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DEVELOPMENT OF A THERAPEUTIC GAME FOR ADHD PATIENTS USING EEG HEADBAND AND TUK, THE SOCIABLE ROBOT

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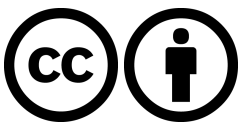
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Abstract

Attention Deficit Hyperactivity Disorder (ADHD) is the most commonly diagnosed mental disorder in children and can continue in adulthood too. Patients with ADHD may be hyperactive and unable to control their impulses or focus. The purpose of this thesis is to design a system capable of reading and interpreting the electroencephalography (EEG) signal of the subject in real-time using a non-invasive portable headband. This system will interface with a social robot, TUK, which is designed at TU Wien and developed by students, to interact with the user. In this thesis, the capability of user interaction according to the EEG data regarding attention is added to TUK. Thus, the subject and the robot will play a game which help the subject to carry out therapeutic activities in order to improve their attention capacity.

Resumen

El trastorno por déficit de atención e hiperactividad TDAH es el trastorno mental más común en los niños y puede prevalecer en la edad adulta. Los pacientes con TDAH pueden ser hiperactivos e incapaces de controlar sus impulsos o su concentración. El propósito de esta tesis es diseñar un sistema capaz de leer e interpretar la señal del electroencefalograma EEG del sujeto en tiempo real utilizando una diadema portátil no invasiva. Este sistema estará conectado con un robot social, TUK, diseñado en la TU Wien y desarrollado por estudiantes, para interactuar con el usuario. En este proyecto, la capacidad de interactuar con el usuario de acuerdo con sus datos de EEG y atención es agregado al robot TUK. Así, el sujeto y el robot jugarán a un juego con el objetivo de realizar actividades terapéuticas para mejorar su capacidad de atención.

Zusammenfassung

Das Aufmerksamkeitsdefizitsyndrom ist die häufigste psychische Krankheit in der Kindheit und kann sich in der Erwachsenenalter durchsetzen. Einige Eigenschaften Patienten mit der Aufmerksamkeitsdefizitsyndrom sind die Hyperaktivität oder die Unfähigkeit ihre Impulse und Konzentration unter Kontrolle zu bringen. Das Ziel dieser These ist ein System zu entwerfen, das in der Lage ist, EEG-Patientensignale in Echtzeit durch ein tragbares, nicht-invasives Stirnband zu interpretieren. Dieses System wird mit einem sozialen Roboter (TUK) verbunden sein, der von TU Wien Studenten entwickelt ist, um mit dem Patienten zu interagieren. In diesem Projekt ist die Fähigkeit der Interaktion mit dem Patienten nach seinen EEG- und Aufmerksamkeitsdaten in den TUK-Roboter eingefügt. Auf diese Weise werden Patient und Roboter zusammenspielen, mit dem Ziel, therapeutische Aktivitäten durchzuführen, um die Aufmerksamkeit des Patienten zu verbessern.

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[Ignacio Pla Penalba]

Acronyms

ADHD Attention Deficit Hyperactivity Disorder. 9, 19–21

BCI Brain-Computer Interface. 3, 21, 26, 27

CDC Centers for Disease Control and Prevention. 19

EEG electroencephalography. 3, 9, 11, 21, 23, 24, 26, 28, 39

NF Neurofeedback. 21

TDAH Attention Deficit Hyperactivity Disorder. 11

TUK Technische Universität Kiwi. 9, 11, 13, 21

Chapter 1

Introduction

1.1 ADHD and Neurofeedback

Attention Deficit Hyperactivity Disorder (ADHD) is one of the most common disorders in childhood and can continue into adolescence and adulthood.

According to the Centers for Disease Control and Prevention (CDC), in 2016, approximately 9.4% of children 2-17 years of age (6.1 million) had ever been diagnosed with ADHD [5].

- Ages 2-5: Approximately 388,000 children
- Ages 6-11: Approximately 2.4 million children
- Ages 12-17: Approximately 3.3 million children

The primary features of ADHD include inattention and hyperactive-impulsive behavior. ADHD symptoms start before age 12, and in some children, they're noticeable as early as 3 years of age. ADHD symptoms can be mild, moderate or severe, and they may continue into adulthood.

ADHD occurs more often in males than in females, and behaviors can be different in boys and girls. For example, boys may be more hyperactive and girls may tend to be quietly inattentive.

A child who shows a pattern of **inattention** may often [6]:

- Fail to pay close attention to details or make careless mistakes in schoolwork
- Have trouble staying focused in tasks or play
- Appear not to listen, even when spoken to directly
- Have difficulty following through on instructions and fail to finish schoolwork or chores
- Have trouble organizing tasks and activities

- Avoid or dislike tasks that require focused mental effort, such as homework
- Lose items needed for tasks or activities, for example, toys, school assignments, pencils
- Be easily distracted
- Forget to do some daily activities, such as forgetting to do chores

A child who shows a pattern of **hyperactive** and **impulsive** symptoms may often [6]:

- Fidget with or tap his or her hands or feet, or squirm in the seat
- Have difficulty staying seated in the classroom or in other situations
- Be on the go, in constant motion
- Run around or climb in situations when it's not appropriate
- Have trouble playing or doing an activity quietly
- Talk too much
- Blurt out answers, interrupting the questioner
- Have difficulty waiting for his or her turn
- Interrupt or intrude on others' conversations, games or activities

Most healthy children are inattentive, hyperactive or impulsive at one time or another. It's typical for preschoolers to have short attention spans and be unable to stick with one activity for long. Even in older children and teenagers, attention span often depends on the level of interest.

The same is true of hyperactivity. Young children are naturally energetic — they often are still full of energy long after they've worn their parents out. In addition, some children just naturally have a higher activity level than others do.

There are three subtypes of ADHD:

- **Predominantly hyperactive-impulsive:**
 - Most of the symptoms (six or more) are in the category of hyperactivity-impulsivity.
 - Less than six inattention symptoms are present, although inattention may still be present to some degree.
- **Predominately inattentive:**
 - Most of the symptoms (six or more) are found in the category of the inattention and fewer than six symptoms of hyperactivity-impulsivity are present, although hyperactivity-impulsivity may still be present to some degree.

- Children with this type are less likely to demonstrate it or have difficulty getting along with other children. They may be calm, but it doesn't mean they're paying attention to what they're doing. Therefore, the child's behavior may be overlooked and parents and teachers may not notice that the child has ADHD.

- **Hyperactive-impulsive and inattentive combination:**

- Six or more inattention symptoms and six or more symptoms of hyperactivity-impulsivity.
- Most children have the combined type of ADHD. Treatments may relieve many of the symptoms of the disorder, but there is no cure. With treatment, most people who have ADHD can succeed in school and live productive lives. Researchers are developing more effective treatments and interventions using new tools such as brain imaging to better understand ADHD and find more effective ways to treat and prevent it [7,8].

However, in the development of new non-pharmacological treatments, the Neurofeedback (NF) has emerged as an intervention technique being researched as an alternative for the care of various neuropsychiatric disorders. Although most of the published studies have focused on establishing its usefulness in the treatment of ADHD, many of these studies have employed methodologies that make it difficult to extrapolate their results to clinical practice. That is why there is some controversy as to the true effectiveness of this technique [3, 9, 10].

The NF, like the Biofeedback, consists of a series of procedures that allow, from the acquired information on a physiological variable of interest, the modification of values voluntarily in the participant. It is also conceived as a technique of self-regulation in which patients learn to have voluntary control of things that were once thought to be involuntary. To do this, the NF relies on teams, designed for the patient to be able to detect changes that are produced in the physiological response selected and, by means of processes of classical or operant conditioning, learn how to modify the values of that signal; in the specific case of the NF, brain waves are used as a physiological signal. From this point of view, it is considered more like a training than a therapy, insofar as patients take an active role and practice until they develop the ability to control their mind.

1.2 Objective and Challenges

When talking about Neurofeedback (NF) therapies for ADHD, the most common used technique consists of using EEG characteristics to modulate aspects of video games. The EEG characteristics are treated to obtain the attention state of the patient providing rewards when he remains in a focused state. The objective is to create patterns for optimal brain function than can be assimilated by the patient and alleviate some of the ADHD symptoms in long term therapies

The aim of this project is to use a type of emerging technology with great prospects for the future, namely Brain-Computer Interface (BCI) systems. This technology will extract information from the patient's brain wave to process it and consequently, send an order to the robot TUK prototype. The values of the brain waves have been obtained by the Mind Wave device and managed with Arduino UNO.

The development of this application is conditioned by the economic expense involved in a project of these characteristics. It is also intended that the technology used in this project can be used for cognitive development in children, allowing them to manage their attention levels according to a stimulus or a specific situation, as an alternative way of using the

Mind Wave.

Finally, it has been intended that this work can be replicated by anyone, as the design can be printed in 3D and uses open software technology and low cost. In this way, the project is perfect as a domestic support for therapies performed in professional centres with more precise instrumentation and computational load.

Chapter 2

Electroencephalography (EEG)

The electroencephalography (EEG) is defined as a technique for studying the electrical currents within the brain. Electrodes are attached to the scalp. Wires attach these electrodes to a machine, which records the electrical impulses and the results are either printed out or displayed on a computer screen.

2.1 History of EEG

It was a war that provided the opportunity to explore the human brain for the first time. In 1870, Fritsch and Hitzig, two military doctors in the Prussian army, observed that by stimulating certain lateral areas of uncovered brains with galvanic current, movements occurred on the opposite side of the body. Following the same line of research, Ferrier experimented with the "faradic current". As a result, by the end of the century there was sufficient evidence that the brains of animals had electrical properties comparable to those found in the nerve and muscle [11, 12].

In 1913, Prawdnicz-Neminski recorded an electro-caphalogram of a dog, being the first to attempt to classify such observations. However, in that time, all the experiments were done on discovered brains. As the electrical changes were very small and without amplification procedures, it was impossible to record the impulses reaching the outside of the skull even if its existence was suspected [12].

It was in 1928 when Hans Berger devised a method that promised an investigation of the cerebral electrical activity, discovering what was known as "Berger's rhythm". However, due to his lack of technical knowledge, it was not until a few years later that its importance was recognized. Meanwhile, in 1929 at a meeting in the Central Pathology Laboratory at Maudsley Hospital in London, the possibilities of clinical electroencephalography were discussed for the first time [11].

In 1934, following a public demonstration before a British auditorium at a meeting of the Society of Physiology in Cambridge, Adrian and Matthews first verified the "Berger Rhythm" [11].

Much progress was made in this field, beginning to interest, among EEG researchers, the study of epilepsy and other mental illnesses, highlighting the complexity of the subject and the impossibility of isolating simple functions, being necessary to study the brain as a total organ.

2.2 International system 10/20

The 10-20 System of Electrode Placement is a method used to describe the location of scalp electrodes that are used to record the electroencephalogram (EEG) using a machine called an electroencephalograph. This record is the result of the activity of thousands of neurons in the brain.

The 10-20 system is based on the relationship between the location of an electrode and the underlying area of cerebral cortex [4].

The head is divided into six zones: frontopolar (Fp), frontal (F), central (C), parietal (P), occipital (O) and temporal (T). Even numbers (2,4,6,8) refer to the right hemisphere and odd numbers (1,3,5,7) refer to the left hemisphere. The z refers to an electrode placed on the mid-line. Also note that the smaller the number, the closer the position is to the mid-line. The letter A is used for reference electrodes that normally are placed in the ears.

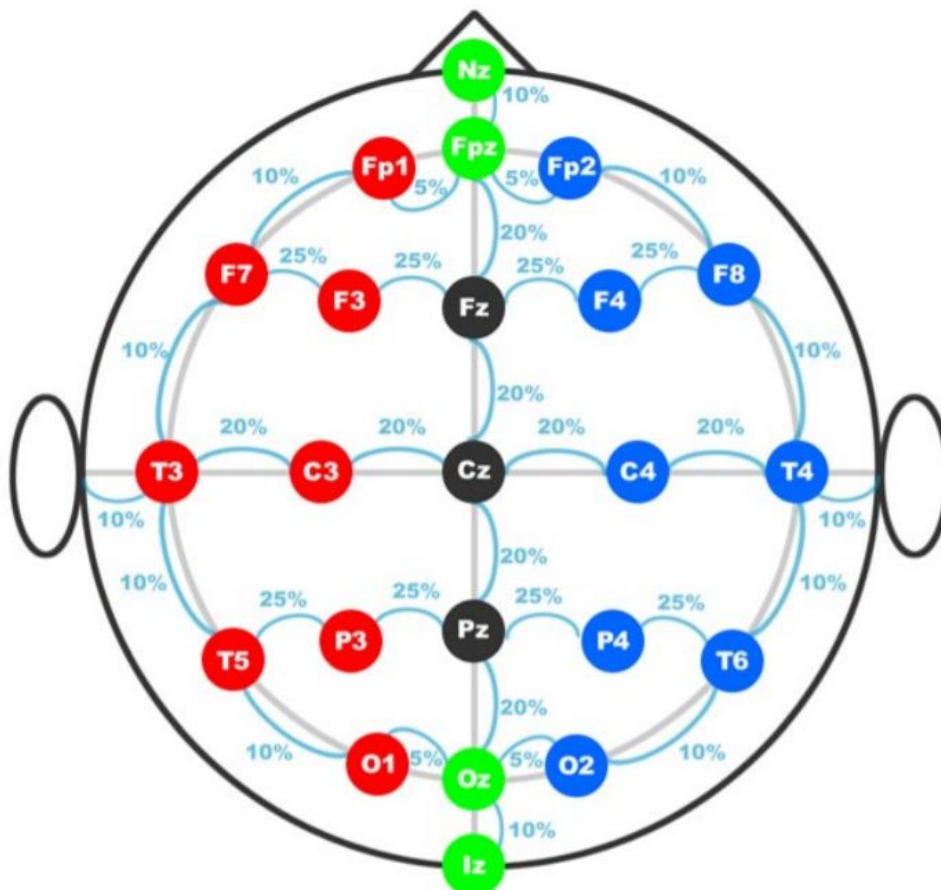


Figure 2.1: International system 10/20 [4]

NeuroSky's Mindwave helmet will be used in the project and will be described below. As can be seen in the image it has an electrode positioned in the section Fp1 and a reference electrode placed in A1.



Figure 2.2: Mindwave position

2.3 Brain rhythms

There are a variety of rhythms that can be highlighted by their frequency band, the location in the brain, the amplitude of the signal, and other inherent aspects of each of them. The amplitude of the signals recorded by electroencephalogram has a magnitude order of μV and its spectrum is contained in frequencies ranging from 0.5 Hz to 100Hz, being important to emphasize that these parameters are very variable in each subject [3]. This results in the classification of four important rhythms within electroencephalography:

Rhythms	Frequency band (Hz)	Amplitude (μV)
Delta (δ)	0.5 – 3.5	20–200
Theta (θ)	4 – 7	20–100
Alpha (α)	8 – 13	20–60
Beta (β)	14 – 30	2–20

Table 2.1: Brain rhythms [3]

•Delta rhythm:

These are the waves with the highest amplitude and lowest frequency. They never reach zero, because that would mean brain death. It is a state of deep sleep. If it occurs in an awake subject, it can lead to a pathological symptom.

•Theta Rhythm:

It is a state of deep meditation. Often, a person has the best ideas when this type of waves predominate. It is a state in which the tasks performed have become so automatic that you do not need to have conscious control over their performance. Ideas that arise in the mind in this state.

•Alpha Rhythm:

It occurs in anyone with eyes closed or in a state of relaxation and little mental activity. This rhythm is attenuated with open eyes. It is most prominent in the posterior region of the brain.

•Beta Rhythm:

They occur in states of mental concentration. They are wide waves and the fastest of the four. They denote intense mental activity. When a person is giving a speech, studying, carrying out a mathematical problem, etc. It is also closely related to the movement of the extremities and is detected mainly in the central and frontal region of the brain.

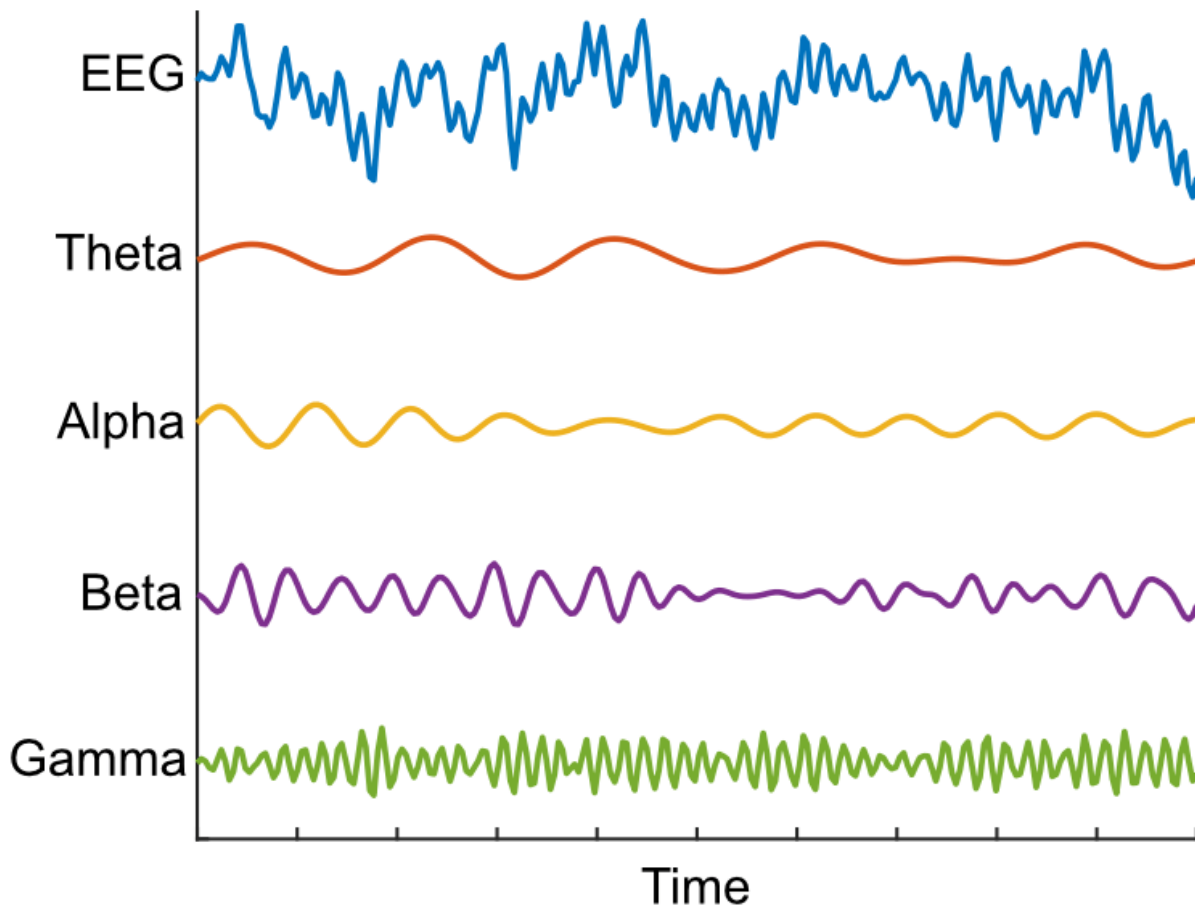


Figure 2.3: Brain rhythms

2.4 Brain-Computer Interfaces (BCI)

Since Hans Berger first applied the technique of electroencephalography in 1929, it has been used primarily by doctors and scientists to investigate brain function. There has also been speculation about the possibility of using the electroencephalogram (EEG) to decipher intentions, so that a person could control certain devices from their brain activity. Thus, Brain-Computer Interface (BCI) is defined as a communication system that monitors brain activity and translates certain characteristics, corresponding to the user's intentions, into device control commands. Under this definition, BCI systems can be very useful for elderly or severely disabled dependents, as they provide a new communication channel [13].

There are different methods for recording brain activity: EEG, electrocorticography (ECoG), magnetoencephalography (MEG), positron emission tomography (PET) or functional Magnetic Resonance Imaging (fMRI). ECoG is an invasive technique, i.e. it requires an intervention to place electrodes on the cortical surface. On the other hand, MEG, PET and fMRI techniques require high-cost installations and equipment. Therefore, the most commonly used method for recording brain activity in BCI systems is the EEG, as it is a simple, non-invasive, portable and low-cost technique.

2.4.1 Types of (BCI)

We can divide BCI systems into three different groups [13, 14]:

- Active:** is characterized by being able to control a BCI system consciously and voluntarily, independently of external events.
- Reactive:** the control of the application is directly related to an external stimulus that indirectly models brain activity.
- Passive:** derived from the processing of arbitrary and unintentional brain signals by the user. The information collected is used to know our cognitive state, such as our levels of attention, relaxation, etc.

A person's brain activity can be characterized according to the type of stimulus to which they have reacted. These can be both exogenous and endogenous. Endogenous systems are based on the recognition of brain patterns without the need for an external stimulus, otherwise they are produced by the will of the user. An example of this process is the use of beta rhythms to control a device when the user imagines or attempts to make movements. The exogenous systems, unlike the previous ones, base their control to external stimulus and the cerebral response of the same is obtained. An example of these devices would be to determine the direction of the look or the posture of the user to obtain a cerebral response.

2.4.2 BCI signal processing

As it has already been commented previously in a BCI system the information coming from an EEG is used to provide us the cerebral signals captured by the electrodes. The signal processing is divided into several stages:

The elimination of artifacts is the main part of the processing of the electroencephalographic signal, since the correct interpretation of the signal depends on this stage. It is done through specifically designed filters.

Then we proceed to the extraction of the characteristics, where we try to discriminate the most relevant information trying to have the maximum efficiency between the signal-to-noise ratio.

Next, characteristic selection methods are applied that choose the most significant characteristics within the extracted set, encoding the user's intention.

Once selected, algorithms are used to classify characteristics that convert the independent variables, that is, the characteristics extracted from the signal, into dependent variables. The success of the algorithm is determined by the selection of appropriate characteristics, the user's ability to control those characteristics and how efficient the algorithm is in translating a device's control commands [14]. Finally, the classification algorithms translate the selected set of characteristics into a concrete command, related to the user's intention. The application stage corresponds to the one that directly interacts with the user. Once the characteristics have been detected and translated into control signals, the implemented application must perform the corresponding actions. Whether an application can be used in practice depends on factors such as speed or accuracy. Some of these applications allow the user to control domestic devices present in a home, answer YES/NO questions, operate a wheelchair, move a prosthesis, etc.

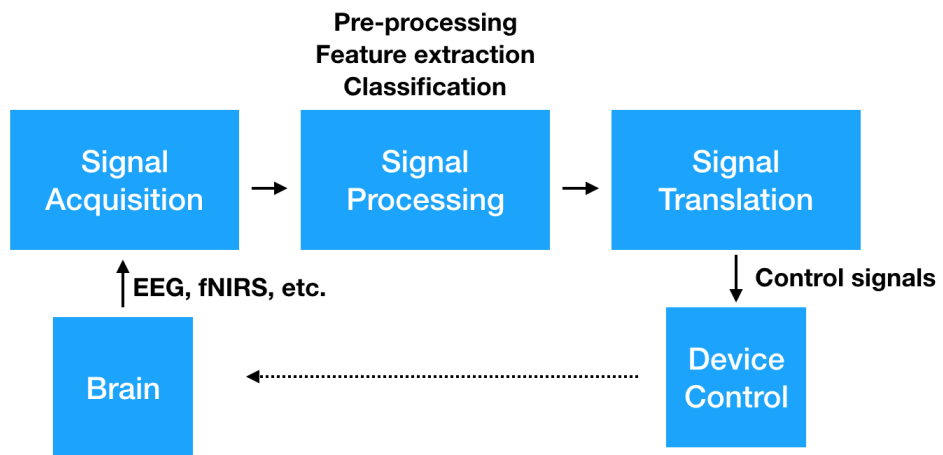


Figure 2.4: BCI Schema

Chapter 3

Tools

3.1 TUK, the social robot

Note: This section is an extended adaptation of the TUKv2 documentation written by Fabian Garber in which some extra assembling information and changes to allow interaction with Neurosky headset has been added.

3.1.1 Introduction



Figure 3.1: TUK, the social robot

Project TUK is an ambitious project to create a companion robot, which can interact with people. This is the second prototype which is called TUKV2. TUKV2 has the ability to express emotions with its eyes, eyelids, nose and neck movements. It is also using 6 different capacitive sensors to register touches from the user. In the following pages I am going to explain from what TUKV2 is build of and how it is functioning. In Addition, the extended TUKV2 version is able to interact with the NeuroSky™ MindWave Mobile Headset to carry out neurofeedback games and has 4 extra capacitive sensor to register touches from the user around the body, head and nose.

3.1.2 Structure

The main body of TUKV2 consists of a plastic pot. Inside the body (bucket) there are two arduino unos mounted to a spine and a 10000 mAh powerbank, to power all the servos. TUKV2 uses 11 servo motors to move its eyelids, eyes, nose and neck. In the neck there is a ball bearing with five steel balls, to improve the smoothness of the movement and to have less strain on the servo motor which is responsible for the neck movement. The sensors of TUKV2 are spread all over its body: 4 around the body (8 in the extended version), one in the nose and one in the head. Those sensors are capacitive sensors and don't need a lot of pressure. Gentle strokes are enough to trigger them. The head is screwed into the base plate of the head and should never be removed. The eyes, eyelids and nose are also screwed into the base plate of the head. TUKV2 has a padding on the head and around its body to improve fluffiness and to create a more stuffed animal like look. Finally, TUKV2 is covered in green fur. For the body a shorter fur was used than for the head. The reason for that is that it is easier to cover up holes around the eyes.

3.1.3 Eyelids

The eyelids are using two servo motors to achieve a rotating and a closing movement. They are mostly 3D printed, all those files can be found on the Fusion 360 servers. The only parts which are not 3D printed are the servo motors, ball-bearings for each side and the cloth covering the eyelid. The cloth used is a violet terrycloth and it is attached to the eyelids using spray glue. Most of the parts are mounted using screws except for the pole which is connecting the gear and the eyelid, this part is glued together using a two-component adhesive or superglue. One of the biggest disadvantage of the eyelid opening and closing mechanism is its slippage and the all together sensible mechanism. the eyelid is attached to the gear moved by the servo using a thin aluminum bar (2-3mm). The bar has to be fixed to the eyelid and the year and pas through the eyelid holder hole permitting free rotation for blinking movement. There's a small space between the eyelid and the eye, is that why it has to be assembled carefully to avoid friction between the 2 pieces.

3.1.4 Eyes

The eyes are using a micro servo motor (Mikro-4 Miniservo, Weight: 1,8 g, Measurements: 16,2 x 13,5 x 6,2 mm, available at mikromodellbau.de) inside the eye to achieve the up/down movement and another servo motor to be able to look left and right. Like the eyelids most of the parts of the eyes are 3D printed, except for the camera and the motors. All the 3D files can be found on the Fusion 360 servers. The cameras used are of the type OV7670 with an VGA resolution of 640 x 480. To have enough space for the micro servo inside the eyeball, it is necessary to replace the pins of the camera by

thin soldered cables. As now (October 2018) the cameras are not used, in the future they should be able to detect faces and one day even emotions using facial recognition software. The eyeballs are assembled by gluing them together, so it is not possible to separate the eyeballs without damaging them. Before finally assembling the eyeballs it is important to cover it with a white terrycloth fixed with spray glue for a more friendly and realistic look. The terrycloth cover has to be thin to avoid any friction with the eyelid.

3.1.5 Nose

The nose has the ability to move upwards and downwards and also left and right. To achieve this two servo motors are used. As with the previous parts the nose also consists mostly of 3D printed parts. Like before the 3D files can be found on the Fusion 360 servers. For the nose it is necessary to add copper tape to the end of the peak and to connect a wire to it, so it can be also used as a sensor. The stick is not included in the Fusion 360 mode. We can use any plastic or silicon stick with desired consistence, then we will have to design and print an empty cylinder with the measures of our stick and attach it to the nose up-down servo. At the end the nose should be covered with yellow terrycloth. To the terrycloth a hook and loop fastener should be added. At the end the nose should be filled with filling.

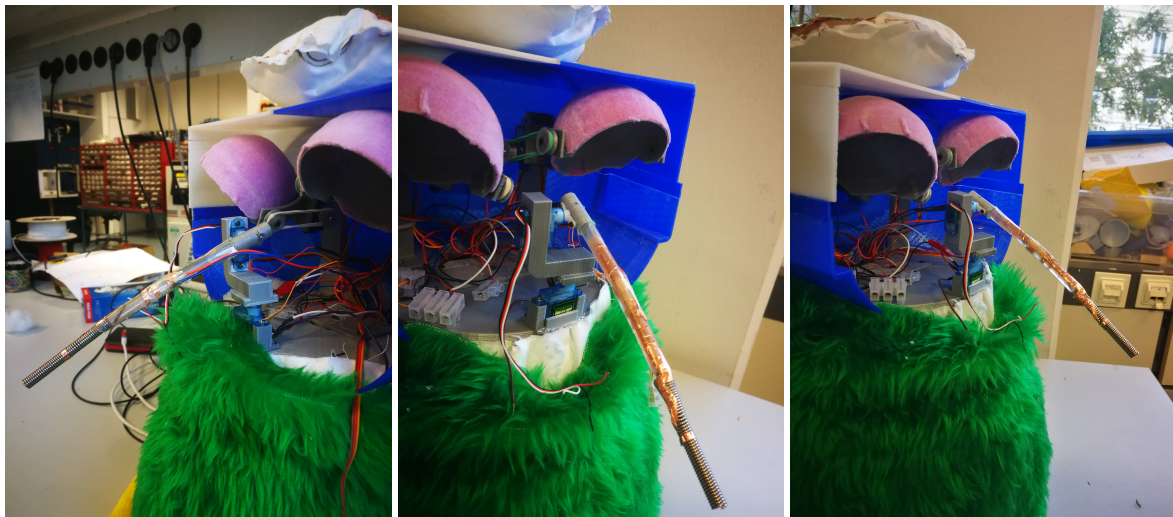


Figure 3.2: TUK nose

3.1.6 Neck

To achieve the neck rotation, one big servo motor is used. It is the only servo motor which is mounted inside the body. There is only one 3D printed mounting bracket needed and it is the only one that it is fixed in the inside part of the bucket. For this, a hole in the bottom of the pocket will be needed. the hole has to be big enough for the servo and all the cables to fill in the bucket but small enough to permit the servo holder be properly fixed in the bucket bottom. For the rotation and fixing the head of the robot to the bucket 3 printed plates are needed. One plate fixed to the bucket, one with several holes in the middle to sustain the metal balls and allow fluent rotation and last one is the one in which all the components of the head are fixed.

3.1.7 Body

The bottom plate of the robot is 3D printed in 4 parts that need to be fixed with 2 components glue or superglue. It is also a good option to help a bit with the solder to improve the fixation. The central Arduino holder is printed in 3 pieces. It is fixed to the bottom plate has enough space for the power bank and both arduinos as can be seen in the picture.

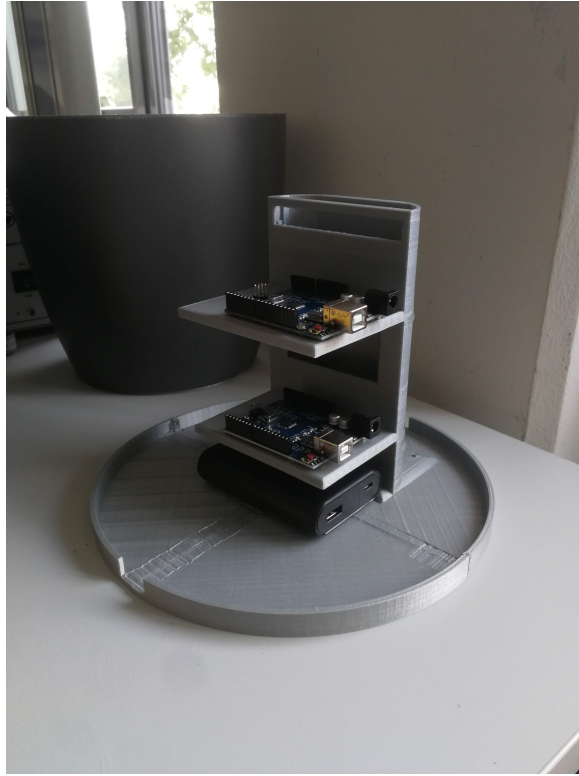


Figure 3.3: TUK body without bucket

3.1.8 Software

There are two different arduinos used for TUKV2. One is handling all the servo motors and movements and the other one is responsible for the sensing. In addition to sensing the sensing Arduino is also in charge of the Bluetooth connection. The Bluetooth module used is a HC-06 4 pin Bluetooth module, the pairing code is "1234". To send commands to the Arduino from the computer the software TeraTerm is used. Commands are sent using strings.

Note: Consider that in the extended version, the Bluetooth module used is a HC-05 that has to be previously configured as a master and paired to a specific Neurosky Mindave headset using AT commands and MAC address.

3.1.9 Motor Arduino

This Arduino manages everything related to the movements and it is handling the main software. In addition this controller is getting the sensor data using a communication pin.

Emotion	Command
Angry	a
Sad	s
Fear/Surprise	f
Happy	h/g
Disgust	d
Open eyes	o
Half close eyes	i
Close eyes	u

Table 3.1: Facial expressions Bluetooth commands

Function	Pin
Left/Right left eye	D2
Up/down right eye	D3
Left/Right right eye	D4
Up/down left eye	D5
Communication	D6
Rotate neck	D7
Left Blink	D8
Right Blink	D9
Right eyelid turn	D10
Left eyelid turn	D11
Up/Down Nose	D12
Right/Left Nose	D13

Table 3.2: Motor Arduino pin connections

3.1.10 MPR121 - Sensing board

This circuit board is responsible for the attached electrodes (sensors). It is communicating with the sensing Arduino Uno using I2C and is telling the Arduino which sensor is being pressed. There are two thresholds used: The sensing threshold and the release threshold. To make the sensors more sensitive it is necessary to decrease the sensing threshold.

Function	Pin
HEAD	0
NOSE	1
LEFT	2
RIGHT	3
FRONT	4
BACK	5
FRONT-LEFT	6
FRONT-RIGHT	7
BACK-LEFT	8
BACK-RIGHT	9

Table 3.3: MPR121 - Sensing board pin connections

3.1.11 Sensor Arduino

This Arduino is responsible solely for sensing and communicating the sensor results to the Motor Arduino. It also has the Bluetooth module paired with the Neurosky and the signal treatment algorithm.

Sensor/Function	Pin
Bluetooth TX	D0
Bluetooth RX	D1
Communication	D3
SCL (MPR121)	A5
SDA (MPR121)	A4
IRQ (MPR121)	D2
Head	10
Left	10
Right	12

Table 3.4: Sensor Arduino pin connections

3.1.12 Motion Range

The motion range describes the allowed movements of the servos used in the project. The range is from center (inner border) to outside (outer border) and from down (inner border) to up (outer border).

Movement	inner border[degrees]	outer border[degrees]	start[degrees]
Left/Right left eye	50	100	70
Up/down right eye	80	160	110
Left/Right right eye	80	20	50
Up/down left eye	60	150	135
Rotate neck	40	130	85
Left Blink	10	140	120
Right Blink	160	20	60
Right eyelid turn	60	150	100
Left eyelid turn	105	30	80
Up/Down Nose	110	20	80
Right/Left Nose	80	0	40

Table 3.5: Servo motors motion range

3.2 Neurosky Mindwave headset

In the following section we will present the device that will be used in this work and define its most important characteristics.

The Mindwave [15] is a headset that collects the electrical activity of the brain and divides the signal according to the frequency into different types of waves, which allows us to infer in our mental state. The recording of this activity is

done with the common reference configuration, given that we only have one channel and the electrode is referenced with the potential of our ear.

Unfortunately, the body produces a great deal of electrical noise, in addition to the activity that comes from our brain. For this reason, this reference contact, in the form of a clip attached to the ear lobe, helps us filter out the non-brain signal received.

Most of the applications of this device are non-scientific, however, as the same company specifies on its website, studies have been conducted that the accuracy of the data captured by this device have a reliability equivalent to devices used in modern medicine. It is able to read, mainly, the state of meditation (measured by alpha/theta waves) or attention/-concentration (measured by beta/gamma waves) that our brain emits. The company has developed an algorithm called eSense that defines on a scale between 0 and 100 the levels of these cognitive states. However, they do not have revealed in detail how the eSense algorithm works.



Figure 3.4: Mindwave headset schema

The structure is made by hard black plastic material. It fits comfortably to the head and can be adjusted in size. The primary sensor rests on the forehead and requires a certain adjustment to adapt it to each user's head. It connects via Bluetooth, and works with most modern operating systems (Windows XP or later, Mac OS X 10.6.5 or later). Battery life is about 8/10 hours on a single AAA battery.

We have to specify that this device is intended primarily for cognitive development in children, therefore, the attached software consists of a series of applications developed in a very simple and friendly environment.

In the mentioned applications there are a series of games in which it is required to have a control over our mental state, either attention or meditation, to reach some objectives. It also has other interesting applications such as Meditation Journal, is probably the most useful software included, which allows you to see significantly the brain wave data in the domain of time. You can't do anything else than save your progress in previous sessions, but it's really useful for those interested in improving attention/meditation.

As for the rest of the applications, due to the nature of the MindWave sensor, they only depend on three types of variables used in a more or less useful way depending on the use that the user wants to give them. These variables are:

- Concentration / non-concentration

- Meditation / non-meditation
- Blinking

3.3 eSense Algorithm [1]

The eSense measurement algorithm [1] is a way to show how effectively the user is involved in mental states such as: Attention (similar to concentration) or meditation (similar to relaxation). Just like the exercise of an infrequently used muscle, it may take some time to gain complete control of each of the eSense meters. In many cases, people tend to be better at one eSense than the other when they start using them. It is recommended that you try different tactics until you are successful with one.

Once a reaction is seen on the screen from the efforts, the user will be able to duplicate the action more easily with additional practice. For each different type of eSense (i.e. attention and meditation), the value is measured on a scale of 1 to 100. On this scale, a value between 40 to 60 obtained at any given time is considered "Neutral" and is similar in concept to the "baselines" established in conventional techniques in wave measurement.

A value of 60 to 80 is considered "slightly high", and can be interpreted as levels that tend to be higher than normal for a given person. Values from 80 to 100 are considered "high", meaning that they are a strong indicator of high levels of a particular cognitive state.

Similarly, at the other end of the scale, a value between 20 and 40 indicates the "low" levels of the eSense meter, while a value between 1 and 20 indicates "considerably low" eSense levels. These levels may indicate states of distraction, agitation, or abnormality.

The reason for using these wide ranges for each interpretation is that some parts of the algorithm act dynamically and at the same time other algorithms are used that work a slow adaptation process to adjust to each user's natural fluctuations and tendencies, which represents a compensation for the fact that brain waves in the human brain are subject to normal ranges of variance and fluctuation. For this reason, the sensors connected to the ThinkGear are capable of operating on a wide range of individuals under an extremely wide range of personal and environmental conditions, while still providing good accuracy and reliability.

Attention eSense:

The eSense Attention Meter indicates the intensity of a user's level of mental "focus" or "attention," such as that which occurs during intense and directed (but stable) mental activity. Distractions, wandering thoughts, lack of concentration, or anxiety can decrease the level of attention. Generally, attention can be controlled through a visual focus. Focus on a singular idea. One option may be to choose a point on the screen to focus and try to imagine that the action you are trying to achieve is happening. For example, look at the eSense attention meter and imagine the marker moving toward higher numbers.

Some manufacturer's recommendations that improve control over attention values are:

- Identify and maintain a concrete thought
- Focusing the gaze on a specific object
- Concentrate on something you like
- Make a mathematical calculation
- Listening intently when someone talks
- Give a speech
- Singing a song silently
- Imagine an action that you are trying to make happen

Meditation eSense:

The eSense Meditation Meter indicates a user's level of mental "calmness" or "relaxation". It ranges from 0 to 100. It should be noted that meditation is a measure of a person's mental states, not on a physical level, so simply relaxing all the muscles of the body does not immediately lead to a higher level of meditation. However, for most people in most normal circumstances, relaxing the body often also helps the mind to relax. Meditation is related to reduced activity by active mental processes in the brain.

It has long been proven that the effect of closing the eyes extinguishes the mental activities of image processing through the eyes. So closing the eyes is often an effective method to increase meditation. Distractions, wandering thoughts, anxiety, agitation, and sensory stimuli can reduce meditation meter levels.

Here are some manufacturer's recommendations for achieving meditation status:

- Slow, deep breathing in and out
- Relax all muscles
- Leaving the mind blank
- Close your eyes
- Imagine you're in bed about to go to sleep
- Imagine you're floating on warm water.

Chapter 4

Arduino and Mindwave

4.1 Arduino

At this point we are able to visualize the signal coming from our EEG reading device. We have also seen how we can manage this information in real time and make an exhaustive analysis of it. However, we need to be able to use the data we are receiving in order to generate a response. As we have already commented previously to be able to control our device we will use an Arduino UNO board [16].

Arduino is an open-source electronics prototype platform based on flexible, easy-to-use hardware and software [16]. It is intended for artists, designers, as a hobby and anyone interested in creating objects or interactive environments.

Arduino can measure the environment through a variety of inputs to which different devices, such as sensors, lights, motors and other artifacts can be connected. The microcontroller on the board is programmed using the Arduino Programming Language (based on Wiring 1) and the Arduino Development Environment (based on Processing 2). Arduino projects can be standalone or can communicate with software running on a computer (e.g. Flash, Processing, MaxMSP, etc.). Boards can be assembled by hand or ordered pre-assembled; the software can be download for free. The reference designs of the hardware (CAD files) are available under open-source license, so it is possible to adapt them to your needs.

Arduino received an honorable mention in the Digital Communities section of the Ars Electronic Prix in 2006.

There are many other microcontrollers and microcontroller platforms available for physical computing. Parallax Basic Stamp, Netmedia's BX-24, Phidgets, MIT's Handyboard, and many other offers of similar functionality. All of these tools take the messy details of microcontroller programming and enclose it in one easy-to-use package. Arduino also simplifies the process of working with microcontrollers, but offers some advantages for teachers, students and interested amateurs over other systems:

- Cheap:** Arduino boards are relatively inexpensive compared to other microcontroller platforms. The less expensive version of the Arduino module can be assembled by hand, and even preassembled Arduino modules cost less than \$ 50.

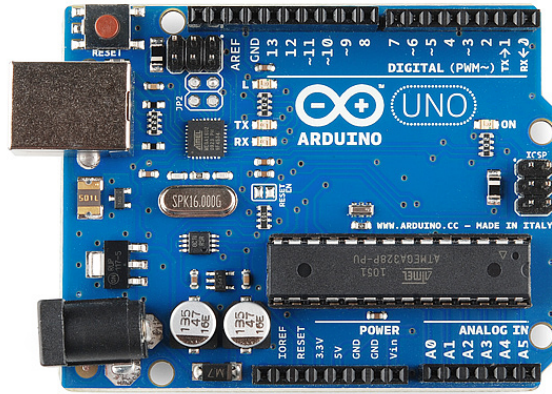


Figure 4.1: Arduino UNO

•**Multiplatform:** Arduino software runs on Windows, Macintosh OSX and GNU/Linux operating systems. Most microcontroller systems are limited to Windows.

•**Simple and clear programming environment:** The Arduino programming environment is easy for beginners to use, but flexible enough for advanced users to take advantage of it as well. For teachers, it is conveniently based on the Processing programming environment, so students learning to program in that environment will be familiar with the look and feel of Arduino.

•**Open Source and Extensible Software:** Open Source and Extensible Software: Arduino software is published as open source tools, available for extension by experienced programmers. The language can be expanded through C++ libraries, and people who want to understand the technical details can make the leap from Arduino to the AVR C programming language on which it is based. Similarly, you can add AVR-C code directly into your Arduino programs if you want.

•**Open source and extensible hardware:** The Arduino is based on ATMEGA8 and ATMEGA168 microcontrollers from Atmel. Plans for the modules are published under a Creative Commons license, so experienced circuit designers can make their own version of the module, extending and improving it. Even relatively inexperienced users can build the board version of the module to understand how it works and save money.

4.2 Neurosky pairing with Arduino [2]

Steps to Follow:

- 1. Make connections as per the connection diagram [2].
- 2. Program (Upload the sketch) the "HC-05 with Arduino" source code to Arduino board using Arduino compiler. You can find it in the appendix.
- 3. Open the "Serial monitor" with baudrate of 9600.
- 4. Type the AT commands and click Enter in Serial monitor:

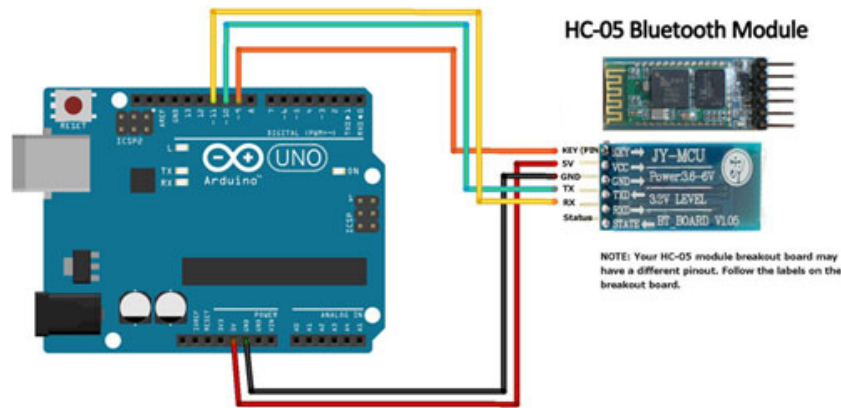


Figure 4.2: Connection diagram for AT commands [2]

1. AT+NAME="(chosen name)"
2. AT+UART="57600,0,0"
3. AT+ROLE="1"
4. AT+PSWD="1234"
5. AT+CMODE="0"
6. AT+BIND="XXXX,YY,ZZZZZ" (Mindwave MAC Adress)
7. AT+IAC="9E8B33"
8. AT+CLASS="0"
9. AT+INQM="1,9,48"

Figure 4.3: AT commands for Mindwave pairing [2]

4.3 Neurosky Data transmission protocol

Once the hardware connection between devices has been made, they will be able to send data to each other. We have to take into account that each one of them has a different way of managing the data that enters and leaves, that is to say, they have an operating protocol. If we want to access this data via software we will have to understand the functioning of this protocol. In the case of the Mind Wave, the protocol is installed in the ThinkGear chip, which is the technology inside the NeuroSky device. This allows the device to obtain the values of brain waves, includes the frontopolar sensor, the contact and reference points located in the ear lobe and the integrated chip that processes all data digitally that will be used in different software applications. Both the primary brain waves (beta, alpha, tetha, gamma) and the eSense algorithms (attention and meditation) are calculated on the ThinkGear chip.

Fortunately, the company NeuroSky makes this protocol available to us in an open way, since its website has a section especially dedicated to potential developers of applications from their product. We will describe a little the different concepts with which we have to familiarize ourselves to be able to access and manage via software the data coming from the Mind Wave:

- Knowing how to analyse the flow of data in bytes that will help us to reconstruct the different types of brainwave data sent by ThinkGear.
- To interpret and use the different types of brainwave data sent from ThinkGear (including attention, meditation, and signal quality data) for our BCI application.
- Be able to send a reconfiguration of byte commands to the ThinkGear, for real-time customization of the module's outputs and way of working.
- Know how to define the types of data values that can be reported by ThinkGear.

In the data transmission protocol is described the application programming interface abbreviated as API (Application Programming Interface), which is the set of subroutines, functions and procedures (or methods, in object-oriented programming) that offers a certain library to be used by other software. They are usually represented in libraries. This information will be necessary when creating your own program from the Arduino programming environment.

One important function received through the ThinkGear chip is (POOR _ SIGNAL): This command represents an integer value of an unsigned byte that describes the quality of the signal measured by the ThinkGear. It has a value ranging from 0 to 255. Any value other than zero indicates that some type of noise pollution has been detected. The higher the number, the more noise is detected. A value of 200 has a special meaning, specifically that ThinkGear electrodes are not in contact with the person's skin.

This value is typically used as an output every second, and indicates the poverty of the most recent measurements. A poor signal can be caused by several reasons:

- Sensor, ground, or reference electrodes are not in contact with the user's head.
- Poor contact of the sensor electrodes, ground, or reference to the user's skin.
- Excessive movement of the user, head or body that moves excessively, moving sensors or reference points from place.
- Excessive environmental electrostatic noise (some environments have strong electrical signals or accumulation of static electricity on the person wearing the sensor).
- Excessive noise from non-electroencephalographic biometric signals (i.e., EMG, EKG/ECG, EOG, etc.)

A certain amount of noise is inevitable in normal ThinkGear use, and both NeuroSky's filtering technology and eSense algorithm have been designed to detect, correct, compensate, explain, and tolerate many types of noise that do not correspond to the EEG signal. Attention and meditation values will not be updated while POOR_SIGNAL is detected. By default, the output of this data value is enabled. It is typically output calculated once per second.

4.3.1 ThinkGear Data Packages

The microcontroller built into the ThinkGear chip delivers your digital data as an asynchronous serial byte stream. To extract and correctly interpret the value of the ThinkGear data packets we must analyze and interpret the data with our software in the same way the microcontroller does.

The package format consists of 3 parts:

- Packet Header
- Packet Payload
- Payload checksum.

Packets are used to deliver data values from a ThinkGear module to a receiver, in our case the Arduino board microcontroller. The I/O serial programming API is different for each platform and operating system. We will analyze the received data packets globally, allowing us to use them on our platform. The packet format is designed by combining

header and checksum, this provides control over data flow synchronization and data integrity, while the data payload format ensures that new data fields can be added to a packet in the future.

Package example

Here we have an example of a typical package. Apart from bytes [SYNC], [PLENGTH] and [CHKSUM] all other bytes (bytes [3] to [10]) are part of the packet payload data. As mentioned earlier the DataRows within the payload will not always appear in all packets.

```
byte: value // Explanation
[ 0]: 0xAA // [SYNC]
[ 1]: 0xAA // [SYNC]
[ 2]: 0x08 // [PLENGTH] (payload length) of 8 bytes
[ 3]: 0x02 // [CODE] POOR_SIGNAL Quality
[ 4]: 0x20 // Some poor signal detected (32/255)
[ 5]: 0x01 // [CODE] BATTERY Level
[ 6]: 0x7E // Almost full 3V of battery (126/127)
[ 7]: 0x04 // [CODE] ATTENTION eSense
[ 8]: 0x12 // eSense Attention level of 18%
[ 9]: 0x05 // [CODE] MEDITATION eSense
[10]: 0x60 // eSense Meditation level of 96%
[11]: 0xE3 // [CHKSUM] (1's comp inverse of 8-bit Payload sum of 0x1C)
```

Figure 4.4: Example of ThinkGear (Neurosky) data package

Once we know how the data is structured we can design the algorithm in Arduino to select the part of the data that we want to use. For this, we have really good recommendations at Neurosky's official website.

Chapter 5

Evaluation

5.1 Neurofeedback game

For creating the game, 5 different facial expressions of the Tuk have been selected and related with the 5 levels of concentration designed by the eSense algorithm. The aim of the game is to bring the TUK to the "asleep" stage, that corresponds to an elevated concentration.

The headset sends the EEG signal in real time to the Arduino Bluetooth module from the TUK. There, the data is processed and selected and the TUK produces a visual stimulation according to the data received.

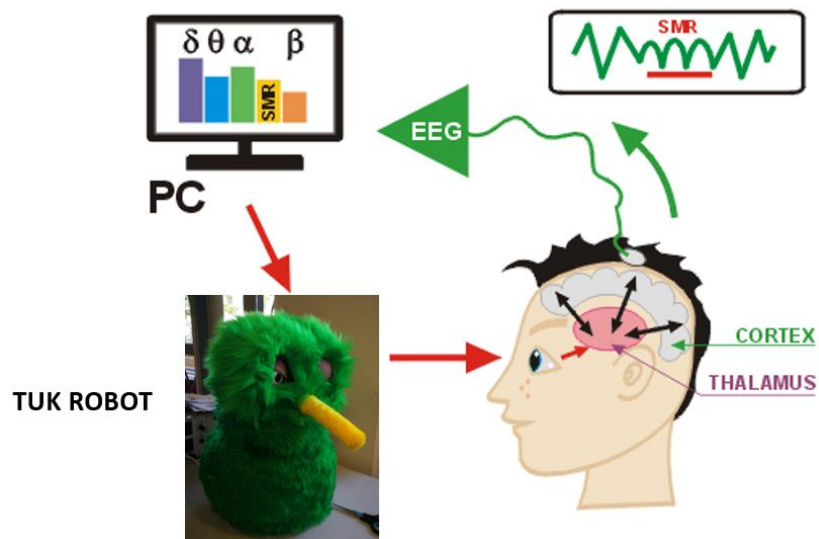


Figure 5.1: TUK neurofeedback game schema

The game has been made following the idea that the subject can know at any time in which stage he is, so he is able to try different concentration techniques and see in real time if they are working or not. With this information, and with lots of repetitions, he will be able to create and unconsciously automatize the concentration patterns or techniques that better work for him.

The algorithm designed for control the changes of the TUK expression is based in fuzzy logic. That means that the

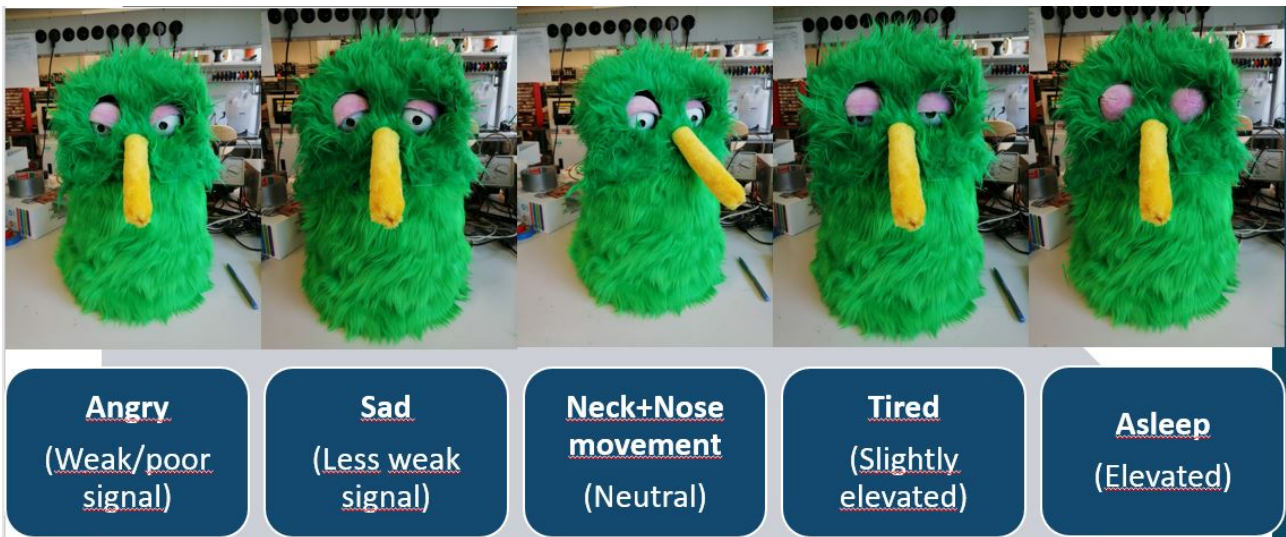


Figure 5.2: TUK stages for the neurofeedback game

thresholds between stages are not fixed. These thresholds are variable depending on the previous stage of the TUK, is called hysteresis. The hysteresis makes a bit more tricky to move along the different stages, what is good because give more stability to the TUK expressions.

5.2 Testing

To test the capacities and potential of the game, 3 female and 3 male subjects aged between 22 and 25 years old were tested with the neurofeedback TUK game 4 times each (2 times in the morning and 2 in the afternoon/evening). Every test lasted 2 minutes.

In the first trial the only instruction was: "try to concentrate and make the robot close his eyes"

After the first trial, they received an explanation about TUK, the game and some advises about how to improve concentration.

The results were that 4 of the 6 subjects were able to reach "elevate" state at the first trial (2min). In addition, all of them improved or maintain the results in the next trials thanks to the patterns created in first trial and the concentration advises given.

During last trial done in the evening after a working day, 4 of them reached worse results than in the morning. That can be produced by the tired state of the brain at the end of the day after a working day.

In general, they had a good opinion about the project and were really interested in future improvements of the TUK as well as possible applications.



Figure 5.3: Neurofeedback TUK game test

Chapter 6

Conclusions

The main motivation for this work has been to be able to carry out a project related to brain-computer-interface systems. It is fascinating to be able to interact with devices directly through our brain waves. This technology is currently under development and has a very promising future.

The development of a BCI system is closely related to the ability to capture the brain waves of the device chosen for this task. We will note that the more electrodes there are, the greater the amount of information collected. In this way, the more information we have, as long as we are able to process it correctly, the more powerful our system will be. In turn, the number of electrodes determines the price of the device. This fact has conditioned the realization of the BCI system presented in this work.

One of the most developed applications within BCI systems is that of biofeedback or neurofeedback applications. It was thought convenient that the best way to make this technology known was to carry out a project within this field, taking into account the limitations that for economic reasons were had. This is how it was decided to make a game of neurofeedback using the robot TUK as visual and tactile estimate.

The prototype realized fulfills the expectations, since it is possible to control the facial expressions or moods from our cognitive state and it clearly reflects how a BCI system works. This work is conceived as a way by which people interested in the subject can see in a practical way the possible applications within this field. It is also an advantage that the design of the TUK can be printed in 3D, so anyone can access it.

It has also been proven that the subject has to go through a stage of training and a high level of sustained attention, which can be annoying for the user. For this reason it is seen as a tool for short training sessions.

It has been possible to verify how, through practice, the use of this device improves our ability to control our cognitive states of attention/relaxation. For this reason it has been proposed to use the Mind Wave device for cognitive development in children using TUK as a complementary game to official therapies.

As a future project is considered the possibility of using the cameras located in the eyes of the robot TUK to recognize the image and add sound stimuli to capture the attention of the subject when it is not concentrated.

Appendix

Sensor Arduino code with the algorithm to extract the Mindwave attention data.

```
void setup() {

  pinMode(irqpin , INPUT);
  digitalWrite(irqpin , HIGH); //enable pullup resistor

  Serial.begin(BAUDRATE);          // USB
  Wire.begin();

  mpr121_setup();

  //Setup port for comms
  pinMode(COM_PIN, OUTPUT);

}

////////////////////////////////////
// Read data from Serial UART //
////////////////////////////////////
byte ReadOneByte() {
  int ByteRead;

  while(!Serial.available());
  ByteRead = Serial.read();
```

```

#if DEBUGOUTPUT
    Serial.print((char)ByteRead);    // echo the same byte out the USB serial (for debug purp
#endif

    return ByteRead;
}

//////////
//MAIN LOOP//
//////////
void loop() {

    // Look for sync bytes
    if(ReadOneByte() == 170) {
        if(ReadOneByte() == 170) {

            payloadLength = ReadOneByte();
            if(payloadLength > 169)                //Payload length can not be greater than
                return;

            generatedChecksum = 0;
            for(int i = 0; i < payloadLength; i++) {
                payloadData[i] = ReadOneByte();    //Read payload into memory
                generatedChecksum += payloadData[i];
            }

            checksum = ReadOneByte();              //Read checksum byte from stream
            generatedChecksum = 255 - generatedChecksum; //Take one's compliment of generated

            if(checksum == generatedChecksum) {

                poorQuality = 200;
                attention = 0;
                meditation = 0;

                for(int i = 0; i < payloadLength; i++) { // Parse the payload
                    switch (payloadData[i]) {
                        case 2:
                            i++;

```

```

        poorQuality = payloadData[i];
        bigPacket = true;
        break;
case 4:
    i++;
    //lastattention = auxattention;
    attention = payloadData[i];
    //auxattention=payloadData[i];
    break;
case 5:
    i++;
    //lastmeditation = auxmeditation;
    meditation = payloadData[i];
    //auxmeditation = payloadData[i];
    break;
case 0x80:
    i = i + 3;
    break;
case 0x83:
    i = i + 25;
    break;
default:
    break;
} // switch

//unsigned long currentMillis = millis();

// if(Serial.available())
// { // if there is data being recieved
//     blueToothVal=Serial.read(); //read it
// }
//
//     readTouchInputs();
// if(blueToothVal == 'a'){
//     sens_nose();
// }
//
///// Disgust
//     else if(blueToothVal == 'd'){

```

```
//      sens_left ();
//    }
//
//// Happy
//      else if (blueToothVal == 'h'){
//          sens_head ();
//      }
//// Surprise and Fear
//      else if (blueToothVal == 'f'){
//          sens_back ();
//      }
//// Sad
//      else if (blueToothVal == 's'){
//          sens_front ();
//      }
//      else if (blueToothVal == 'g'){
//          sens_head ();
//      }
//      else if (blueToothVal == 'o'){
//          open_eyes ();
//      }
//      else if (blueToothVal == 'i'){
//          half_close_eyes ();
//      }
//      else if (blueToothVal == 'u'){
//          close_eyes ();
//      } else {}
//
//      digitalWrite (COM_PIN, LOW);
//      delay (200);
//      blueToothVal = 'z';

} // for loop
```

```

#if !DEBUGOUTPUT

// *** Add your code here ***

if(bigPacket) {
  if(poorQuality == 0)
    Serial.print(" PoorQuality in the signal");
  else
    // digitalWrite(LED, LOW);
    Serial.print(" PoorQuality: ");
    Serial.print(poorQuality, DEC);
    Serial.print(" Attention: ");
    Serial.print(attention, DEC);
    Serial.print(" Time since last packet: ");
    Serial.print(millis() - lastReceivedPacket, DEC);
    lastReceivedPacket = millis();
    Serial.print("\n");

switch(attention / 12) {
  case 0:
    sens_nose();
    Serial.print(" angry ");
    lastcase=0;
    break;
  case 1:
    if (lastcase=0){
      sens_nose();
      Serial.print(" angry ");
    } else {
      sens_front();
      Serial.println(" sad ");
      lastcase=2;
    }
    break;
  case 2:
    sens_front();
    Serial.println(" sad ");
    lastcase=2;
    break;
}
}

```



```
case 3:
    if (lastcase =2){
        sens_front ();
        Serial.println (" sad ");
    } else {
        sens_right ();
        Serial.println (" neck swing ");
        lastcase =4;
    }
    break;
case 4:
    sens_right ();
    Serial.println (" neck swing ");
    lastcase =4;
    break;
case 5:
    if (lastcase =4){
        sens_right ();
        Serial.println (" neck swing ");
    } else {
        sens_left ();
        Serial.println (" tired ");
        lastcase =6;
    }
    break;
case 6:
    sens_left ();
    Serial.println (" tired ");
    lastcase =6;
    break;
case 7:
    if (lastcase =6){
        sens_left ();
        Serial.println (" tired ");
    } else if ((lastcase =6)|| (attention >=90)){
        close_eyes ();
        Serial.println (" Sleepy ");
        lastcase =8;
    } else {
        close_eyes ();
```

```
        Serial.println(" Sleepy "); ;
        lastcase =8;
    }
    break;
case 8:
    close_eyes ();
    Serial.println(" Sleepy ");
    lastcase =10;
    break;

}
}
#endif
    bigPacket = false;
}
else {
    // Checksum Error
} // end if else for checksum
} // end if read 0xAA byte
} // end if read 0xAA byte
}
```


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