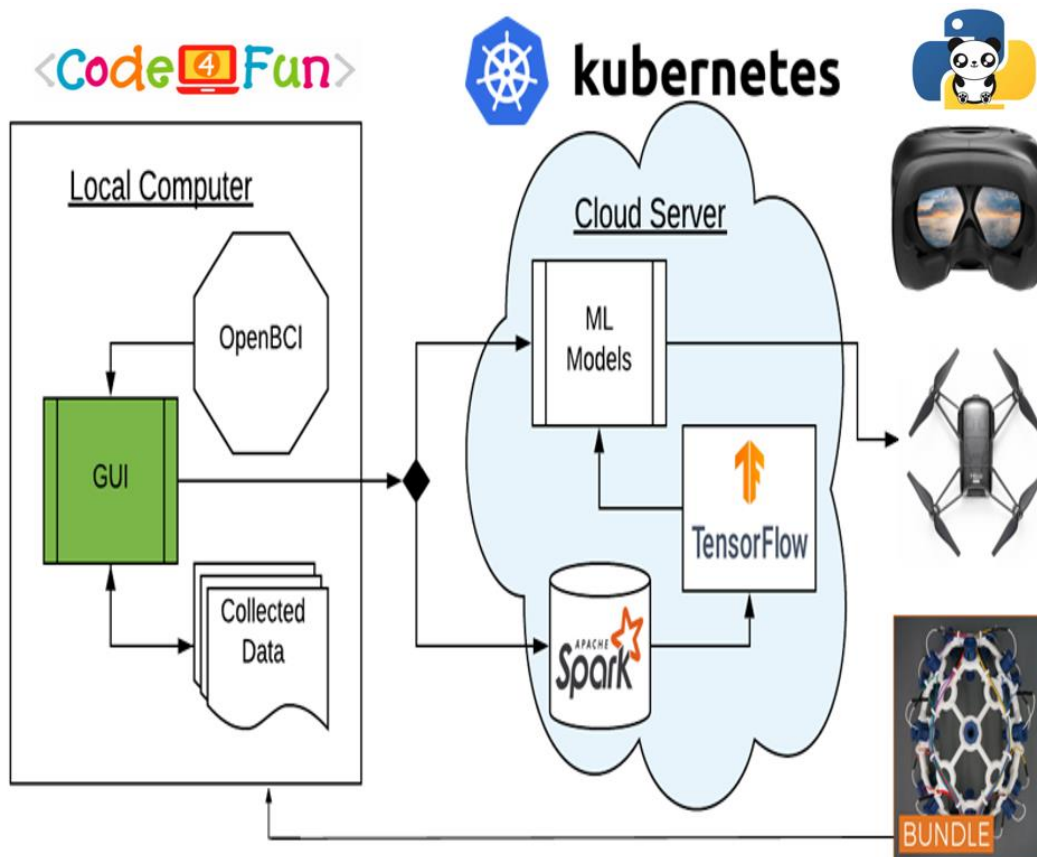


Figure 15: System architecture.

6.3 Spark

We define all necessary configurations to Spark for the 16 sensors reading from the OpenBCI headset. For such, we define Dataframe and RDD, set by default as part of Spark 2 once you create a SparkSession. The SparkSession import with SparkContext has most of the needed capabilities, including SparkSQL [10]. Pandas Dataframe allows easy data format compatibility for importing and exporting the data we connect from the cloud.

```
DF1 = InputFrame.input("TakeOFF")
DF2 = InputFrame.input("Higher")
DF3 = InputFrame.input("Landing")

set_df = df.concat([DF1, DF2, DF3], ignore_index=True)
```

Then, input all sensors data to the DenseVector:

```
dataset = []
for x in range(0, len(set_df)):
    vec = []
    for y in range(1, 10):
        if (y != 1):
            vec.append(Vectors.dense(set_df[y][x]))
        else:
            vec.append(set_df[y][x])
    dataset.append(vec)

df = spark.createDataFrame(dataset,
    ["label", "ch1", "ch2", "ch3", "ch4", "ch5", "ch6", "ch7", "ch8",
     "ch9", "ch10", "ch11", "ch12", "ch13", "ch14", "ch14", "ch16"])
```

6.4 TensorFlow

For machine learning, clustering, and classification, some of the most popular open-source libraries are respectively: TensorFlow, ScikitLearn, PyTorch, and Keras. Among those alternatives, we choose TensorFlow, which integrates with Keras. Additionally, TensorFlow is considered a robust framework for Big Data processing. Specifically for Brain Computer Interface, using the algorithm derived from the Neural Networks is the

most known effective way of supervised learning training your model applicable to EEG brain signal reading and pattern identification processing.

Organize the data for classification and analysis:

```
supervised_learn = []
for action in dataset:
    for data in all_data[action]:
        if action == 'TakeOFF':
            supervised_learn.append(['TakeOFF', data])
        elif action == 'Higher':
            supervised_learn.append(['Higher', data])
        elif action == 'Landing':
            supervised_learn.append(['Landing', data])
```

Apply the TensorFlow learning process to clustering classification to a dense vector:

```
def data_normalization(data):
    set = []
    set.append(dataset[0])
    for sensorBCI in dataset[1]:
        set.append(Vectors.dense(sensorBCI))
    return set
```

Define and import sensor data into Dataframe:

```
Rdd = sc.parallelize(supervised_learn).map(dataset)

sc.parallelize(supervised_learn.collect())
df = rdd.toDF(["label", "ch1", "ch2", "ch3", "ch4", "ch5", "ch6", "ch7", "ch8",
             "ch9", "ch10", "ch11", "ch12", "ch13", "ch14", "ch15",
             "ch16"])
```

blockSize – the larger the size, the faster will be the training times. One must ensure to set a value between 100-1000, and the default is 128. For better performance, we put it to 256.

_ layers – define the network configuration. For example, our BCI headset with sixteen sensors can look like this [960, 480, 3].

```

NNM = MultilayerPerceptronClassifier(labelCol="labelIndex",
featuresCol="features",
layers=[960,480,3],
upper_interaction=200,
blockSize=256)

```



Figure 16: Data transmission.

After you have defined your machine learning and the spark session, you can then transmit the data using the open "Networking" window and set the networking fields as shown to allow data transmission (Figure 16). The information "Data stream started" will appear in the bottom left-hand corner if the transmission is processing without problems. If you eventually see no message indicating that the stream started, press the stop transmission button.

7 Conclusion

This paper described the key components and steps to assemble the necessary supporting environment to allow the effective learning and development of the Brain-Computer Interface for undergrad and post-grad students. At St. Cloud State University, this aim is effectively growing stronger once the Interdisciplinary Computer Hub was established,

with the subsequent arrival of the equipment put in place. Additional activities helped to instigate interest and broader engagement toward contributing to the project code that is part of the Cloud Computing Club activities. The primary motivation for students getting involved is the prospect of aiding several skill sets to help them differentiate themselves in the job market. All technologies used in the current implementation framework also hint at why so many students have decided to join the Cloud Computing Club and actively participate in the activities in the Brain Computer Interface Lab at Interdisciplinary Computer Hub. The possibilities for machine learning, distributed scalable cluster computing, and using BCI for human-computer interaction have become a reality moving quickly toward system applications where the student's brain has the power.

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