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# COMPARING USER EXPERIENCE BETWEEN FUZZY LOGIC AND EXACT FEEDBACK SYSTEMS IN AN E-LEARNING ENVIRONMENT

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BACHELOR’S THESIS | ABSTRACT

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# COMPARING USER EXPERIENCE BETWEEN FUZZY LOGIC AND EXACT FEEDBACK SYSTEMS IN AN E-LEARNING ENVIRONMENT

Neurophysiology students, including nursing students, must complete a course on electroencephalogram (EEG) sensor placement as part of their third-year studies. Currently, students attend and observe an EEG placement demonstration by experienced EEG professionals at the beginning of a semester and at the end of the semester they receive hands-on training. The lecturers have suggested building an e-learning environment that will help to bridge the gap between the observation and practical training sessions.

This thesis presents the design, development, and implementation of such an e-learning environment that provides feedback to the students about the accuracy of EEG electrode placement. The learning environment contains two different feedback systems. One that provides fuzzy (more human) guidance to the students and another giving exact value error feedback. The purpose of this thesis was to determine which of the two systems the students enjoyed more and which one they thought would provide the best learning.

The learning environment bases its evaluation of the virtual EEG placement on the 10-20 system—an international standard for the placement of EEG electrodes. Students were asked to spend two weeks with the system after their observation training. After their experience with the learning environment, students were invited to fill in a questionnaire and have a group discussion about their experiences with the virtual EEG placement system. The questionnaire measured student perceptions over three error categories, namely: short, medium and long distances between virtual placement and ideal positioning.

The results showed that the students preferred the fuzzy logic over the exact feedback system. Although the students noted that the exact feedback system provided overall a more precise error feedback, the fuzzy logic was generally better-received for short and medium errors. For long errors, the exact and fuzzy feedback systems received similar results. Group discussions also indicated that the students welcomed the additional learning opportunity between their observation and practical training sessions and felt it would be beneficial to their learning.

From this user experience test, in conclusion, the system warrants further development and possibly future formal integration into the lesson plan for neurophysiology students.

KEYWORDS:

Evaluation of EEG Electrode Placement, Electrode Placement, EEG, 10-20 System, Fuzzy Logic, Human evaluation, Human-friendly evaluation, Exact evaluation, Feedback systems, Electroencephalogram, User experience questionnaire, Focus discussion group, User experience.

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# LIST OF ABBREVIATIONS (OR) SYMBOLS

| Abbreviation | Explanation of abbreviation (Source) |
|---|---|
| 2D | Two-dimensional |
| 3D | Three-dimensional |
| AI | Artificial Intelligence |
| Cm | Centimeters |
| COG | Center of Gravity |
| COS | Center of Sums |
| EEG | Electroencephalogram |
| FDG | Focus Discussion Group |
| IT | Information Technology |
| MF | Membership function (Fuzzy Logic) |
| UML | Unified Modeling Language |
| UX | User experience |

# 1 INTRODUCTION

Neurophysiology students have to learn how to carry out an Electroencephalogram. Electrograms are difficult to perform and they require a lot of time and effort. Thus, an in-depth process of learning is needed for these students to carry them out correctly.

Students learn about how to carry out an electroencephalogram, by observing a real EEG session at the University Hospital, in which a nurse carries out an electroencephalogram on a real patient.

Students can only observe and annotate some notes about the process and ask some questions about the procedure. The tutor-student interaction is limited.

According to Hume (1996), one-on-one tutoring is a particularly effective mode of instruction, therefore the most desired pedagogy would be to have one-on-one sessions in which the students could experience and learn about EEG placement. This utopian one-on-one tutoring happens only once, during the last weeks of the semester where each student receives a single 20-minute opportunity for such tutoring. In practice, this is understandable, and probably the current most viable solution as it would take too much time from the learning programme and valuable professional resources.

An AI agent that imitates this tutor-student interaction could provide every student with their own tutor, improving the process of learning of those students. The question is what kind of AI agent would be most suitable.

There are some studies and literature about the use of AI in education. In some of them, they use Chatbots (Kerly, Hall, & Bull, 2007) as Tutors/Teachers and Machine Learning for Educational Data Analytics (Kotsiantis, 2012) and Quality Monitoring. AI is also used in the adaptive learning to adapt the content to a specific kind of student.

**Artificial intelligence** has been traditionally used to solve those kinds of problems over time. AI allows the implementation of autonomous entities (Intelligent Agents) who can observe the environment through its sensors and produce a response using its actuators towards achieving goals.

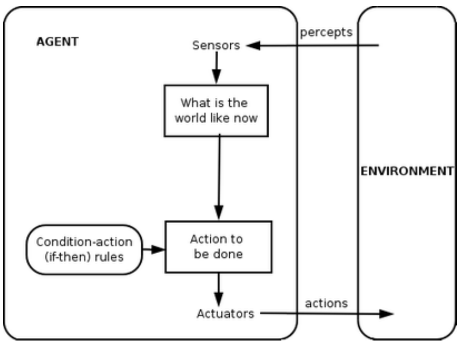



Figure 1. Diagrammatic representation of agent actuation (wikipedia.org/wiki/Intelligent_agent, 2009)

Although the most common method to replicate a tutoring scenario involves user modelling for content adaptivity by means of machine learning, it was decided to use a fuzzy logic feedback system. The reason for this choice is that machine learning for adaptivity typically involves subtle changes to the content or difficulty level in order to match the learner's abilities. The system proposed in this thesis, on the other hand, focusses on immediate feedback as the user interacts with the system—the way a real-time tutor would provide it. Also, machine learning and similar AI techniques are far removed from the learner (i.e., operate in the background), in that the learner does not actually feel the presence of a tutor. Fuzzy logic, as it is based on heuristics, best mimics a real-time tutor. Without tools, humans are not exact machines and they express their thinking on rules of thumb from previous experience.

The word fuzzy refers to something which is not clear or is vague. Sometimes in the real world, it is not possible to describe something as true or false, some of them are fuzzy and they are in the middle of both extremes.

Fuzzy Logic Systems (Figure 2) produce acceptable but definite output in response to an incomplete, ambiguous, distorted, or inaccurate input (tutorialspoint.com, 2016).

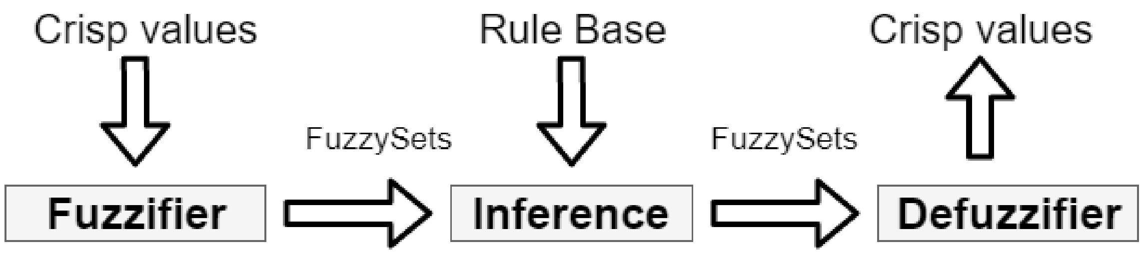



Figure 2. Block diagram of a general fuzzy logic system

Fuzzy Logic is used in the AI tutor to provide useful feedback about the EEG electrode placement on the skull in order to guide the student in the process of learning.

There are not many studies or literature about the specific topic of this Thesis because fuzzy logic as a tutor has not been widely investigated and this study aims to look more deeply into such possibilities.

## 1.1 Aim and objectives of the study

The aim of this Bachelor's Thesis was to build a digital learning environment for training students to place EEG sensors on a human head. The learning environment contains two immediate feedback systems (exact and fuzzy) to guide students in their EEG sensor placement training. The feedback systems simply provide the user with information about how far each electrode placement is away from the ideal position on the human head. Feedback is given on a per electrode basis with the fuzzy system providing human-like answers (e.g. a bit more up, a little to the left… etc.) and the exact system stating actual distances in centimeters to the second decimal.

The primary objective of the thesis was to assess which of the two feedback systems the students preferred. This study did not test or compare the learning effect of the two systems, but rather focused on usability and user experience indicators. Future studies will utilize this student feedback to refine the learning environment, before designing an experiment to test the actual learning effects of the two feedback systems.

In order to achieve the set objective of the study, the following work was carried out:

- Creating a suitable digital environment with a 3D human head model;
- Calculating the exact electrode positioning on the head according to the international 10-20 system;
- Implementing the exact feedback system;
- Implementing the fuzzy feedback system, using Fuzzy logic;
- Testing the two feedback systems (application) with students;

The author is a programmer and has no experience in 3D modeling. Therefore, the 3D model of the head and electrodes were made by engineers at Turku Game Lab. All other work in this thesis has been the work of the author. The work done in the Thesis includes finding the exact position of the EEG electrodes on the human head in accordance to the international 10-20 System and considering the 4 reference points (Nasion, Inion, left preauricular and right preauricular points).

In addition to this, the author is responsible for the implementation of both EEG feedback system: human-friendly and exact feedback systems. Those feedbacks systems guide the students through the process of EEG positioning.

The implementation of a Fuzzy Logic module is also the responsibility of the author of this Thesis. This module uses the human-friendly feedback system to generate the feedback message to the user.

The structure of thesis is divided into the following sections.

Chapter 1 is the introduction.

Chapter 2 introduce the Theoretical background. In that chapter, there are detailed discussions of the 10-20 international system and Fuzzy Logic.

Chapter 3 describes the design, development, and implementation of the learning environment. This part describes how the EEG electrode positions are calculated in accordance with the International 10-20 system. The implementation of the Fuzzy Logic module as well as and the implementation and operation of the two feedback systems are described in this section. Finally, this section focuses on the methodology to evaluate both feedback systems using a group discussion and user experience questionnaire.

Last chapters correspond to the results obtained, their discussion, the conclusion and the references.

# 2 THEORETICAL BACKGROUND

## 2.1 The international 10-20 system for EEG placement

The 10-20 system or International 10-20 system is an international standard procedure to find the EEG electrode placement on the skull in the context of EEG. The 10-20 maps the location of an electrode with the underlying region of the cerebral cortex. In this way, it is possible to read the activity of the brain in those regions. The name of the International 10-20 system is derived from the fact that the distances between adjacent EEG electrodes on the skull are 10 or 20 percent (Klem, Lüders, Jasper, & Elger, 1999).

### 2.1.1 Notation

There is a special notation to designate the EEG electrodes, on the skull. In the EEG field, each spot where an EEG electrode is placed has a specific letter to indicate the lobe and a number to indicate the hemisphere location (Acharya, Hani, Cheek, Thirumala, & Tsuchidak, 2016).

| Electrode | Lobe |
|---|---|
| F | Frontal |
| T | Temporal |
| C | Central |
| P | Parietal |
| O | Occipital |

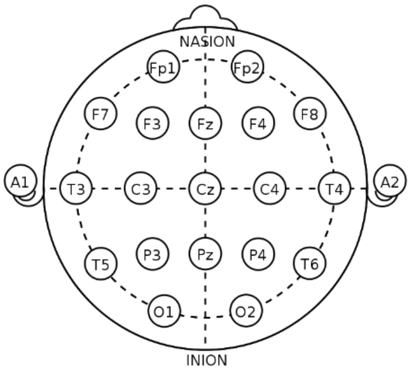


Figure 3. EEG electrode positions

Figure 3 shows a flattened view of the top of a human head to indicate the various electrodes and their notation.

- The zero refers to an electrode placed on the midline, while even numbers (2,4,6,8) refer to electrode positions on the right hemisphere and odd numbers (1,3,5,7) refer to electrode positions on the left hemisphere.

Four anatomical reference points are used for the essential positioning of the electrodes (Klem, Lüders, Jasper, & Elger, 1999):

- The nasion which is the point between the forehead and the nose.
- The inion which is the lowest point of the skull from the back of the head (bump).

- The 2 pre-auricular points anterior to the ear (depressions at the root of the zygoma, just anterior to the tragus).

### 2.1.2 Procedure

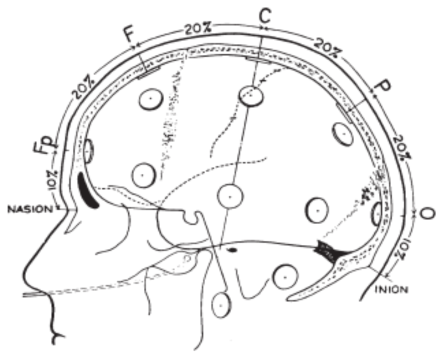
It is essential to understand how to carry out an EEG electroencephalogram to understand how the application has to calculate the exact position of the EEG electrodes on the skull.

The measurement procedure described below is based on “The ten and twenty electrode system of the International Federation” (Klem, Lüders, Jasper, & Elger, 1999).

Firstly, it is necessary to find the landmarks of the skull: nasion, inion, and the left and right preauricular points.

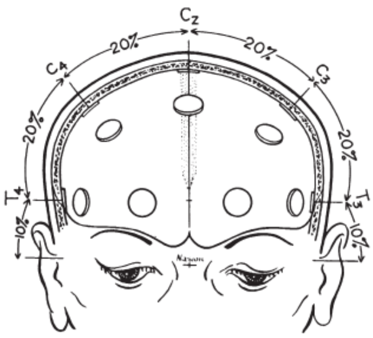
The first measuring is taken from the nasion to the inion. This measurement is divided into 5 separate sections.

The first mark, Fp (Fronto Polar) is placed at 10% of the total measurement. The frontal(F), central(C), parietal(P) and occipital(O) areas are placed at 20% intervals of the total measurement after the previous mark.



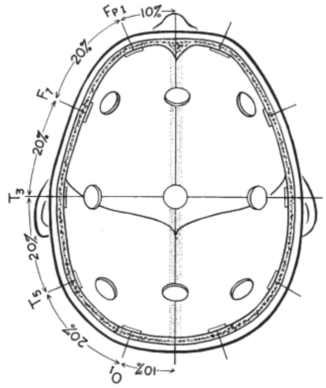

The second measuring is taken from the left preauricular point to the right preauricular point.

The location of the Temporal area(T) is found 10% over this measuring. The other 3 marks (left C, right C, and the C vertex location) are placed at 20% of the lateral measurement.



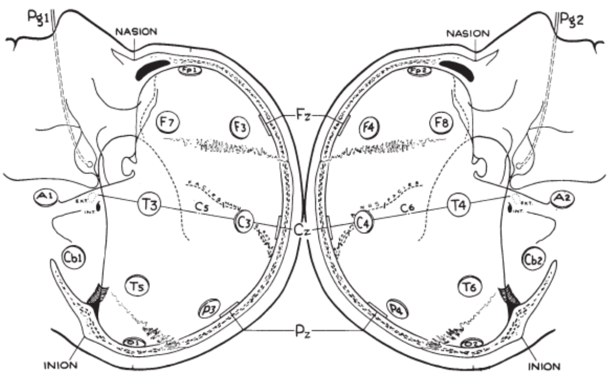
The third measuring is taken from the midline Fp position to the midline O position.

A mark is made at 10% of the measuring indicating the left or right Fp electrode position. After that, frontal, mid-temporal, and posterior temporal and left or right occipital marks are made at 20% of the measurement. The remaining 10% would be the midline O position.




F3, F4, P3, and P4 are at the intersection of 4 EEG electrodes respectively. For its calculations, measurements are taken from the Fp positions (left and right) to the O positions (left and right) through the C positions (C3 and C4). The placement of F3, F4, P3, and P4 has to respect the following rules:

1. F3 has to be placed so that the distance from Fp1 and C3 is identical to the distance from F7 and Fz.
2. F4 has to be placed so that the distance from Fp2 and C4 is identical to the distance from F8 and Fz.
3. P3 has to be placed so that the distance from O1 and C3 is identical to the distance from T5 and Pz.
4. P4 has to be placed so that the distance from O2 and C4 is identical to the distance from T6 and Pz.




The location of 19 EEG electrodes was provided by those measurements. The remaining 2 electrodes, auricular electrodes, are placed on the ear lobes.

## 2.2 Fuzzy Logic

The word fuzzy refers to concepts or measurements which are not clear or are vague. Sometimes in the real world, it is not possible to describe things as true or false, some of them are fuzzy and they are in the middle of both extremes.

As an example of this it could a bottle of milk. Is the bottle empty or full? What happens when the bottle has almost no milk, but is not empty?

In the previous example, it can be seen how the traditional logic has problems to represent that state because of fuzziness. That is the reason why Fuzzy Logic is needed in the real world. According to some authors such as Chen & Pham (2000), Fuzzy Logic is a logic used to describe fuzziness because Fuzzy Logic imitates the way that a human makes decisions because, in most real life cases, there are intermediate possibilities between 1(yes) and 0(no).

Fuzzy Logic has 4 main components (Figure 4):

1. **Fuzzifier**: It transforms the input crisp values into an input fuzzy set using the definition of the input membership functions(MFs).
2. **Rule Base**: It stores the logic (Rules).
3. **Inference system**: It maps fuzzy values of input membership functions into output fuzzy values of output membership functions.
4. **Defuzzifier**: It transforms output fuzzy sets obtained in the inference process into crisp values.

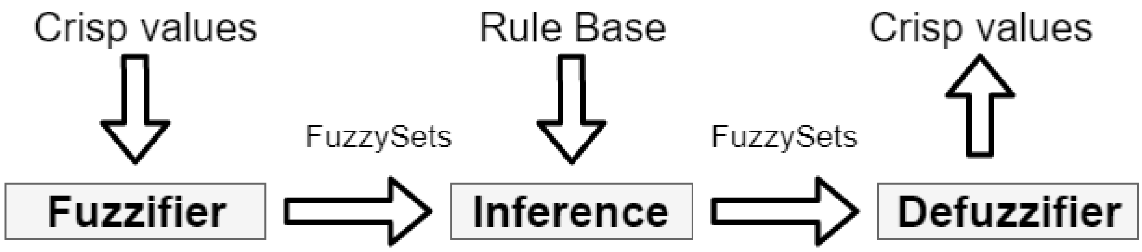



Figure 4. Description of the Fuzzy Logic process and components.

Crisp values of the inputs are transformed into input fuzzy sets using membership functions (MFs) in the Fuzzification process, those input fuzzy sets are used in the rule evaluation to calculate the strength of the rules to generate the output fuzzy sets. Those output fuzzy sets are de-fuzzified to obtain an output crisp value.

2.2.1 Fuzzy sets

Fuzzy sets can be considered as an extension of the classical notion of sets. Fuzzy sets are sets whose elements have degrees of membership, in contradistinction to classical sets which contain elements that satisfy precise properties.

**Mathematical definition**

Fuzzy sets are defined as a pair $(\boldsymbol{U}, \boldsymbol{m})$, where $(\boldsymbol{U})$ is a set and $\boldsymbol{m}: \boldsymbol{U} \rightarrow [\mathbf{0}, \mathbf{1}]$ a membership function. For a finite set U = $\{x_1, \ldots, x_n\}$, the fuzzy set $(\boldsymbol{U}, \boldsymbol{m})$ is often denoted by $\{\frac{m(x_1)}{x_1}, \ldots, \frac{m(x_n)}{x_n}\}$,

**Membership functions**

Membership functions represent the degree of truth or membership of an input. They give a value for certain things.

There are many kinds of membership functions the most common one in fuzzy logic are: triangular membership function and trapezoid membership functions.

**Triangular function**: defined by a lower limit a, an upper limit b, and a value m, where a < m < b.

$$\mu_A(x) = \begin{cases} 0, & x \leq a \\ \frac{x-a}{m-a}, & a < x \leq m \\ \frac{b-x}{b-m}, & m < x < b \\ 0, & x \geq b \end{cases}$$

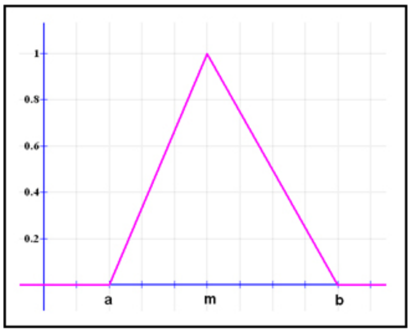



Figure 5. Definition of a triangular MF (Polytechnic University of Madrid, 2011)

**Trapezoidal function**: defined by a lower limit a, an upper limit d, a lower support limit b, and an upper support limit c, where a < b < c < d.

$$\mu_A(x) = \begin{cases} 0, & (x < a) \text{ or } (x > d) \\ \dfrac{x-a}{b-a}, & a \le x \le b \\ 1, & b \le x \le c \\ \dfrac{d-x}{d-c}, & c \le x \le d \end{cases}$$

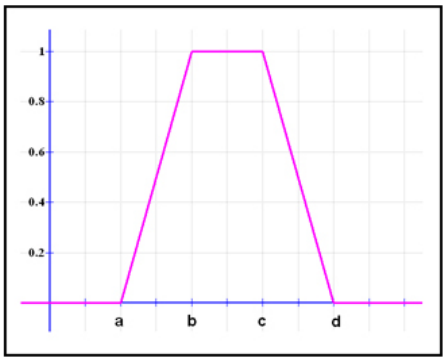



Figure 6. Definition of a trapezoidal MF (Polytechnic University of Madrid, 2011)

The shapes of MFs are important for a particular problem since they effect on a fuzzy inference system.

### 2.2.2 Fuzzification

In this process, the crisp values of inputs are transformed into fuzzy sets. Basically, this operation translates accurate crisp input values into linguistic variables.

A fuzzy set contains many membership functions, those membership functions take as an argument a crisp value(input) and return the degree of membership of that crisp value to that MF.

Therefore, each membership function is mapping a crisp value into a fuzzy value (between 0 and 1) accordingly to the definition and shape of that membership function.

At the end of this process, the degree of membership for that specific crisp value is calculated for each input membership function of every input. Consequently, all the fuzzy sets of all inputs are obtained.

The most important steps of the fuzzification process are:

- Defining the input membership functions
- Fuzzify all input values using the definition of those membership functions.
- Obtaining the fuzzy sets.

### 2.2.3 Rule Evaluation

The rule evaluation or fuzzy inference is the process of converting or mapping the given input to an output using fuzzy rules that were writing in the fuzzy logic process. This process of involves the fuzzy sets calculated in the fuzzification process, logical operations, and If-Then Rules. In addition to this, it is necessary an aggregation process to combine all the strength of the rules into a single output fuzzy set.

**Definition of fuzzy rules**

Fuzzy rules are the core of fuzzy logic, they contain the all the logic of the system. A fuzzy rule is defined as a conditional statement with the following structure:

$$\overbrace{\text{IF } \textbf{input1} \text{ is } \textbf{x}}^{\textbf{Antecendet}} \quad \overbrace{\text{THEN } \textbf{ouput1} \text{ is } \textbf{y}}^{\textbf{Consequent}}$$

x and y are linguistic variables, x is an input membership function and y is an output membership function.

The antecedent and consequence of a rule can have multiple parts, so it is possible to add as many antecedents and consequences as needed.

$$\overbrace{\text{IF } \overbrace{\textbf{input1} \text{ is } \textbf{x}}^{\textbf{Antecedent 1}} \text{ and } \overbrace{\textbf{input1} \text{ is not } \textbf{v}}^{\textbf{Antecedent 2}} \text{ or } \overbrace{\textbf{input2} \text{ is } \textbf{w}}^{\textbf{Antecedent 3}}}^{\textbf{Antecedent}} \quad \overbrace{\text{THEN } \overbrace{\textbf{ouput1} \text{ is } \textbf{y}}^{\textbf{Consequent 1}} \text{ and } \overbrace{\textbf{output2} \text{ is } \textbf{z}}^{\textbf{Consequent 2}}}^{\textbf{Consequent}}$$

### Calculation of the strength of a rule

Calculating the strength of a rule is necessary to obtain the degree of membership of all the input membership functions that appear in all the antecedents of that rule. Between antecedents, there are operators that combine the values of those antecedents. The final strength value of a rule is assigned to consequents of that rule.

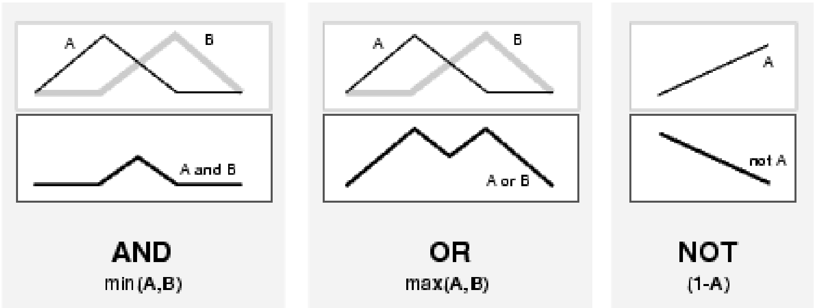



Figure 7. Rule operators (radio.feld.cvut.cz, n.d.)

Bellow, there is an example in which the strength of a rule is calculated:

IF **input1** is **x** and **input1** is not **v** or **input2** is **w** THEN **ouput1** is **y** and **output2** is **z**

IF **0.7** and **(not 0.9)** or **0.4** THEN **ouput1** is **y** and **output2** is **z**

IF **0.4** THEN **ouput1** is **y** and **output2** is **z**

The strength of that rule is 0.4

### Assignation of the strength of a rule

Once the strength of a rule is calculated, that strength is assigned to the corresponding output membership function of the output fuzzy set.

IF **0.4** THEN **ouput1** is **y** and **output2** is **z**

**Output 1 {...,0.4/y….}**

**Output 2 {...,0.4/z….}**

**Aggregation process**

At the end of the rule evaluation process, it is necessary to do an aggregation process to combine the strength of all the different rules into a fuzzy set for each output.

An output fuzzy set will contain in each membership function the maximum strength of all rules whose consequent include that output membership function.

There are some cases where the 2 output membership functions in the generated output fuzzy set are intersected. In those cases, the maximum value would be the maximum degree of membership of those functions.

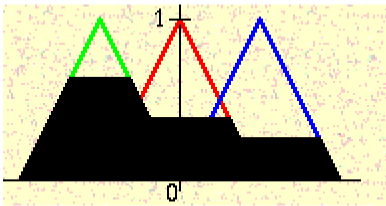


Figure 8. Aggregation process.

2.2.4 Defuzzification

After the inference, the obtained overall result is a fuzzy value. This result should be de-fuzzified to obtain a final crisp output (Bai & Wang, 2006). Defuzzification is performed according to the membership function of the output variable.

At the end of the rule evaluation process, an output fuzzy set for each output is obtained containing the degree of membership in each MF.

In most cases, this fuzzy value is useless because the linguistic variable is not suitable for further computations. It is necessary to defuzzify this linguistic value to a crisp value that can be used for calculations in an application.

There are many Defuzzification methods, but the more important commonly used and more important are: COG and COS.

**Centroid – Center of Gravity (COG)**

The Center of Gravity method (COG) is one of the most popular defuzzification techniques and it is widely used. This method is based in the center of gravity in physics.

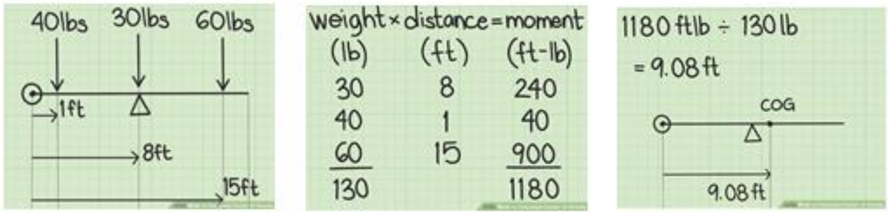



Figure 9. Calculation of the center of gravity in physics. (www.wikihow.com/Calculate-Center-of-Gravity, 2012)

Understanding how to calculate the center of gravity in physics is essential to understand the COG.

In the case of COG, the degree of membership is the weight(lbs.) and the x value is the distance.

$$x^* = \frac{\int x.\mu_C(x)dx}{\int \mu_C(x)dx}$$

If $\mu_C$ is defined with a discrete membership function, then COG can be stated as:

$$x^* = \frac{\sum_{i=1}^{n} x_i \cdot \mu_C(x_i)}{\sum_{i=1}^{n} \mu_C(x_i)} \; ;$$

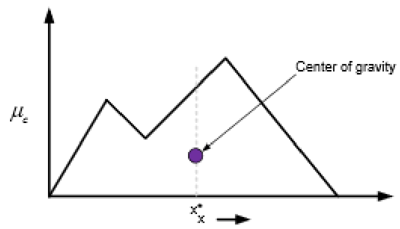



Figure 10. Center of Gravity in a Chart.

**Center of Sums (COS)**

This method is very commonly used but the overlapping area is counted twice. COS is similar to COG but instead of working with masses (degree of membership) it uses areas.

$$x^* = \frac{\sum_{i=1}^{k} A_i \times \bar{x}_i}{\sum_{i=1}^{k} A_i} \; ,$$

$\boldsymbol{A_i}$ represents the area of that MF. $\bar{\boldsymbol{x}}$ represents the center of area(centroid) of that MF.

The centroid of a plane can be computed like:

$$C_x = \frac{\sum C_{i_x} A_i}{\sum A_i}$$

# 3 METHODS

To obtain the results required in the thesis, it is needed to build a learning environment in which the two kinds of feedback system could be tested by students.

For the purpose of this thesis, it is needed to work on a three-dimensional space because users need to be able to place EEG electrodes on the human head. It is also needed a platform that allows to manipulate and display 3D models. Unity was chosen as the main tool to develop and built this learning environment. Unity is a cross-platform (several computing platforms) game engine that allows the creation of two-dimensional and 3-dimensional video games. Unity allows to code with 2 programming languages, C# or JavaScript. C# was selected as the main programming language because of its interoperability.

One of the first parts of the thesis consists of calculating mathematically, with high precision, the location of the 21 EEG electrodes on the human head. That position has to be accurate and without errors. In addition to this, it must work with different head sizes and shapes. This point was extremely important to the result of the Thesis because all 2 feedback systems need to compare the correct position to the user input electrode position to give a feedback according to it. Basically, the module uses 4 points (Nasion, Inion, left pre-auricular point and right pre-auricular point to calculate the position of the 21 EEG electrodes on the human head.

Once the exact position of all the electrodes is determined on the human head, it is necessary to implement the 2 kinds of feedbacks systems, fuzzy logic system, and exact system.

Fuzzy logic provides a human-friendly evaluation to students and the computer precise feedback provides a computer-precise feedback to students.

The human-friendly feedback provides indications using different scales/grades of distance and it also provides the direction of the location of the EEG electrode.

Fuzzy logic is logic that describes many degrees of truth. In the traditional logic, there were just 2 states true or false. Now, in fuzzy logic we have many states between 0 and 1, both included.

Fuzzy logic is used in this Bachelor's Thesis to provide a human-friendly evaluation. It is used to select the range of the distance accordingly to that membership functions and it is also used to obtain a grade between 0-10 about the precision of that placement.

The distance between an EEG placed electrode and the correct position of that electrode is fuzzified using membership functions that describe the grade of distance obtaining fuzzified values ([0,1]) of those membership functions. Then, in the rule evaluation the strength of each rule is calculated according to the fuzzified values of the antecedents After this, rules are combined in the aggregation process obtaining the fuzzified output.

But this output is useless, because it is a value between 0 and 1, so it needs to be de-fuzzified using methods like the Center of Gravity(COG) or Center of Sums(COS). Obtaining a crisp value that can be interpreted.

On the other hand, the computer-precise feedback provides the exact distance in centimeters and millimeters between the user-input electrode and the correct position of that EEG electrode. This distance is discomposed into the 3 axes (x, y, z) for allowing students to find the correct position according to the axis.

Once the learning environment was built and working correctly, a group of students tested it.  There was a focus group discussion (FGD) to obtain feedback from the students and they filled in a user experience questionnaire, with the goal to evaluate which approach was preferred by the students and which one would be better for learning.

## 3.1 Calculation of the EEG Electrodes

Calculating the precise position of the EEG electrodes on the application is essential for the correct working of the application. The application cannot work if the positions of the EEG electrodes is unknown because both feedback systems base their calculations on the difference between the ideal position and user placement of the electrodes. Solving this problem was not a trivial task because it was necessary to design and implement an algorithm that follows the guidelines of the International 10-20 system.

The implemented EEG electrode calculation module is able to handle many kinds of heads, shapes, and symmetries if input parameters are configured properly.

### 3.1.1 Input

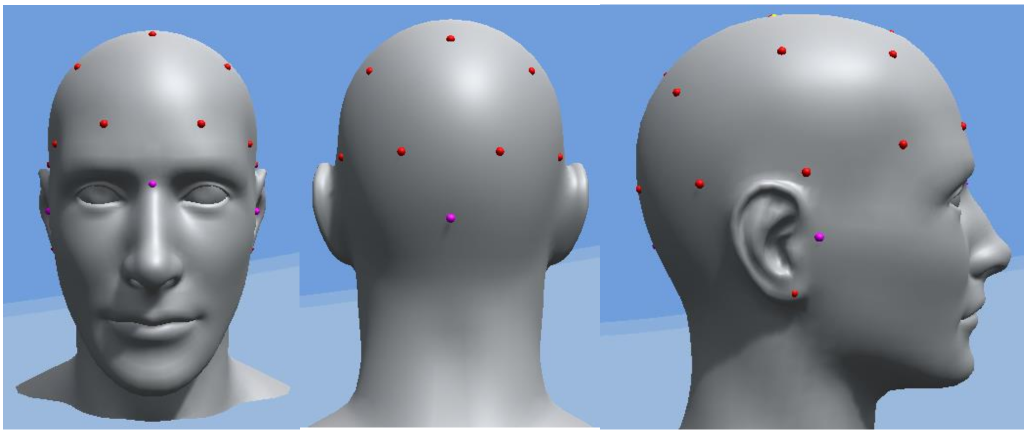
As a starting point for determining the ideal positioning of all electrodes, the author had to determine the precise location of the nasion, inion and two preauricular points on the head and use these positions as input parameters for the other electrode positions. These points are relatively easy to identify on a head mesh as well as on a person's real head.

The EEG electrode calculation module also needs 2 more parameters: A1 and A2 EEG electrodes. Those electrodes are located in the lobule of the ear and it is not possible to find its position mathematically using the international 10-20 system because there is not any rule or symmetry property to calculate those points.

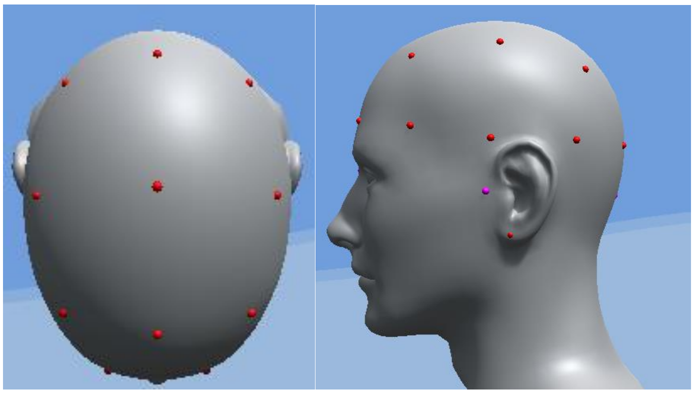
### 3.1.2 Output:

The output of the EEG electrode calculation module provides the position of all the EEG electrodes on the skull according to the International 10-20 system.

In the following images, the position of the EEG electrodes obtained by the EEG electrode calculation module was represented on the skull.



In these images the position of the EEG electrodes match to the specification of the International 10-20 system.



### 3.1.3 Calculation:

This section describes the algorithm that it is used to calculate the exact position of the EEG electrodes on the human head. The algorithm used the idea of the cross product to find the exact position of the electrodes.

The cross product is a binary operation on two vectors in three-dimensional space (R3) whose result is a vector that is perpendicular to both original vectors and to the plane containing them (Wikipedia, en.wikipedia.org/wiki/Cross_product, 2000).

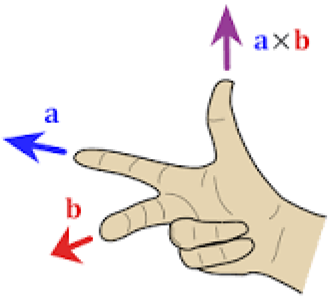
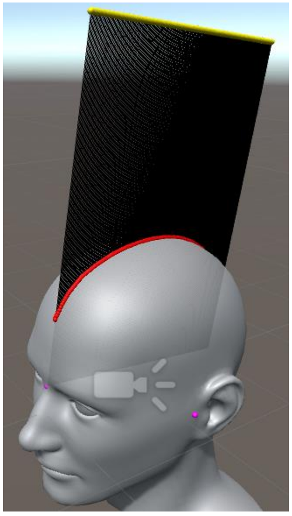



Figure 11. Cross product.

**Firstly, it is necessary to calculate 3 vectors that are essential to take into account the inclination and rotation of the head.**

1. Nasion Inion vector: $\overline{NI} = inion - nasion$.
2. Right and left preauricular vector: $\overline{RL} = left - right\ preauricular\ points$.
3. The cross product of the 2 previous vectors, Nasion Inion vector with the right and left preauricular vector. $\overline{NIRL} = \overline{NI}\ \ x\ \overline{RL}$

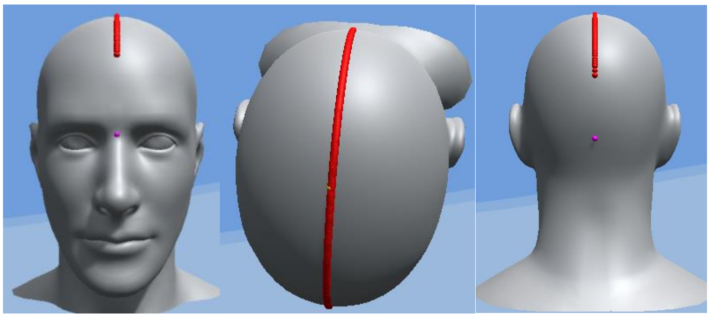
**Secondly, the calculation of the Nasion-Inion EEG electrodes**



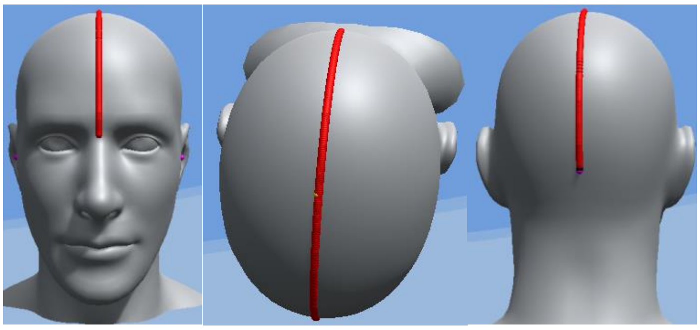
1. The distance between Nasion and Inion is divided into hundreds of points (the more points you use the more precision you will get).
2. Those points are projected outside the head using the direction of $\overline{NIRL} = \overline{NI}\ \ x\ \overline{RL}$
3. The points outside the head generated in the previous step, are projected again on the head, changing the sign of the direction. The reason why it is necessary to project again, it is because in Unity you cannot ray cast inside the objects.
4. The hit points on the human head are collected and stored in a List data structure.
5. There is a lack of precision close to the Nasion and Close to the Inion because of the natural shape of the head. There are not many hit points around them, so

it is necessary to find more hits on those points.

Problem:



Solution:



It is necessary to repeat the same process that we did, just changing some parameters:

a. Get **precision** at the **beginning**:
    i. The origin: First point of the List (previous step).
    ii. The destiny: A point close to the first point of the List.
    iii. The direction:
        1. The vector of the origin and destiny points is calculated $\overline{OriginDestiny}$.
        2. The $\overline{RL}$ $(left - right\ preauricular\ vector)$ is selected to do the cross product with the $\overline{OriginDestiny}$.

$$\overline{NIRL} = \overline{OriginDestiny}\ x\ \overline{RL}$$

    iv. That origin, destiny and direction are used to find the hit points on the head (as it was done in the previous steps).
    v. The hit points are added at the beginning of the list.

b. Get **Precision** at the **end**:
    i. The origin: A point close to the last point of the List.
    ii. The destiny: The last point of the List (previous step)

iii. The direction:

1. The vector of the origin and destiny points is calculated $\overline{OriginDestiny}$.
2. The $\overline{RL}$ $(left - right\ pre - auricular\ vector)$ is selected to do the cross product with the $\overline{OriginDestiny}$.

$$\overline{NIRL} = \overline{OriginDestiny}\ x\,\overline{RL}$$

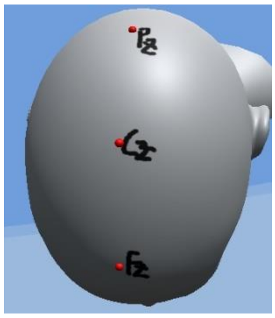
iv. That origin, destiny and direction are used to find the hit points on the head (as it was done in the previous steps).

v. The hit points are added at the end of the list.

c. The generated List contains all the necessary points to calculate the length of the line between the Nasion and the Inion. The distance would be the sum of all the small distances between those points.

d. To find the position of the EEG electrodes on the NasionInion line, it is necessary to iterate around all its points, accumulating the distance. When the accumulating distance is equivalent to the percentage of the total distance, the specific point is returned. That point represents the position of that percentage on the line. In the case of the NasionInion line it is necessary to find 5 percentages:

i. 10%: It is the Fp point, which is 10% up from the Inion. It is used in the calculation of Fp1, F7, T3, T5, O1.



ii. 30%: Fz EEG electrode.

iii. 50%: Cz EEG electrode.

iv. 70%: Pz EEG electrode.

v. 90%: It is the O point, which is 10% up from the Inion. It is used in the calculation of Fp1, F7, T3, T5, O1.

**Calculation of the Left, right preauricular EEG electrodes:**

1. The distance between the left and right pre-auricular points is divided into hundreds of points (the more points you use the more precision you will get).
2. Those points are projected outside the head using the direction of $\overline{NIRL} = \overline{NI}\ x\,\overline{RL}$ .
3. The points outside the head generated in the previous step, are projected again on the head, changing the sign of the direction.
4. The hit points on the human head are collected and stored in a List data structure.

5. There is a lack of precision close to the left preauricular point and close to the right preauricular point because of the natural shape of the head. There are not many hit points around them, so it is necessary to find more hits.

   It is necessary to repeat the same process that we did, just changing some parameters:

   a. Get **precision** at the **beginning** (same algorithm with different direction):
      i. The direction: Nasion Inion vector: $\overline{NI}$.
   b. Get **Precision** at the **end** (same algorithm with different parameters):
      i. The direction: Nasion Inion vector: $\overline{NI}$.
   c. To find the position of the EEG electrodes on the Preauricular line, it is necessary to iterate around all its points, accumulating the distance. When the accumulating distance is equivalent to the percentage of the total distance, the specific point is returned. That point represents the position of that percentage on the line. In the case of the Preauricular line it is necessary to find 5 percentages:
      i. 10%: T3 EEG electrode.
      ii. 30%: C3 EEG electrode.
      iii. 50%: Cz EEG electrode.
      iv. 70%: C4 EEG electrode.
      v. 90%: T4 EEG electrode.

**Calculation of the lines tenPercentUpNasion and T3, and T3 and tenPecentUpInion EEG electrodes:**

1. **tenPercentUpNasion and T3:**
   a. The distance between the tenPercentUpNasion and T3 EEG electrode position is divided into hundreds of points (the more points you use the more precision you will get).
   b. Those points are projected outside the head using the direction of $(\overline{10\%upNas\imath on} - \overline{T3}\,)\ x\ \overline{NIRL}$ .
   c. The points outside the head generated in the previous step, are projected again on the head, changing the sign to the direction.
   d. The hit points on the human head are collected and stored in a List data structure.

e. There is a lack of precision close to the tenPercentUpNasion and close to T3 because of the natural shape of the head. There are not many hit points around them, so it is necessary to find more hits on those points.

   It is necessary to repeat the same process that we did, just changing some parameters:

f. Obtain the **precision** at the **beginning** (same algorithm with different direction):
   i. The direction: The direction: - $\overline{NIRL} = \overline{NI}\ x\,\overline{RL}$

g. Obtain the **Precision** at the **end** (same algorithm with different parameters):
   i. The direction: - $\overline{NIRL} = \overline{NI}\ x\,\overline{RL}$

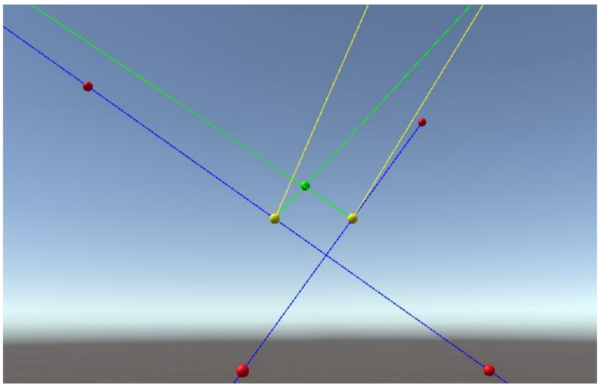
h. Calculation of Fp1 (20%) and F7(60%), as previous steps. It is multiplied by 2 because the distance is the half.

2. **T3 and tenPecentUpInion:**
   a. The distance between T3 EEG electrode and tenPercentUpInion is divided into hundreds of points (the more points you use the more precision you will get).
   b. Those points are projected outside the head using the direction of $(\overline{T3} - \overline{10\%upNasion})\ x\ \overline{NIRL}$
   c. The same operations as before.
   d. Calculation of Fp1 (40%) and F7(80%), as previous steps.

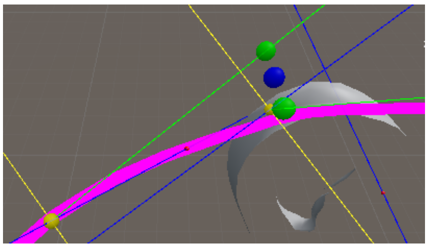
**Calculation of F3 and P3 (hard geometry):**

1. F3, P3, F4 and P4 are located at the intersection of 4 different EEG electrodes respectively. For instance: F3 is found at the intersection of 4 points: F7-Fz and Fp1-T3. There are some requirements and it is that the distance between the F3 and F7, and the distance between F3 and Fz has to be the same. In addition to this, the distance between Fp1 and F3 and C3 and F3 needs also to be the same.
2. The idea that was used to solve the problem was to create two vectors: $\overline{\mathrm{F7\_Fz}}$ and $\overline{\mathrm{Fp1\_C3}}$.
3. The normal of those vectors are calculated using the cross product.

4. After that, the middle points of these 2 vectors ( $\overline{\mathrm{F7\_Fz}}$ and $\overline{\mathrm{Fp1\_C3}}$) are calculated.



5. Then, perpendiculars of those vectors ( the cross product of the normal and the vector), are calculated using the cross product.
6. It is necessary to find the intersection of those middle points and those perpendiculars. As a result, a center of the plane of those 4 points (Fp1, C3, F7,Fz) is obtained.
7. This center is not on the head, so it is necessary to project it using the cross product of $\overline{\mathrm{F7\_Fz}}$ and $\overline{\mathrm{Fp1\_C3}}$ as direction.
8. This process is repeated with P3.
9. It is important to remark that there is a small error in this calculation because in most of the cases there is not an intersection. The EEG electrode is placed in the middle of the closest points of both lines to reduce the average error.



**Calculation of the other electrodes on the other part head.**

1. The algorithm took advantage of the fact that the 2 parts of the head are exactly or almost the same. The algorithm only calculated the left part of the head. Therefore, it is necessary to calculate the position of the rest of the EEG electrodes on the other part of the head.
2. For each uncalculated EEG electrode of the right part of the head (**Fp2, F8, T4, T6, O2, F4, P4**):
    a. The equivalent EEG electrode on the left part of the head is taken as a point.
    b. After that, the direction $\overline{RL}$ $(left - right\ pre\ auricular\ vectors)$ is taken but with negative sign because the direction is the opposite.
    c. Having a specific point and a specific direction, it is possible to cast a ray from that point to the other side of the head. A point outside the head it is obtained. There is another casting of a ray, from the outside point to the head using the previous direction but with negative sign. This way the position of each symmetric EEG electrode is found.

### 3.2 Implementation of the Fuzzy Logic module

It was necessary to implement a Fuzzy logic module that provides the functionalities needed by the human-friendly feedback system.

This diagram represents the structure of the Fuzzy logic module implemented by the author of this Bachelor's Thesis.

The main class of the module is the **FuzzyLogic** class that implements all the required methods of Fuzzy Logic (Fuzzification, rule evaluation, defuzzification). FuzzyLogic is composed mainly of 3 kinds of Objects: Inputs, Rules, and Outputs.  This allows the FuzzyLogic class to implement the required functionalities using the functionalities of those objects. That implementation is the reason of its modularity and its reusability.

The Figure 12 shows the structure of the Fuzzy Logic module: all its components, attributes and methods, using the notation of the Unified Modeling Language (**UML**).

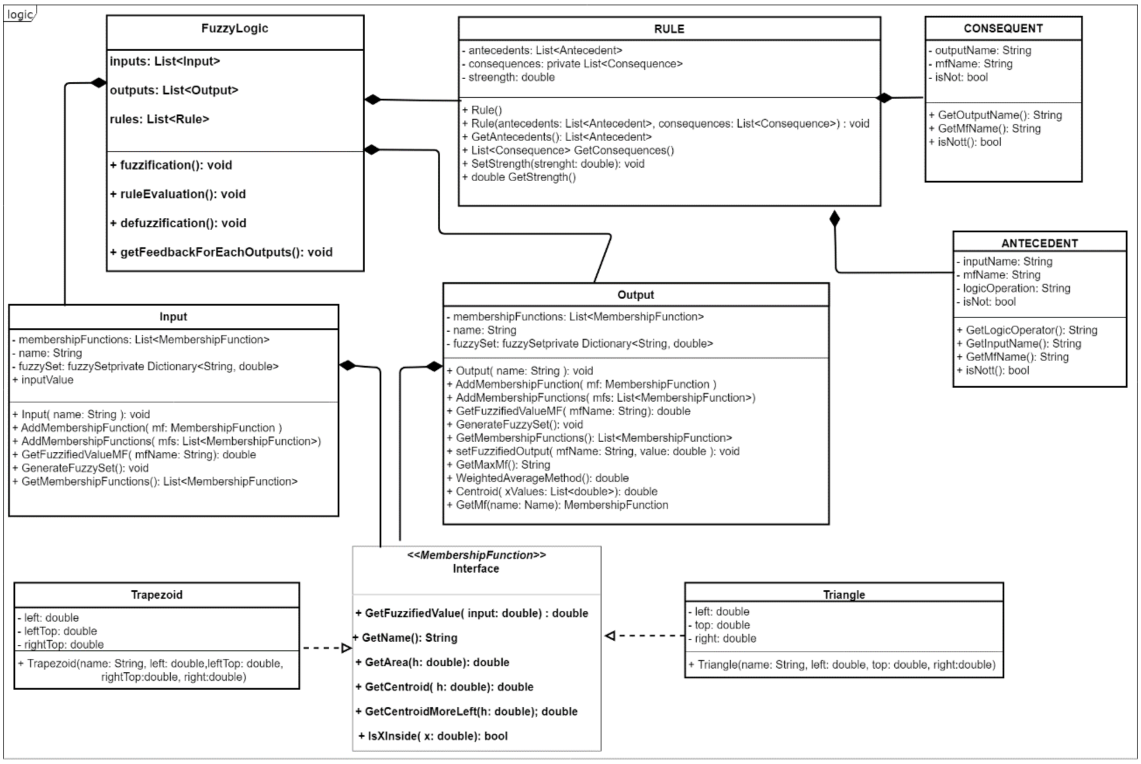



Figure 12. Fuzzy Logic Module - Implementation.

## 3.3 Human-friendly (Fuzzy Logic) Feedback System

The chosen design of the human-friendly feedback system provides reliable and accurate fuzzy feedback information for each axis, this way the feedback is easy to follow and it can be easily understood by users.

The human-friendly feedback system is composed of 3 components (Figure 13):

1. **Input**: which takes the position of the exact EEG electrode and the position of the input EEG electrode that the user placed on the head. After that, it calculates the error the error between these 2 positions in each axis. This error or distance in cm between the ideal position and the input position of the EEG electrode is used as an input of the fuzzy logic module.
2. **Fuzzy logic interface**: which obtains a generic feedback message and grade for that error or distance. This feedback message is modified in the output to take into account the direction (axis) and sense.
3. **Output**: which is represented in the UI in 2 different ways. In a graphical way, the message is represented using arrows that are very intuitive and easy to follow. In a second way, the feedback message will be represented in a textual way.

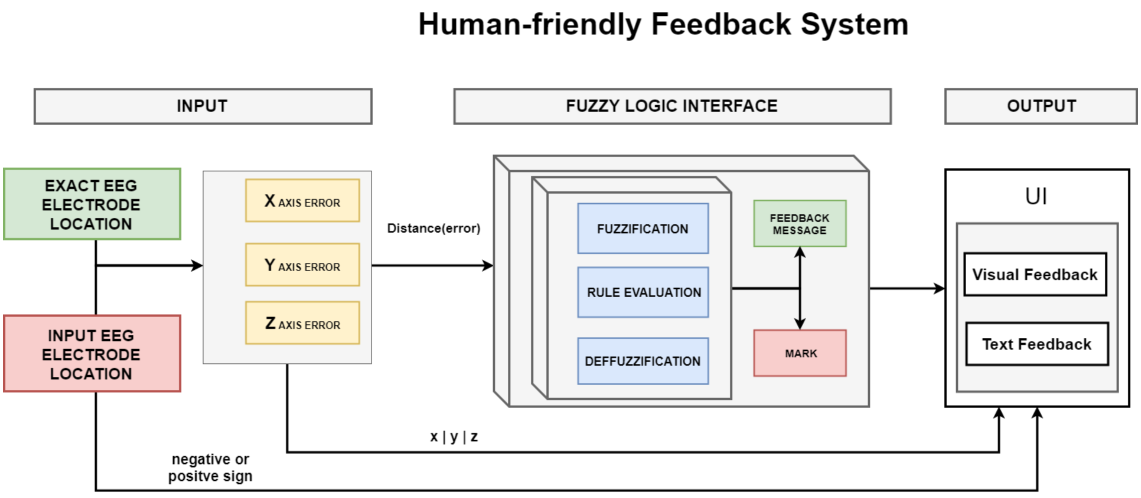



Figure 13. Internal structure of the human-friendly feedback system.

### 3.3.1 Input

The human-friendly feedback system takes two parameters:

**The exact position of the EEG electrode**: The position of this EEG electrode was calculated by the Exact electrode calculation module. This electrode position is composed of three axes(x,y,z).

**The position in which the user placed the EEG electrode**: this position is obtained from the electrode that the user place on the head. This position is composed of three axes(x,y,z).

The error between those 2 positions is calculated in cm:

$$Errors = [Error_x\ ,\ \ Error_y\ ,\ \ Error_z]$$

$$Error_x = |\ ExactPoint_x - inputPoint_x\ |$$

$$Error_y = |\ ExactPoint_y - inputPoint_y\ |$$

$$Error_z = |\ ExactPoint_z - inputPoint_z\ |$$

Each error (each axis) represents the input of the fuzzy logic module. Therefore, it is necessary to execute the fuzzy logic module 3 times (3 axes) for getting the human-friendly feedback of one placement.

It is important to point out that the axis of that specific error is used to obtain a direction. In addition to this, the sign of error ($ExactPoint_x - inputPoint_x$) is used to calculate the sense in that specific direction. In the case of having a distance or error in the x-axis with a negative sign. It would mean that the exact point is on the left of that input EEG electrode. In the case of having a distance or error in the x-axis with a positive sign. It would mean that the exact point is on the right of that input EEG electrode.

### 3.3.2 Fuzzy Logic Interface

The logic of the human-friendly feedback system is implemented using fuzzy logic because the feedback system should represent the different degrees or kinds of distance. It is not enough to say if the placement was correct or not, it has to provide useful feedback to users that indicates the extent of their error in placement.

Fuzzy Logic is immensely useful at the time of describing degrees or kinds of distance between the correct position and where the user thought the EEG electrode was placed. Those degrees or kinds of distances are very fuzzy because It is impossible to know the exact point where a grade of distance ends and when the other grade of distance starts.

In the case of not using fuzzy logic, it would probably end up taking our measurements, our crisp values and applying an awful lot of if-statements. It would have been much less maintainable and changeable in code, it would have been messy.

Using Fuzzy Logic, you avoid changing the logic of the application. It would be enough to change the definition of the grade of distance.

A great advantage of using Fuzzy Logic is that all membership values are calculated for a specific distance. An example of this is this fuzzy set which shows all the membership values for a specific distance:

{ Perfect = 0 , Very_Close = 0**, Close = 0.3** , **Medium = 0.8**, Far_Medium = 0, Far = 0, Far_Away = 0 }

#### Input Membership functions

The shape of MFs is important for a particular problem since they have an effect on the fuzzy inference system. For that reason, it was necessary to choose a membership function suitable for the EEG sensor placement.

The **trapezoid membership function** was the election for this Thesis. It was chosen because in the EEG sensor placement, it is necessary to provide an interval (small) in which the placement is considered correct or an interval that that specific distance corresponds fully to a feedback message. Triangular membership functions do not allow it because of its core (a single point). On the other hand, trapezoid functions allow configuring the core(μ(x) = 1) between 2 values.

The following input membership functions were created to represent the different kinds/grades of distance (a visual representation of these MFs is given in Figure 14):

1. **Perfect MF**:
```
new Trapezoid("Perfect",0, 0, 0.3, 0.5)
```
2. **Very Close MF**:
```
new Trapezoid("Very_Close", 0.3, 0.5, 1.25, 1.75)
```
3. **Close MF**:
```
new Trapezoid("Close", 1.25, 1.75, 3, 3.25)
```
4. **Medium MF**:
```
new Trapezoid("Medium",3,4,5,6)
```
5. **Far_Medium MF**:
```
new Trapezoid("Far_Medium", 5, 5.5, 7.5, 8)
```
6. **Far MF**:
```
new Trapezoid("Far", 7, 8, 9, 10)
```
7. **Far_Away MF**:
```
new Trapezoid("Far_Away", 9, 14, 20, 20)
```

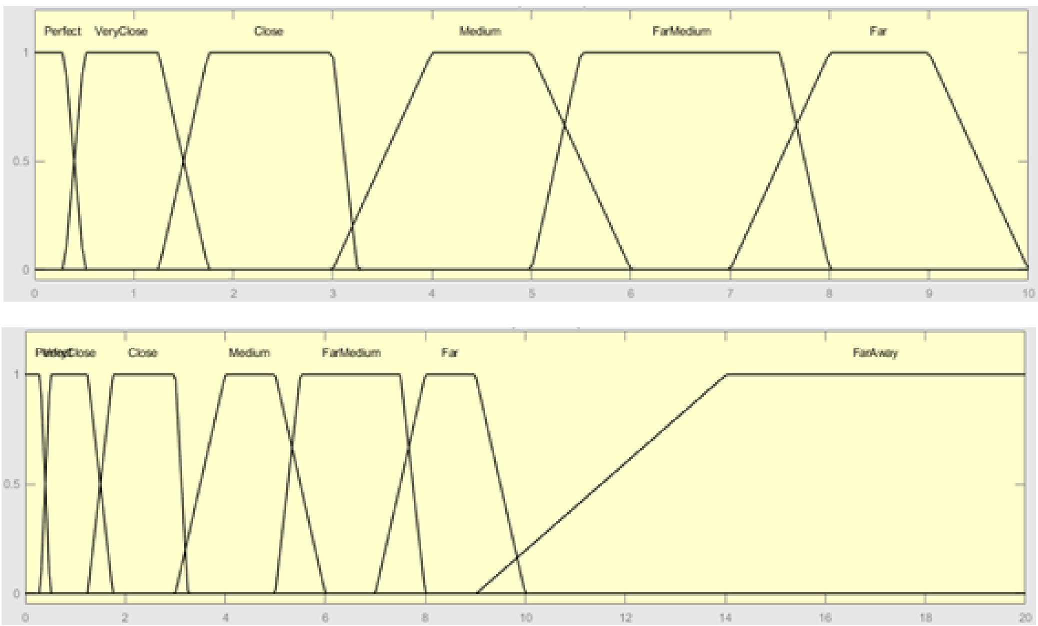



Figure 14. Input membership functions.

The range of the input MFs was set from 0 to 20 cm.

### Output Membership functions

The fuzzy logic used in the EEG application only has 1 output.

The output membership functions are:

Very much more, much more, more, somewhat more, a bit more, a little more and exact.

1. **Very much more MF**:
```
new Trapezoid("very_much_more", 0, 0, 1, 1.3)
```
2. **Much More MF**:
```
new Trapezoid("much_more", 1.0, 1.5, 2, 3)
```
3. **More MF**:
```
new Trapezoid("more", 2.5, 3, 3.5, 4.5)
```
4. **Somewhat more MF**:
```
new Trapezoid("somewhat_more", 4, 5, 6, 6.5)
```
5. **A bit more MF**:
```
new Trapezoid("a_bit_more", 6, 6.5, 7, 7.5)
```
6. **A little bit more MF**:
```
new Trapezoid("a_little_bit_more", 7, 8, 8.5, 9.5)
```
7. **Exact MF**:
```
new Trapezoid("exact", 9, 9.5, 10, 10)
```

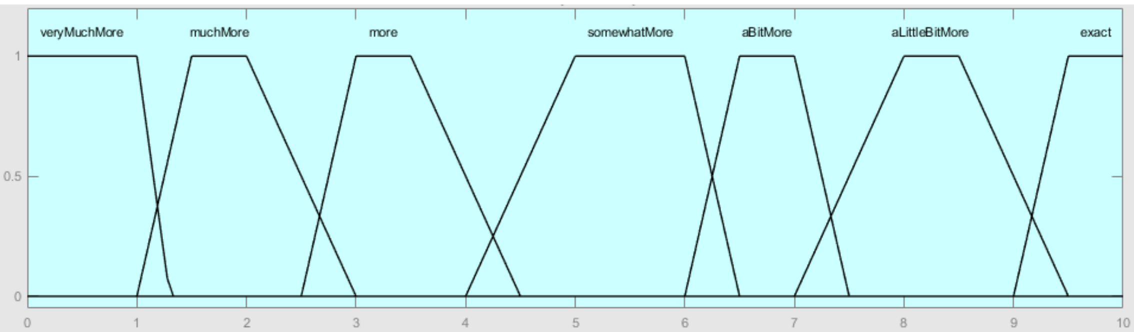



Figure 15. Output membership functions.

The range of the output MFs is between 0 and 10. That range represents the grade associated with a concrete output membership function.

In the Defuzzification process, a grade between 0 and 10 will be obtained. This will allow grading the placement of an electrode using Fuzzy Logic.

### Rules

The rules used in the fuzzy logic were the following:

```
"IF Distance IS Perfect THEN Feedback IS exact"
"IF Distance IS Very_Close THEN Feedback IS a_little_bit_more"
"IF Distance IS Close THEN Feedback IS a_bit_more"
"IF Distance IS Medium THEN Feedback IS somewhat_more"
"IF Distance IS Far_Medium THEN Feedback IS more"
"IF Distance IS Far THEN Feedback IS much_more"
"IF Distance IS Far_Away THEN Feedback IS very_much_more"
```

The EEG electrode placement requires precision at the time of placing an EEG electrode. For that reason, it was necessary to implement a set of rules that work perfectly and precisely in every kind of situations.

For achieving this objective, the number of rules was reduced and the complexity of those rules were simplified.

### Defuzzification

In the rule evaluation process, an output fuzzy set is obtained for each output. Those output fuzzy sets contain the strength of the rules that affect those output MFs.

That contained information is not very useful because its values are fuzzified between 0 and 1. It is necessary to convert those fuzzy sets into crisp values that could be used in the EEG application.

In the case of this EEG application, those values would be a grade between 0 and 10 per axis. This grade will be used in the scoring system of the application to grade the students in accordance with the proximity to the correct EEG spot.

In addition to this, the obtained grade would be used to select the feedback message of the output membership function that has a higher output fuzzy value in that mark.

In the human-friendly feedback system, there are 2 defuzzification methods to obtain the crisp values. Those methods are Center of Gravity(COG) and Center of Sums(COS).

Both methods are implemented correctly, according to the definition of each one. However, the Center of Sums(COS) method was chosen because it works with the idea of geometric center of an area. This is very practical because it allows defining where is the geometrical center of an area of a MF. This could be used in the first and last MFs to represent the lowest and maximum grade of an EEG placement. Otherwise, the lowest and maximum values will never be reached.

### 3.3.3 Output

The following 2 images are examples that show how the feedback system works. EEG electrode positions are represented to help in the visualization. The right-hand-side of the screen is dedicated to the feedback system output.

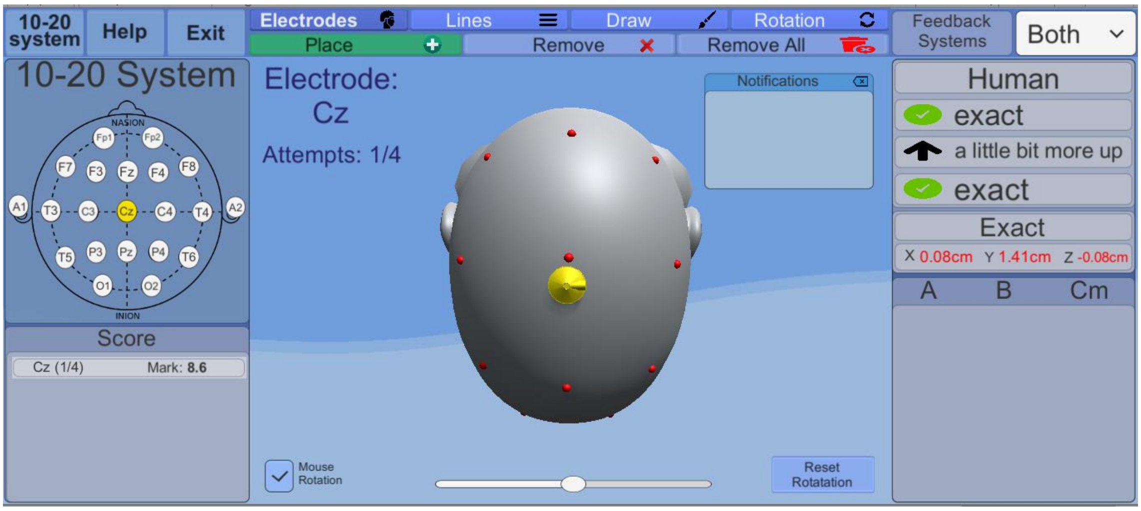



Figure 16. Feedback Systems - Learning Environment

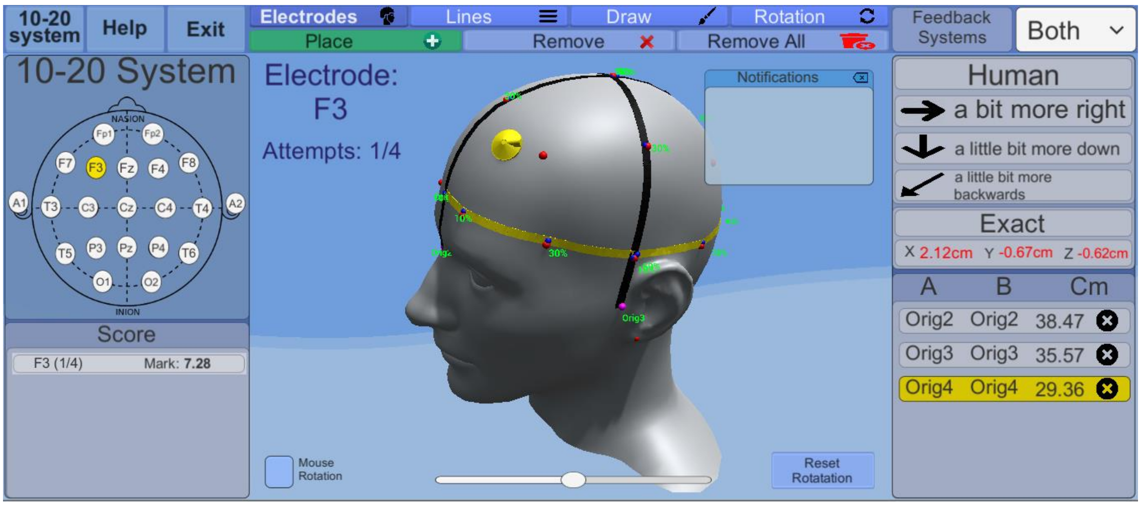


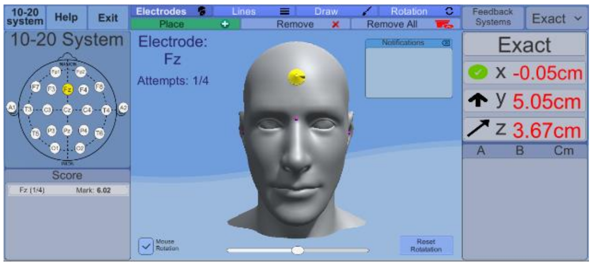

Figure 17. Feedback Systems - Learning Environment

### 3.4 Exact Feedback System

The exact feedback system provides a computer precise feedback to the user of the application in the context of EEG electrode positioning.

This feedback system provides the distance in centimeters between the correct EEG electrode point and the user input electrode point.

That distance is discomposed in the 3 axes: x-axis, y-axis and z-axis. Doing this, users can know exactly how many centimeters they must move the EEG electrodes to the left/right (x-axis), up/down (y-axis) or backward/forward(z-axis).




The negative centimeter value indicate that the sense is the opposite.

This table shows the direction and sense of the exact feedback system:

| Axes | Negative Sign | Positive Sign |
|---|---|---|
| **x** | Left | Right |
| **y** | Down | Up |
| **z** | Backward | Forward |

In the exact feedback system users only receive numerical data about the distance to find the correct EEG spot. It has the advantage of being very precise, but I hypothesize that it takes more time to be understood than the human-friendly feedback. The results and analyses in the following sections are aimed at testing this hypothesis.

### 3.5 Evaluation of both Feedback systems

Once the learning environment was built and tested to see if it works correctly, a group of students was asked to use it. The goal was to evaluate student perceptions about which feedback approach they preferred and which one they thought would be better for learning.

In this evaluation, the application was set up so that students were able to experience each of the feedback systems separately. Students were asked to use both feedback systems several times on their own time as part of their course work. The students used the application after been given an EEG placement demonstration by health professionals.

The author collected data from the students by assembling all those who used the application and asked them to fill in a questionnaire before having a group discussion with them. The questionnaire contained both quantitative and qualitative questions, while the group discussion was used to provide richer understanding of the student experience with the EEG placement application. There were 19 students who participated in the data gathering session.

#### 3.5.1 User experience questionnaire

A user experience questionnaire was designed to collect the most important information about the application and the two feedback systems. Please note that this is the author's own questionnaire design and is by no means validated or tested for reliability.

It is essential to collect meta-data about users who fill in the user experience questionnaire for a- posteriori classification of the users. For this thesis, it was important to classify the users according to the time they have used the digital learning environment and the scores they have obtained. The reason for collecting the names of the students was purely to match the questionnaires to individual comments

USER EXPERIENCE QUESTIONNAIRE

USER INFORMATION

| | |
|---|---|
| **Name:** | |
| **Surname:** | |
| **Age:** | |
| **Gender (male / female ):** | |
| **Previous experience in EEG (yes / no):** | |
| **Time spent playing the game:** | |
| **Average Score:** | |

during the group discussion so that these comments remain in the respective user classifications.

The evaluation of both feedback systems is mainly contained in the following table that formed part of the UX questionnaire:

| | | Feedback Systems | |
|---|---|---|---|
| | | **Human-friendly** | **Exact** |
| **Short distances** | More precise | | |
| | More useful | | |
| | More intuitive | | |
| | preferable one | | |
| **Medium distances** | More precise | | |
| | More useful | | |
| | More intuitive | | |
| | preferable one | | |
| **Long distances** | More precise | | |
| | More useful | | |
| | More intuitive | | |
| | preferable one | | |

It evaluates each feedback system in 4 fields: precision, utility, intuition and preference by the user. This evaluation it is realized in 3 distance ranges. This table covers all the possible cases that users might have.

In addition to this, users are asked about their opinion on many aspects of the digital learning environment, feedback systems and learning process:

General aspects:

1. What parts/functionalities of the application do you enjoy?
2. What parts/functionalities of the application do you dislike?
3. What aspects of the application would you improve?
4. How would you grade it (between 0 and 10)?

Feedback systems:

1. Are the indications of the human-friendly system easy to understand?

2. Are the distances in centimeters provided by the exact feedback system useful?
3. Which feedback system do you prefer to use?
4. With what feedback system have you obtained a better score?
5. How would you improve the feedback system of the EEG application?

Learning:

1. Do you think the application is useful for learning EEG? Why?
2. Has your knowledge of the International 10-20 system improved?
3. Do you plan to use it again?
4. Do you plan to use it as part of your studies?
5. Would you recommend the application to somebody else? Who?

All qualitative and quantitative answers were objectively collated and analyzed, before being reported as an aggregated result.

### 3.5.2 Group discussion

A group discussion is a qualitative research method in which a group of people is placed in one place by researchers to study their reactions, feelings or points of views towards one product (Morgan & Spanish, 1984). In the group discussion, there is a moderator who asks questions and helps to establish and keep the flow of the conversation. On the other hand, participants take part in the conversation answering those questions and talking with other members of the group, exchanging their ideas or opinions. During the process, the researcher takes notes and records the intervention of the participants.

In the case of this Thesis, a group of students was gathered in one classroom, where they were guided by three moderators (the author, the tutor of the author and the course lecturer). They were explained about the purpose of the meeting and introduced to the topic it was discussed.

The users were asked about their opinion on the more important points of the application and in special about the 2 feedback systems.

The sentiments, emotions, thoughts and points of views were recorded and analyzed carefully.

# 4 RESULTS

In the comparison of the two feedback systems, most of the students chose the human-friendly (Fuzzy Logic) feedback system as their preferred feedback system and as the system where they obtained better results.

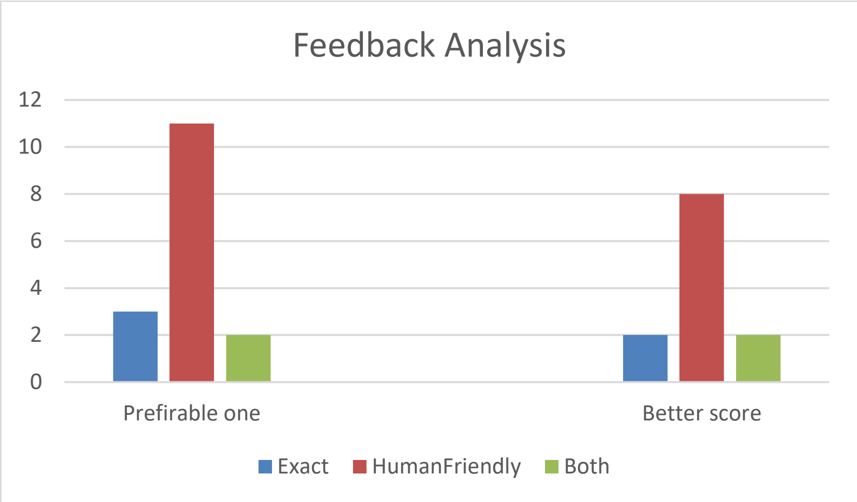



Figure 18. Feedback Analysis - Main results

In the group discussion, many comments of the students suggested that the human-friendly (Fuzzy Logic) feedback system was more fun to use than the exact feedback system. Comments included:

- *I didn't bother with the exact feedback system*;
- *I enjoyed the fuzzy logic system and it felt natural, so I didn't even look for another feedback system;*
- *I used the fuzzy system about 80% of the time I used the app… I only tried the exact system so that I could make comparison notes.*

The group discussion also indicated some of the student preferences when engaging with the interface. The most prominent points included:

- A desire for gamification of the learning environment;
- Using a centimeter scale as opposed to a percentage scale on the drawn lines;
- An area indicator to point out which area on the head a chosen electrode should be placed.

The questionnaire highlighted several prominent points for consideration regarding the further development of the system:

- The line for measuring the head was difficult to draw and manipulate;
- Difficulties in rotating the head;
- The corrective prompting (feedback) should be more clear, specifically regarding the direction in which the electrode should be moved;

The questionnaire also showed that the majority of students reacted favourably to the e-learning environment. Out of 19 respondents:

- 18 felt it was useful to their studies;
- 15 felt that their knowledge of the 10-20 system had improved;
- 15 would recommend it to other students specializing in EEG.

In addition to this, many interesting results were obtained analyzing the user experience questionnaire where students had to choose between one feedback system in 4 aspects (precision, utility, intuition and preference) in 3 ranges of distances (short, medium and long distances).

Users prefer to use the human feedback system with medium and long distances, however, when the placement of the EEG electrode is close to the correct spot, they prefer the exact feedback system.

In the intuition field, the human-friendly system is more intuitive in all the cases.

In the utility, the human-friendly feedback system is more useful than the exact system in relatively short-medium distances the than exact one.

The exact feedback system is more precise in all the cases. Although the precision of the exact feedback system, the fuzzy logic was generally better-received for short and medium errors. For long errors, the exact and fuzzy feedback systems received similar results.

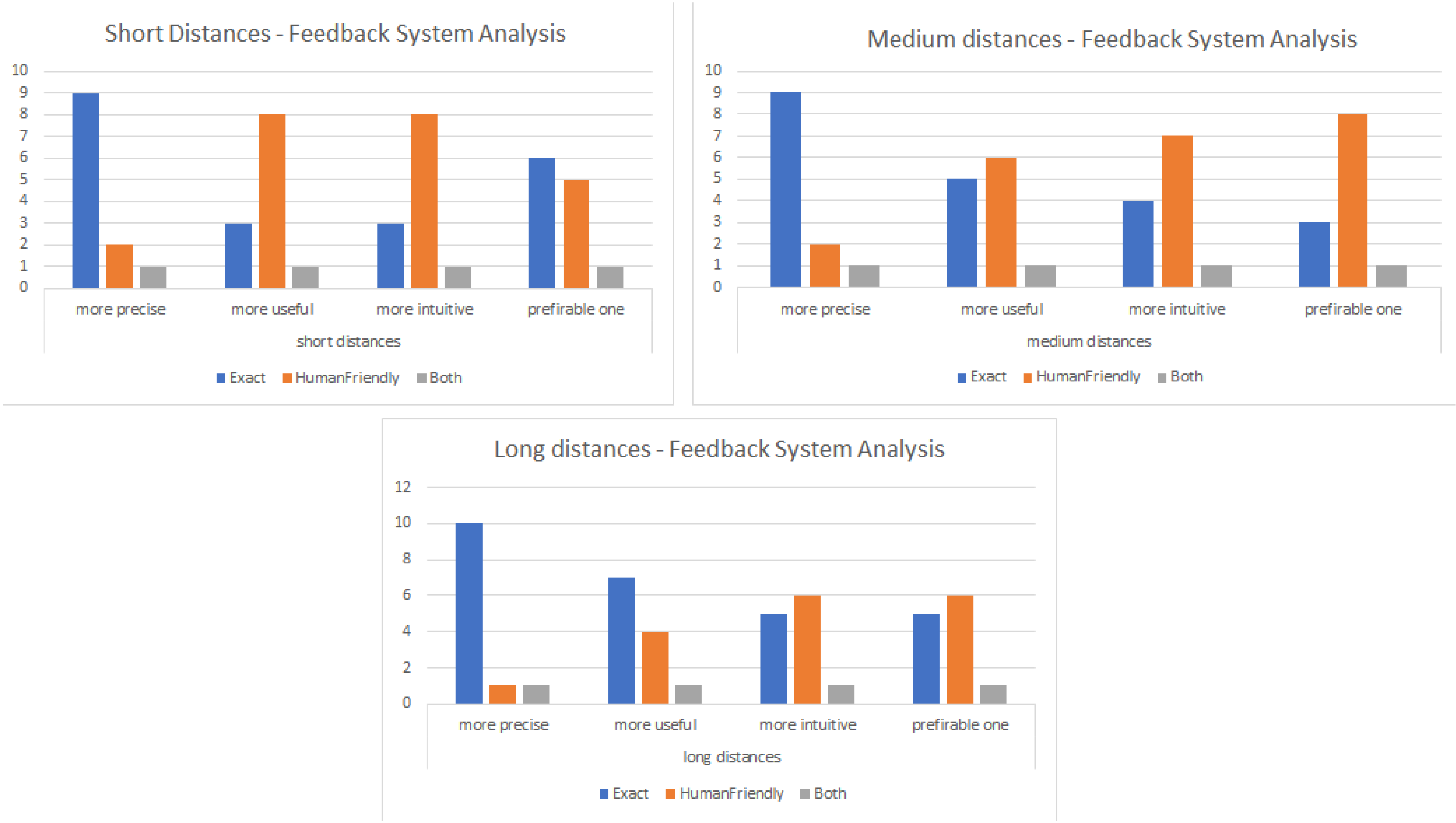



Figure 19. Feedback Analysis - Secondary results

# 5 DISCUSSION

The results obtained point out that indications provided by the human-friendly (fuzzy logic) feedback system are preferred by the students and its better for learning. The reason of that could be related to fun. Some articles like "Fun in Learning: The Role of Fun in Adventure Education" (Luckner & Bisson, 1996), suggest that the more fun something is, the more you will learn from it. This fact could explain why students obtained a better score in the digital learning environment using the human-feedback system than the exact feedback system.

Another reason that explains the results obtained is that the human-friendly system uses Fuzzy Logic, which imitates the way of decision making in humans because it involves intermediate possibilities between 1(yes) and 0(no).

A remarkable event that seems to happen in the process of learning using the AI-tutor (Fuzzy Logic) is that users associate internally that human-friendly feedback with specific ranges of distances. This allows users to map that linguistic term into a distance and know exactly where to place the EEG electrode. That is, the learners use their own heuristic mapping to translate linguistic feedback into distances. This improves the learning process of students because once they have memorized those linguistic terms (feedback messages) and their associated distances, they can know automatically where to place the EEG electrodes.

In the secondary results, there is a slight preference to use the exact feedback system when the placement is close to the correct EEG electrode position. The reason could be related to the fact that the exact feedback system indicates in a more precise way (in cm) the correct EEG electrode position.

However, the human-friendly system is preferred in medium and long distances because thinking in cm instead of linguistic terms is harder for users. This could be related to the fact that users have to try and figure the distance given on a rounded 3D object. This is not intuitive for inexperienced students who may be more used to measuring flat surfaces.

The preference towards the exact feedback system for short distances could be related to the trustworthiness of exact numbers opposed to the vagueness of linguistic terms. Particularly when the learner is close enough to the ideal placement so that an exact number more readily meets the learner’s ability to judge distance on the virtual head’s rounded surface.

# 6 CONCLUSION AND FUTURE WORK

This Thesis (Evaluation of EEG electrode Placement) realizes an evaluation of two feedback systems for an e-learning environment in the field of EEG. This Thesis has attempted to demonstrate which feedback system, the human-friendly feedback system or the precise feedback system, is better for learning how to carry out an electroencephalogram.

The obtained results suggest that the human-feedback system which is implemented using Fuzzy Logic is preferred by students and it is better for the process of learning than the exact feedback system.

These results will allow improvements in the process of learning in the field of EEG improving the learning process of the students.

The results were obtained in a small group of students in the field of EEG, its extrapolation to other fields could not be as good ad in EEG. Despite the small number of participants, the obtained results have shown a clear preference by students for the human-friendly system.

The results can be applied in the field of EEG to improve the learning process of the students in the international 10-20 system. These results could be extrapolated to other fields in which it is necessary to provide some feedback to the user. They could replace the current feedback system with a human-friendly feedback system which is easy to understand and which improves the learning process.

The learner response to the system also indicated that the e-learning environment still has some flaws (most prominently regarding the head rotation and line manipulation) and that these should be addressed before fully implementing into the learning curriculum. Nevertheless, the students are longing for a solution to convert their observation training into a higher level of preparedness for their hands-on training and the next cohort of students would benefit greatly from a revised version of the author's proposed e-learning environment.

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