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ON THE DEVELOPMENT AND EVALUATION OF A FRAMEWORK FOR BRAIN-COMPUTER INTERFACE AND VIBROTACTILE FEEDBACK FOR HUMAN-ROBOT-INTERACTION IN VIRTUAL SPACES AND ROBOTIC HARDWARE

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ABSTRACT

Research in Brain-Computer Interface (BCI) aims to understand human intent with the goal to enhance Human-Robot Interaction (HRI) especially in the field of assistive robotics. The goal of this research is to develop a behavioral sequence based framework to help persons with upper limb disabilities to maintain self-dependence. The framework aims to operate in stages and links multiple functional components to identify human intent and control a robotic arm. The development, operation, and evaluation of the framework and the linked functional components to acquire, process, evaluate, and map BCI signals generated using facial expressions and head movements to predefined actions will be introduced.The framework will integrate multiple functional components such as a non-invasive BCI control device, a vibrotactile haptic feedback device, a visual feedback environment, the evaluation and training platform, and a robotic arm. The robot pick, move and place actions are mapped to different facial expressions and presented using haptic and visual feedback to the user for classified action verification before performing the process using a robotic arm. The initial evaluation of the developed framework was 100% *successful with two volunteers who also provided constructive feedback. The initial successful evaluation provides confidence to further test the framework with more volunteers to identify limitations and/or areas of improvement and its application for further research in HRI as it applies to assistive robotic systems.*

Keywords: Human Robot Interaction, Brain Computer Interface, Vibrotactile Feedback, Process Verification, Virtual Environment, Assistive Robotics, Interaction Framework

NOMENCLATURE

Abbreviations

BCI	Brain Computer Interface
HRI	Human Robot Interaction
EEG	Electroencephalogram
GUI	Graphical User Interface
ERM	Eccentric Rotating Mass
WVF	Waveform Pattern
FG	Facial expression

1. INTRODUCTION

HRI and BCI belong in a multidisciplinary field that allows for interlinking multiple functional components while providing an interaction interface. This interface provides a person the ability to interact, control and monitor the behavior of the components in a physical environment. A framework is required to interlink the different functional components and organize the information flow to follow a certain behavioral sequence. The framework provides the ability to set control protocols to simulate autonomous behavior while confirming interactions that are approved for a certain scenario.

As a part of daily life, a person accomplishes various actions by performing motion actions related to grasping and moving objects, coordinating motion sequences, and sensing object properties performed using the hand and utilizing human haptics during physical exploration. These actions are generally easy for an able-bodied person. However, for an individual with upper limb disability they can be a challenge to perform without additional human assistance. In such scenarios, the integration of assistive robotic systems in the daily life of a person can help them maintain self-dependence. Assistive robotic system refers to a system which can maintain or improve the functional capability of a person with disability [1].

Assistive robotic systems for social interactions consider various factors and interaction methods [2]. The robot needs to understand when humans want to engage and be able to communicate with the user. These communication methods include verbal

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*Corresponding author: shiakolas@uta.edu and non-verbal modalities. The proposed interaction approach would allow a user to interact with the robot using non-verbal form of communication, facial expressions and nods (types of head movement), as well as sense robot responses or intended actions through the vibrotactile interaction.

An upper limb disability could be due to different reasons such as spinal cord injuries, strokes, muscular dystrophy or upper limb amputation. In the majority of the cases, the person retains the ability to generate brain signals for various physical actions even after loosing motor controls. In the United States alone approximately 5,400,000 people have some form of paralysis [3] and almost 185,000 people undergo some form of amputation every year [4]. The field of HRI and BCI could consider such limitations towards identifying ways to enable the interaction of humans with assistive robotic systems.

In this study, we propose a framework to interlink multiple functional components and establish an operation sequence for an assistive robotic system. The framework is implemented in LabVIEW due to its ability to easily communicate with diverse hardware components, ease of graphical programming and development of customized graphical user interfaces (GUIs). The system utilizes the framework to communicate with various functional components such as a non-invasive Emotiv EPOC+ headset, a custom developed glove-based haptic feedback system, a Braccio robot, and Webots (a robot simulator). This system could enable a person with upper limb disability to interact with an assistive robot using a combination of EEG signals of facial expressions and head movements based commands to define a desired action, obtain haptic feedback on the understood action before execution and confirm or abort execution.

2. RELATED WORK

With the growing market for commercially available EEG based devices, research in the field of BCI has expanded over the last few years. Emotiv EPOC+ is one of the many available EEG sensing devices and frequently used in academic research. Several studies have utilized the Emotiv headset to extract either raw EEG data or classified data to control some form of robotic hardware [5–12].

Chowdhury et al. [5] investigated the use of four mental commands to control the motion of a mobile robot in four directions and an untrained facial expression to stop an ongoing motion. They presented an accuracy of 72.65% for motion control by able-bodied people and 82% by individuals with a disability. They also reported that mental commands training success rates varied by large margins for all mental commands which could lead to a false interpretation. Ouyang et al. [10] investigated an implementation of mapping four mental commands to move a robotic end effector. A majority of the subjects were able to only perform control using one to two mental commands with low accuracy, and had difficulty triggering more than 2 commands.

Aguiar et al. [8] and Zamora et al. [11] presented the usage of facial expressions and gyroscope data captured using Emotiv EEG headsets to control a simple robotic arm. A robotic arm was controlled in both the studies with an accuracy of over 80%. While these studies were able to achieve a reasonably high accuracy, there were still opportunities for false positives, resulting in the robot performing an unintended action. Therefore, the understood or classified action must be verified before robot execution to avoid unintended motions or worse injuring a person.

Virtual simulations can be an effective medium to validate robot actions to avoid undesirable behaviour. According to Choi et. al. [13] virtual simulation provides the ability to present an operation selected based on the user decisions. This is beneficial in the field of HRI since it provides a safe environment for verification of the selected action before robot execution. Webots [14] is a virtual simulation package commonly used in investigations with BCI to simulate robot actions [15–18].

Vibrotactile feedback can be used to guide a person by providing a perception which could be interpreted in reference to the direction a movement should follow [19] or aid in proprioceptive rehabilitation [20] or generate sensory illusions for virtual reality applications [21]. Vibrotactile feedback provided on the fingertips allows a person to sense vibration variations due to the presence of high concentration of mechanoreceptors under the glaborous skin [22]. This ability could allow a person to understand non-visual information provided in the form of tactons. Tactons are waveform patterns which vary in amplitude, frequency, duration and rhythm [23]. Chan et al. [24] reported that these haptic feedback patterns can be identified by a person even when a person is engaged in a task.

Previously proposed frameworks to control robotic systems using BCI inputs, capture and interpret an EEG signal for an intended task and send appropriate signals to control a robot. On receiving an BCI input, the EEG signals are interpreted by being processed through a controller which will extract features that are recognizable and classifiable to generate control commands for a robotic system. On receiving the control commands the robotic system can perform the intended task and update the user using sensory stimuli which could be visual, auditory, or tactile. These frameworks purely focus on using signal processing methodologies to interpret EEG signals provided by the user and to reduce false positives. In such scenarios once the framework has received the EEG signals the user is not part of the decision making process and would need to visually monitor the assistive hardware to understand and react if the action being performed is correct or not [25–28].

Research in our laboratory investigates methodologies to integrate multiple functional components of BCI and HRI into a behavioral procedure and provide vibrotactile haptic feedback to the user, thus providing an interface to communicate between multiple functional components and a library of distinguishable haptic waveform patterns. Node-RED, a browser based programming language, was used to transfer information pertaining to classified mental commands, facial expressions, and extracted gyroscope data for head movements from the EmotivBCI application to Webots, and LabVIEW to control the simulation and operation of a Braccio robot based on the classified action[29]. As a part of our investigation in the field of haptics, a procedure is developed to generate distinguishable vibrotactile feedback. A set of waveform patterns were prepared and evaluated to determine the ability of a person to distinguish and identify these waveform patterns[30] in order affirm or verify the execution of the classified action or abort it.

This investigation further extends our research in the field of BCI and HRI and presents a framework which could be used by individuals with upper limb disability. The proposed framework will establish an operational behavioral based process sequence and combine multiple functional components to safely perform a desired action by an assistive robotic system. The proposed framework is intended to increase the involvement of a user in the decision making process before sending the control commands to an assistive device to reduce the number of false positives and to allow a user to act before the action is performed instead of reacting while observing the action being performed by it.

3. FRAMEWORK

The proposed framework is based on a behavioral sequence to link the multiple functional components and operate them in an ecosystem consisting of the user, BCI control device (Emotiv EPOC+), LabVIEW based control interface, haptic feedback device (haptic feedback glove), visual feedback, training, and evaluation platform (Webots), a robotic arm for action or task execution (Braccio robot) and its associated microcontroller (LabVIEW based myRIO). In order to apply the framework to an assistive robotic system a set of requirements are defined. The framework should have the ability to

- Sense and interpret BCI inputs such as facial expressions and head movements.
- Map a desired action and a corresponding tactile feedback to a BCI input.
- Verify an understood or classified action using tactile and visual feedback before execution by robotic system.

The functional components interlinked by the framework are categorised into four (4) modules based on the defined requirements.

- Module 1: EEG signal read and classify

  This module acquires and processes data for facial expressions and head movements. After acquiring the raw information using the BCI control device the EmotivBCI program (supplied by manufacturer) classifies and interprets the EEG signals based on the initially performed training for facial expressions and provides X-, Y-, and Z-axis gyroscope data based on the user's head movement.

- Module 2: Signal verification using haptic feedback

  This module initiates a verification process utilizing haptic feedback to confirm if the action "understood" or classified by the framework is the intended user defined action. This module is also invoked when an action has been executed by a robotic arm to indicate that all stages of operation have been completed. A haptic feedback device is used to provide a predefined distinguishable haptic feedback.

- Module 3: Signal verification using virtual simulation of the classified task

  This module initiates a verification process utilizing visual feedback to confirm if the action "understood" or classified by the framework is the intended user defined action. Visual feedback is provided by generating a virtual simulation of the robotic arm motion for a desired action using Webots. Webots could also be used for training the user and evaluating the robotic arm motion before executing the understood action.

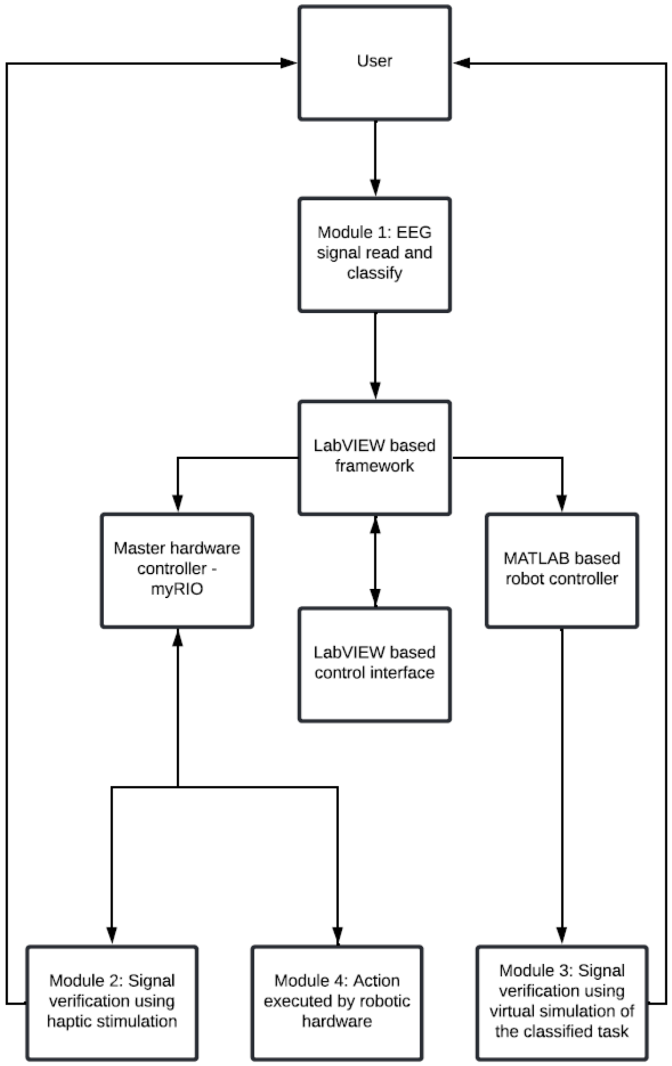


FIGURE 1: SIMPLIFIED FRAMEWORK MODEL LINKING FUNCTIONAL MODULES

- Module 4: Action execution by robotic hardware

  This module executes the desired action using a robotic arm. The motion of the robotic arm is governed by the motion commands according to a mapped action and executed using the Braccio robot.

The simplified model of the proposed framework linking all four (4) modules is presented in figure 1.

3.1 Framework Processes

The modules are linked according to the framework forming an interactive system that can execute actions based on classification of the user input provided in the form of facial expressions

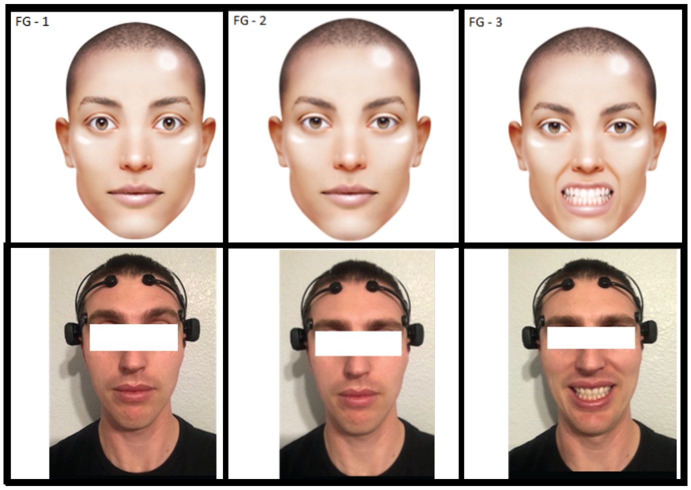


FIGURE 2: FACIAL EXPRESSIONS: FG-1 RAISED EYEBROWS, FG-2 NEUTRAL FACE, FG-3 CLENCH [32]

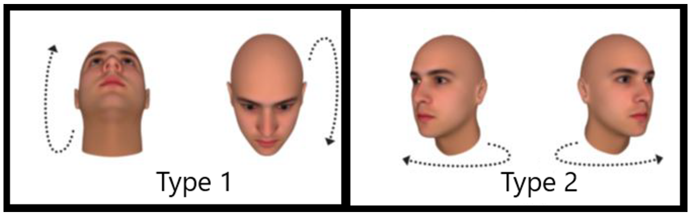


FIGURE 3: TYPES OF NODS: TYPE 1 FOR A "YES" COMMAND, TYPE 2 FOR A "NO" COMMAND [33]

and nods. Facial expressions and nods are a form of unique and personal human-human non-verbal communication [31]. This allows for the framework inputs to be personalized and mapped to generate control signals to command the robotic system. The current framework, as the first step, has two trained facial expressions mapped to two actions, and two types of nods mapped for the verification processes as shown in figures 2 and 3 respectively. The waveform patterns used for haptic feedback verification are presented in figure 4. The actions to be performed by the robotic system are predefined, pick and place an object from and to a known location.

Table 1 presents a list of facial expressions and nods, mapped associated robot actions and the haptic feedback waveform patterns predefined in the framework. The framework is intended to operate in stages invoking modules as needed. The stages of the framework operation are as follows:

- Stage 1: Action classification

  In this stage only Module 1 is initiated. The facial expressions performed by the user are captured and recognised by the BCI control device. This recognition allows the framework to classify an action and retrieve the commands for the robot motion and the corresponding haptic feedback. After an action is classified correctly, the framework will proceed to Stage 2, otherwise it will maintain the current state of all interlinked components and wait for a predefined user input.

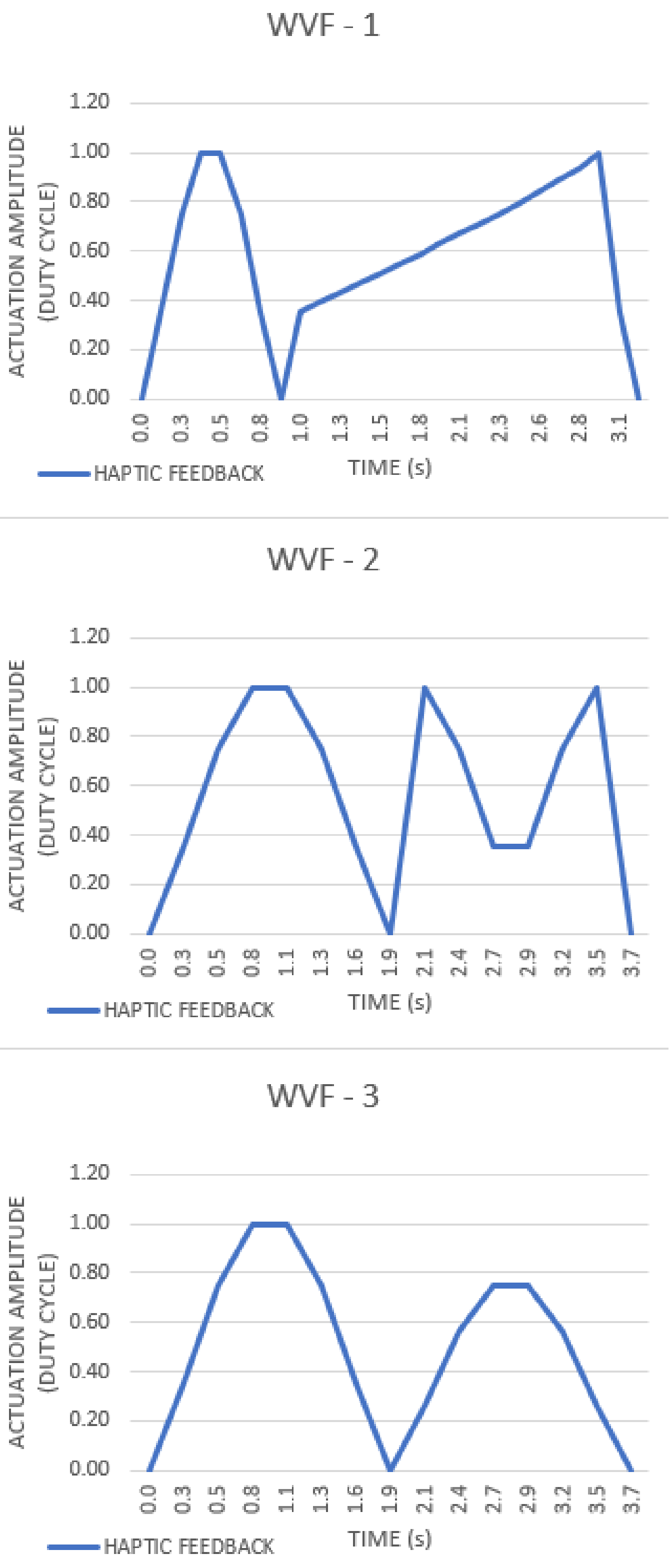


FIGURE 4: ACTION MAPPING FOR HAPTIC WAVEFORM PATTERNS: WVF-1 PICK OBJECT, WVF-2 PLACE OBJECT, WVF-3 CONFIRM ACTION COMPLETED

TABLE 1: LIST OF MAPPED COMMANDS, ACTIONS AND HAPTIC FEEDBACK WAVEFORM

Input Command	Robot Action	Haptic Feedback	Action Description
Facial expression: *Clench*	Pick Object	WVF-1	Initiate robot motion to move the end effector at the object pick up location while ensuring the gripper is open.
Facial expression: *Raised Eyebrow*	Place object	WVF-2	Initiate robot motion for object pick by closing the gripper, move robot to target location and open gripper to place the object at the target location.
Head movement: *Nod Type 1*	Task Confirmation: *Yes*		Capture the user intent to confirm if the classified task is correct during the verification phase.
Head movement: *Nod Type 2*	Task Confirmation: *No*		Capture the user intent to confirm if the classified task is incorrect during the verification phase.
	Robot task execution Completion notification	WVF-3	Indicate at system level that the actuation command signal for the robot action has been sent to the controller for execution.

- Stage 2: Action verification

  In this stage Module 1, Module 2 and Module 3 are initiated. The action classified in the framework is first verified using haptic feedback and then using visual feedback if the verification using haptic feedback is successful. The haptic feedback is provided through a haptic feedback device which utilizes the waveform pattern associated with the classified action. Visual feedback is provided by simulating the motion of the robot according to the classified action. For every verification feedback step provided, the user is required to respond using nods to confirm if the action classified is correct or not in a verification response period of 5 seconds. If the action classified is correct, the framework will proceed to Stage 3. If the action classified is incorrect, the framework will reinitialise all system inputs and return to Stage 1 and wait for the next input. The simulated robot motion for two actions, Pick object and Place object, in Webots is shown in figure 5.

- Stage 3: Action execution

  In this stage Module 4 and Module 2 are initiated. On successful verification of the classified action, the Braccio robot is used to perform an action using the motion commands retrieved during Stage 1. On completion of the classified action, the user is notified using haptic feedback on the status of the action execution. On completion of the action, the framework will reinitialise the system inputs to accept new commands and return to Stage 1. A sequence of actions performed by the Braccio robot for the two actions, Pick object and Place object, after being classified and verified is shown in figure 6.

The detailed behavioral sequence based on the operation of the framework is presented in figure 7.

4. FRAMEWORK SYSTEM COMPONENTS

The framework interlinks multiple hardware components (Emotiv EPOC+ headset, haptic feedback glove, Braccio Robot and myRIO microcontroller) using a LabVIEW based interface to link programs such as EmotivBCI, Webots, and MATLAB to control the hardware and provide an interactive interface to the user.

4.1 Hardware and Software Components

The Emotiv EPOC+ headset is a non-invasive 14-electrode EEG headset paired with the EmotivBCI program. The EmotivBCI program is capable of classifying facial expressions based on the sensed EEG signals and user training. The program also allows for visualisation of the EEG signals based on performance metrics and collects gyroscopic information pertaining to head movements in real-time. The collected and classified information is extracted using Node-RED, a browser-based programming tool, that utilizes an EmotivBCI toolbox to communicate with the Emotiv EPOC+. This information is sent from Node-RED to the LabVIEW based master controller.

LabVIEW is a system design platform and development environment for visual programming and is used to program the master controller utilizing the framework. LabVIEW interfaces seamlessly to the NI myRIO microcontroller used to control the Braccio robot and the haptic feedback device. The haptic feedback device is glove-based developed at our research lab (MARS Lab) and shown in figure 8. The device consists of 5 eccentric rotating mass (ERM) actuators of 10mm diameter operated at a frequency of 220Hz to provide cutaneous sensation at the fingertip. The actuators are driven using a DRV2605L actuator driver board powered using a 3.3V power supply provided through the myRIO microcontroller. The NI myRIO microcontroller operates at a frequency of 1kHz to generate a PWM signal corresponding to a duty cycle range of 0 to 1 based on the input haptic waveform pattern to drive the ERM actuators.

The Braccio robot is tabletop 6-axis robotic arm with a maximum load capacity of $150g$ at an operating distance range of $32cm$. A PWM signal, generated by the myRIO microcontroller, is required to control the joint servo actuators to perform the pick and place operations.

The master controller software implemented in LabVIEW

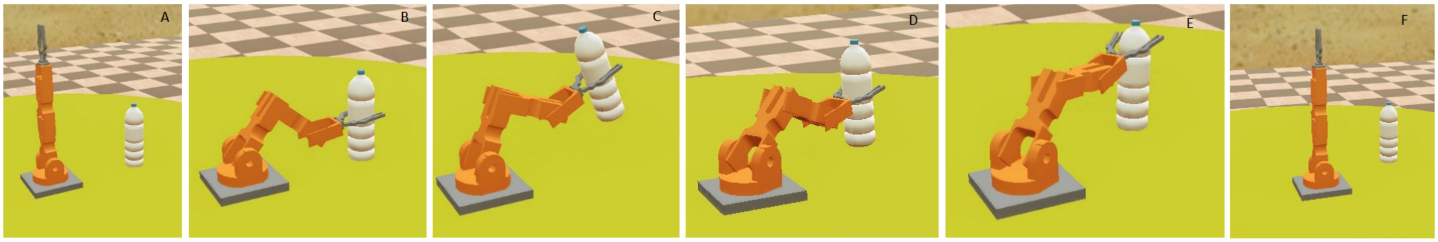


FIGURE 5: WEBOTS VIRTUAL SIMULATION OF ROBOT PERFORMING THE CLASSIFIED ACTIONS OF PICK (APPROACH AND GRASP) OBJECT AND PLACE (PLACE AND RELEASE) OBJECT

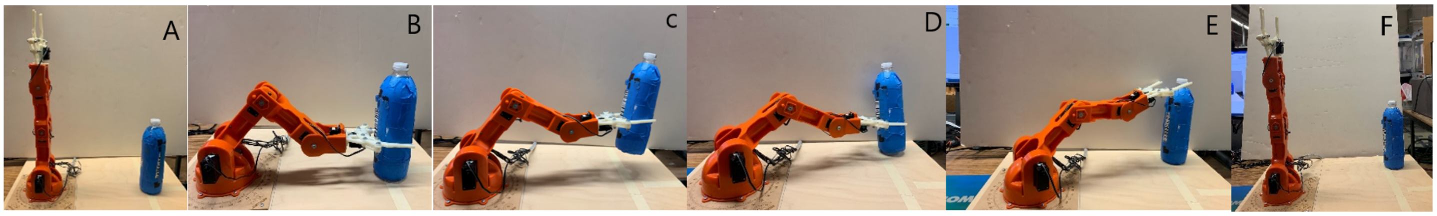


FIGURE 6: ACTUAL ROBOT PERFORMING THE CLASSIFIED ACTIONS OF PICK (APPROACH AND GRASP) OBJECT AND PLACE (PLACE AND RELEASE) OBJECT

is also interfaced with a MATLAB based robot controller which provides the control commands for the visual simulation of the robot motion in Webots, an open source 3D robot simulator. The GUI for the master controller provides an interactive interface for continuous monitoring of the various Stages of operation of the framework and signals. Figure 9a presents the interactive interface for monitoring the operation of Stage 1, and figure 9b presents the interactive interface to monitor the operations of Stage 2 and Stage 3.

4.2 EmotivBCI Training and Gyroscope Data Interpretation

The training for the EmotivBCI program to recognize facial expressions is performed using the on-screen avatar. The avatars for the corresponding facial expressions are shown in figure 2. The first training step is to establish a baseline based on neutral expression (FG-2). Then, facial expressions such as raised eyebrows (FG-1), neutral (FG-2) or clench (FG-3) are trained following software guidelines [32, 34].

The gyroscope data obtained from the Emotiv EPOC+ was analyzed in LabVIEW by comparing the gyroscope data to the defined threshold values to be achieved during the nods. The threshold values are minimum gyroscope sensor magnitude values in the X-, Y- and Z-axes which should be reached in order to be usable. The thereshold values are experimentally determined by recording the gyroscope data for each type of nod. Sample gyroscope data corresponding to nods are presented in figure 10; NOD-TYPE 1 represents a 'Yes' nod, and NOD-TYPE 2 represents a 'No' nod. Based on the data collected, threshold values are defined per axis for each type of nod; a value of 800 along the Y- and Z-axes for a 'Yes' and a 'No' nod respectively.

5. FRAMEWORK EVALUATION AND DISCUSSION

The operation and function of the proposed and developed framework is evaluated to verify its effectiveness to follow a certain behavioral sequence using a volunteer based test. The three stages of the framework operation are evaluated to determine its ability to follow a behavioral sequence to perform a desired action and determine factors which could affect the performance of this BCI and HRI interface.

5.1 Evaluation Protocol

In this initial evaluation there were 2 volunteers (able-bodied male doctoral students in the age range of 25-30) who participated on their own accord without expectation of special treatment. These volunteers are provided instructional cues regarding the framework stages and their order of operation using figure 7, hardware components to be used, and types of inputs and expected outputs.

After receiving the instructional cues, the volunteers are introduced to the EmotivBCI program used to train facial expressions and the distinguishable vibrotactile feedback to be provided through the haptic feedback device. The volunteers are asked to wear the headset according to the manufacturer (Emotiv Inc.) guidelines such that the EEG signal strength reaches a minimum of 95% and take part in the training process available through the EmotivBCI program for facial expression recognition for facial expressions Clench and Raised Eyebrows. The volunteers are required to wear a glove based vibrotactile feedback device and informed that feedback would only be provided on the tip of the index finger. The volunteers are also introduced and trained to the feedback patterns to be employed during the evaluation process.

Before starting the evaluation, the volunteers are guided to perform a complete action sequence of picking and placing an object. While performing the action sequence in a guided manner, the expected inputs for Stages 1 and 2 were provided manually through the system to avoid additional volunteer training and focus on the operation of the complete framework. Upon completion of the guided action sequence all functional modules of

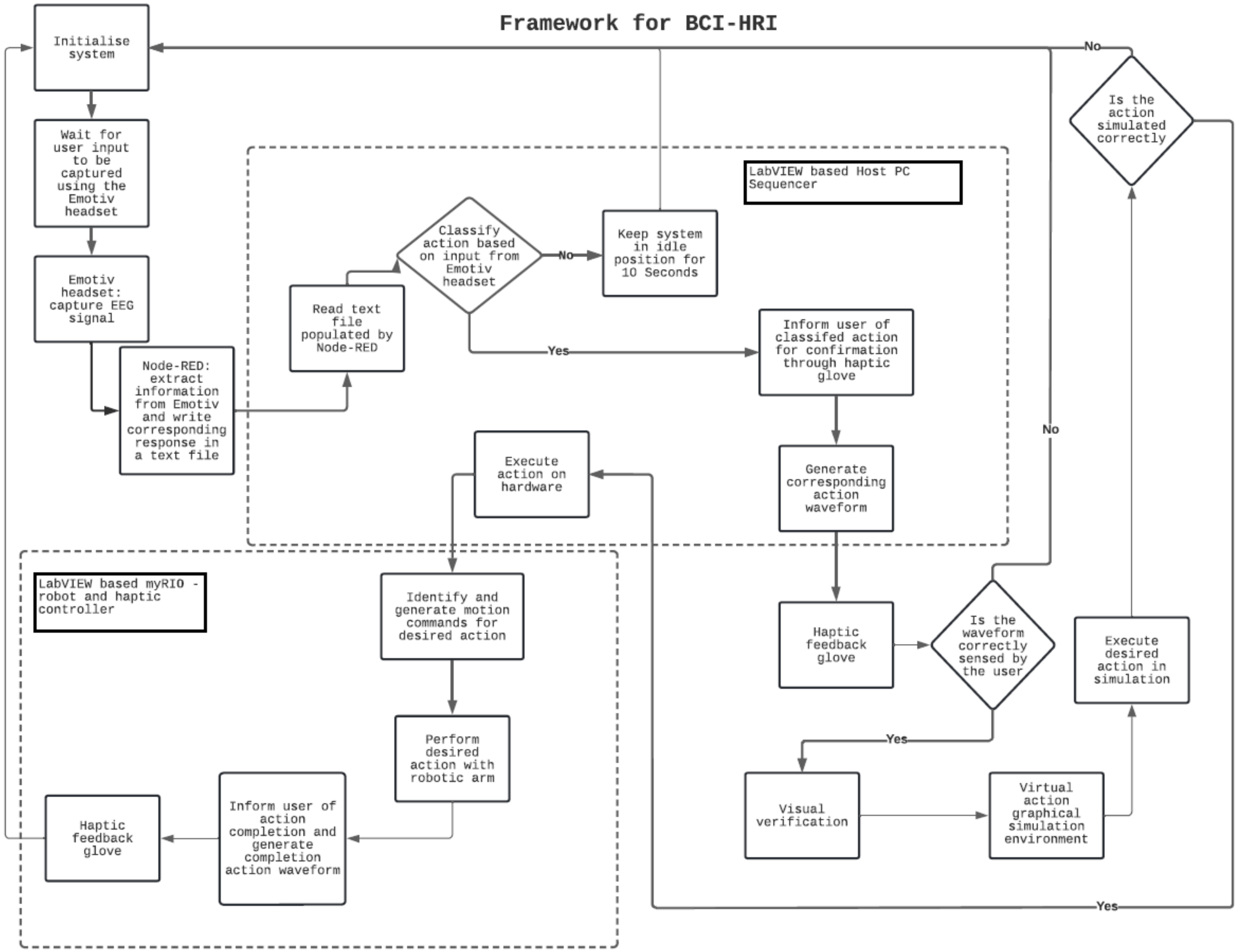


FIGURE 7: BEHAVIORAL SEQUENCE FOLLOWED BY THE FRAMEWORK

FIGURE 8: HAPTIC FEEDBACK GLOVE: A) GLOVE OUTER SIDE, B) GLOVE INNER SIDE [30]

the framework were initialised to accept predefined facial expression commands which are classified at Stage 1 of the framework operation.

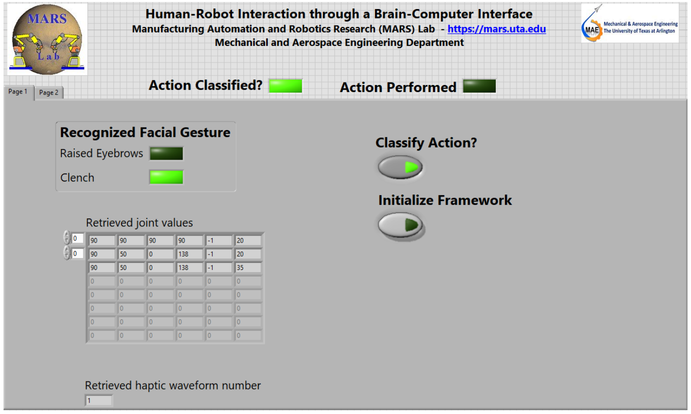
Following completion of the training process, the evaluation of the proposed framework was performed.

5.2 Evaluation

The ability of the system to recognize facial expressions and nods was evaluated and the procedure followed and the results are discussed in this section including the ability of the framework to follow a behavioral sequence to execute a desired action and handle unintended facial expressions or false positive BCI inputs.

1. Evaluation of facial expression recognition

   A score in the range of 0 to 100 is provided by the EmotivBCI program and used to determine the quality of facial expression recognition. Using a researcher developed training dataset, a recognition score of 90 out of 100 was defined as the threshold cutoff to achieve consistent facial

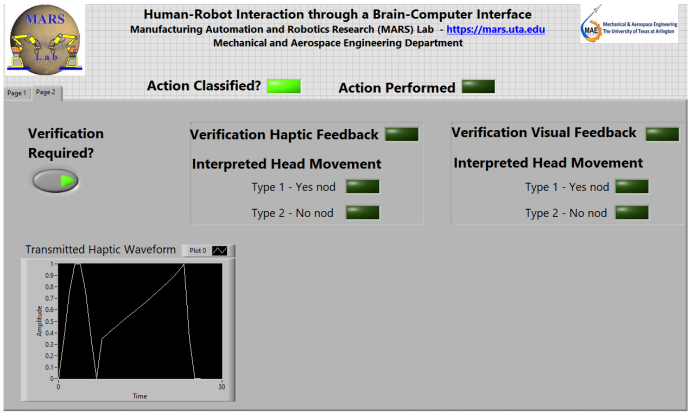


Retrieved joint values

90	90	90	90	-1	20
90	50	0	138	-1	20
90	50	0	138	-1	35
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0

Retrieved haptic waveform number: 1

(a) Interactive interface for Stage 1



(b) Interactive interface for Stage 2 and Stage 3

FIGURE 9: FRAMEWORK INTERACTIVE INTERFACE IMPLEMENTED IN LABVIEW

expression recognition. When this dataset was applied to the volunteers no consistent recognition was observed even when the threshold cutoff value was reduced.

A different customized training dataset generated by each volunteer for the facial expression achieved a consistent recognition with a threshold cutoff value of 90. Therefore, it is concluded that the BCI device training for facial expression cannot be applied to different persons but it must be customized for every individual.

2. Evaluation of nod recognition

   A recognition threshold of 800 was set by the researcher based on the data collected along the Y-axis to represent a 'Yes' nod and along the Z-axis to represent a 'No' nod. Each volunteer performed both the nods which were recognized correctly by the system. During the evaluation, the raw data for the nods indicated different maximum gyroscope magnitude values corresponding to the axis of rotation as the volunteers had a different range of neck motion. Therefore, the threshold values should be personalized as needed.

The ability of the framework to follow a behavioral sequence was verified according to the sequence of actions as presented in figure 7 and based on the evaluation of inputs by each individual. The customized training dataset generated by each volunteer and a threshold value of 800 for nod recognition is used for the evaluation of two cases as follows:

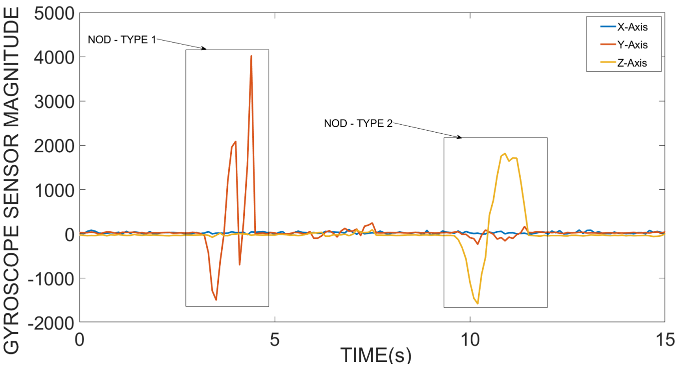


FIGURE 10: GYROSCOPE DATA TO IDENTIFY NODS DEPENDING ON HEAD MOVEMENT

1. Case 1: Ability of framework to execute a desired action.

   The volunteers provided facial expressions in a specified order to first pick the object and then place it. This evaluation was performed twice with changing verification response time periods, 5 seconds during the first trial and 10 seconds during the second trial. The facial expression provided by the volunteers as input is recognized by the system and they were able to successfully complete both verification processes for which a 'Yes' nod is provided as the response input. The volunteers were able to successfully perform the desired action with the robotic arm using the facial expressions and nods as inputs. The framework was found to follow the specified behavioral sequence for both the volunteers during evaluation. The volunteers were observed to provide a response during the verification process and then wait for the system to proceed, further indicating that the verification response time periods for the system might be long and need to be adjusted.

2. Case 2: Ability of framework to handle unintended facial expressions or false positive BCI inputs.

   During this evaluation phase, the volunteers were asked to provide either a Clench or Raised eyebrow facial expression as input but are directed to provide a response in the form of a 'No' nod for the verification process to treat it as an unintended input and prevent the framework from executing the action using the robot. The volunteers were able to successfully stop the framework from executing the action and the framework reinitialized to accept new inputs.

According to the preliminary results and observations, it might be beneficial to introduce in the framework a user calibration stage. This calibration stage will provide for user based customization by allowing the user to prepare training data and adjust threshold values as well as response wait times required for both verification processes.

This initial evaluation had a 100% success rate for the framework to follow the behavioral sequence which provides confidence to start recruiting additional test subjects for a more comprehensive study on the utility of the framework and to identify limitations and/or areas of improvement.

6. CONCLUSIONS

This research in BCI and HRI presented the development, operation, and evaluation of a behavioral based framework linking, operating and controlling multiple functional components. A set of actions to be performed by a robotic arm based on the corresponding BCI signal and haptic feedback verification were mapped prior to operating the framework. The developed framework provided the ability for a person to generate an intended action based on facial expressions using an Emotiv EPOC+ headset, verify the understood action through a custom developed wearable haptic feedback device and visual simulation through Webots prior to the action executed by a robotic arm. The initial successful evaluation of the proposed framework demonstrates its utility for possible application in assistive robotic systems and especially for persons with upper limb disability where a robot could prove beneficial for simple daily tasks.

Even though the framework currently assumes the availability of paired a-priori actions with facial expressions and ability of the user to receive haptic feedback through the wearable glove, future research could introduce more autonomy in the framework as it relates to predefined actions and corresponding robot control commands; for example for the pick and place locations or handling and manipulation of different objects. Also, the success of the hand based vibrotactile feedback could be customized and extended to other body locations that could sense and discriminate vibration signals.

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