Playing with robots using your brain

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***Abstract*— The use of EEG (electroencephalography) has been perceived as an interesting tool for people with motor disabilities to control a sort of electronic devices like robotic wheelchairs, exoskeletons, robotic arms, computers, among others. This kind of BCI (Brain Computer Interface) can be useful to help those people to carry out daily chores as well as to engage in recreational activities, like playing games, just for fun or as a way of performing the necessary training for the mental control of electronic devices in a playful way. In this sense, this paper presents a proposal for a Hot and Cold game using a Turtlebot3 Waffle robot and an EMOTIV Insight 5 channel mobile EEG.**

Keywords- EEG; BCI, robots; games;

I. INTRODUCTION

In the last few years, the use of Brain-Computer Interfaces (BCIs) has made it possible the development of systems that enable people with motor disabilities to perform tasks previously impossible for them. [1]

BCIs are systems that translate the electrical signals produced by the brain into inputs to control devices without the requirement of any muscular action. The most common way of data acquisition for use with BCI is electroencephalography (EEG), by which brain electrical impulses can be detected, in a non-invasive way, through electrodes attached to the scalp [1][2].

Recent technological advances related to BCI has brought into the market some low-cost BCI systems based on EEG. One of these systems is the EMOTIV [3], adopted in this investigation.

Research on the use of BCI by people with motor disabilities is usually related to the development of systems that allow them to perform daily tasks, such as locomotion, moving objects, switching devices on and off, among others. However, a yet little-explored area is the use of BCIs in entertainment activities that include the manipulation of real objects. The emergence of low-cost wireless BCIs, such as EMOTIV, may help to change this scenario.

Beyond pure entertainment, using games that rely on robot control through encephalography may also help to engage people with motor disabilities, or lack of limbs, during the necessary training to control the physical devices they intend to use to aid their daily chores.

In this context, this paper presents a Hot and Cold game where the player commands a wheeled robot with the brain guiding it to a goal. The results obtained point to the viability of developing games, with few commands, using the technologies adopted in this research.

We also observed that the initial contact with commanding a robot via encephalography is not an easy task. So, the use of games with few commands may contribute to making more pleasant and playful the first stages of learning to control robotic devices with EEG.

II. ELECTROENCEPHALOGRAPHY, ROBOTS AND GAMES

A. Controling Robots with EEG

To observe the current scenario of research on robots control with EEG, a bibliographical review was carried out at two major IEEE conferences dedicated to robotics: ICRA and IROS. The review covered research published between 2012 and 2018 and was carried out on the content of the papers abstracts and based on the following search string: (robot OR robotic) AND (EEG OR BCI OR BMI). Of the 26 papers found, we included in the results presented in Table I and Fig. 1 only those that could bring us up the following information:

- Adopted sensor: EEG only or Mixed (EEG associated with other sensors such as electromyography and video camera).
- Robot type.
- Study purpose.
- Experiment type.
- Number of subjects.
- EEG device (Cap or Headset).
- Number of electrodes used to read EEG signals.

These results allowed us to make the following observations:

- A predominance of studies using EEG to control assistant robots such as humanoid robots, exoskeletons, robotic arms, among others used to assist people with physical disabilities, or lack of limbs, to perform a variety of tasks such as locomotion, object manipulation, and eating. None of the found studies had games with robots as their goal (Fig. 2).

- The prevalence of the use of caps with electrodes for reading EEG signals. Only 3 studies used headsets, and two of them used EMOTIV Epoc Headsets (fourteen electrodes). We did not find research using the EMOTIV Insight (five electrodes), adopted in this study (Fig. 3).
- The use of few electrodes (Eight being the most common number) to capture EEG data in most studies (Fig. 4)
- Few studies using wheeled robots (the type of robot used in this research) (Fig. 5)
- The predominance of studies with few subjects (one, two or three), being one the most frequent number (Fig. 6).
- A prevalence of studies coming from Asia (Fig. 7).

TABLE I. SEARCH RESULTS

PP	CF	PY	RG	ST	RT	PP	ET	NS	DT	NE
[4]	1	17	EU	*EEG*	RA	AS	RR	1	HS*	14
[5]	1	17	EU	*EEG*	HM	NE	RR	12	CP	48
[6]	1	17	NA	*EEG*	WRA	AS	RR	3	CP	16
[7]	1	17	AS	MST	RA	AS	RR	8	CP	8
[8]	1	16	AS	*EEG*	EE	AS	RR	3	HS	19
[9]	1	15	AS	*EEG*	HM	AS	RR	1	CP	?
[10]	1	15	NA	MST	RA	AS	RR	6	CP	96
[11]	1	14	AS	MST	HM	AS	RR	5	HS*	14
[12]	1	14	AS	MST	EE	AS	RR	10	CP	32
[13]	1	13	EU	*EEG*	HM	AS	RR	18	CP	16
[14]	1	12	AS	MST	EE	AS	RR	3	CP	256
[15]	1	12	NA	*EEG*	HM	AS	SM	2	CP	?
[16]	2	17	NA	MST	DR	NE	RR	1	CP	11
[17]	2	13	AS	*EEG*	RW	AS	RR	1	CP	8
[18]	2	13	AS	MST	HM	AS	RR	4	CP	8
[19]	2	12	NA	*EEG*	WR	NE	SM	2	CP	8
[20]	2	12	EU	*EEG*	HM	AS	RR	1	CP	8
[21]	2	12	EU	*EEG*	RA	AS	RR	1	CP	8

Table I legend:

PP: Paper / **CF**: Conference (1:ICRA, 2:IROS) / **PY**: Publication Year / **RG**:\ Region (EU: Europe, NA: North America, AS: Asia) / **ST**: Sensor Type (EEG: EEG Only, MIX: Mixed Sensors) / **RT**: Robot Type (RA: Robotic Arm, HM: Humanoid, WR: Wheeled Robot, WRA: Wheeled Robot + Robotic Arm, EE: Exoskeleton, RW: Robotic Wheelchair, DR: Drone) / **PP**: Purpose (AS: Assistant Robot, NE: Nonspecific Purpose) / **ET**: Experiment Type (RR: Real Robot / SM: Simulation) / **NS**: Number of Study Subjects / **DT**: EEG Device Type (CP: Cap, HS: Headset, HS*: Headset EMOTIV Epoc)/ **NE**: Number of electrodes used for EEG signals reading.

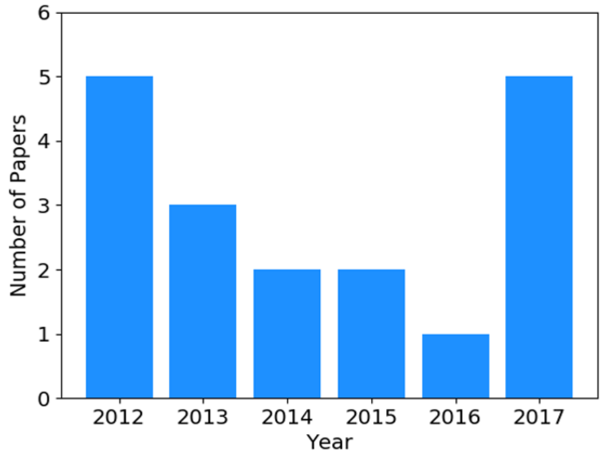

Figure 1. Number of papers per year

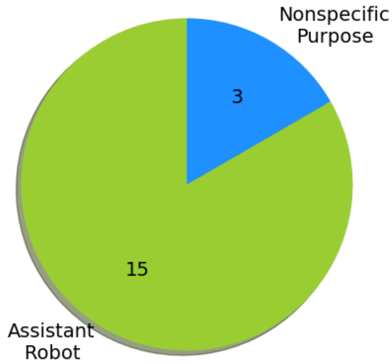

Figure 2. Number of papers per purpose

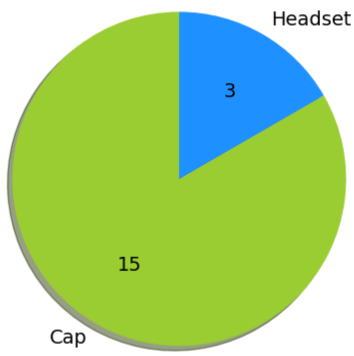

Figure 3. Number of papers per EEG device type

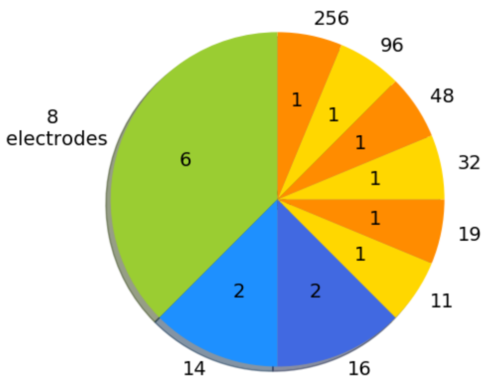

Figure 4. Number of papers per number of electrodes

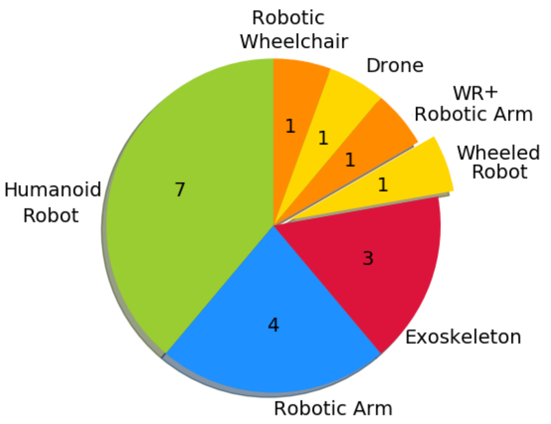

Figure 5. Number of papers per robot type

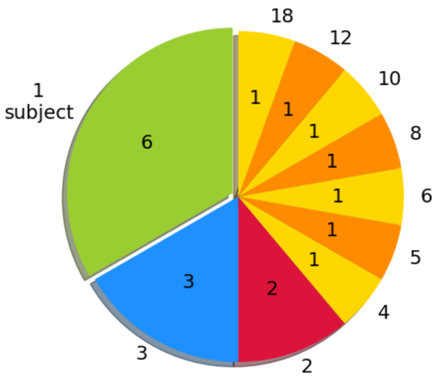

Figure 6. Number of papers per number of study subjects

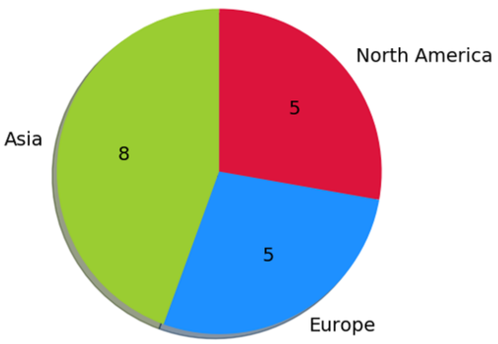

Figure 7. Number of papers per region

Once this bibliographical review was carried out in a reduced universe, the information presented here may not be generalized, but allows us to observe the existence of a still unexplored field of research regarding the use of EMOTIV Insight in the control of robots with wheels, especially for playing games.

B. *Games using EEG and robots*

The review presented in the previous section indicates the existence of little research dedicated to the study of robot control through electroencephalography, which points to the occurrence of an even smaller number of studies dedicated to games using these technologies association.

To confirm this assumption, we carried out a search, in the complete IEEE explore base, for papers containing the words “robot AND game AND (EEG OR BCI)” in their abstracts. This search returned 13 papers, published between 2014 and 2016, only three of which discoursed about games with EEG controlled robots.

The first paper [22], published in 2014, presented a checkers game where EEG signals are used to control robot arms responsible for moving the game pieces. The authors said that EEG is commonly adopted for software-based games using a computer screen and few hardware-based games using this technology have been developed. They also pointed out that this sort of game can present unique challenges, once the distance between the object and the player, the viewing angle, occlusions, may influence the stimuli that the controlled object produces in the user.

Using EEG and a wheeled robot, the work in [23], published in 2016, presented a game where the user needs to move a robot, through a maze, from a start position to an end position. The player can control the mobile robot to move forward, backward or turn around. “F”/ “B” command makes the robot move forward/backward for 2 seconds and stop. When the robot receives “R”/ “L” command, it rotates 30º clockwise/counterclockwise and automatically stops.

The last paper, published in 2016, [24] presents a game to test the improvement of the patient engagement in robot-assisted rehabilitation therapy using EEG signals to help user to control a finger robotic exoskeleton. In the game, the player tries to match the time of his finger movement, assisted by the exoskeleton, to audio-visual stimuli in the form of notes approaching a target on the screen, like the famous Guitar Hero video-game [25].

None of those three studies used EEG headsets, all used EEG caps. Only one study used a wheeled robot.

III. THE HOT AND COLD GAME

A. *The Classic Hot and Cold game*

The Hot and Cold game is a Party Game in which a player (the hunter) needs to find a hidden object while the other players (who know where the hidden object is) help the hunter to achieve his/her goal telling him how near or far he/she is from the hidden target. Hot means the hunter is getting close to finding the hidden object. Cold means he/she is distancing itself from the target.

- Number of players: two or more
- Objective: Get hot commands and find a hidden object
- Dynamics:
  - Choose an object to hide.
  - Choose a player to be the hunter.
  - The hunter leaves the room (the game space).
  - The other players hide the chosen object.
  - The hunter returns to the game space and starts to search for the hidden object.
  - The other players say words like *hot*, *burning*, *scorching*, indicating the hunter is near the goal, and words such as *cold*, *freezing*, *icy*, indicating the hunter is far from the hidden object.
  - When the hunter finds the hidden object, another player is chosen to be the new hunter and the game restarts.
  - Time taken to find the target could be registered.

B. The BCI based Hot and Cold game

The idea of designing a BCI game inspired on the Hot and Cold game described above came from the fact that we planned to develop a game that could be played with few commands to simplify the initial user contact with hardware control through EEG. In this game version, the player needs to guide a robot to a goal while avoiding obstacles using two commands generated by EEG signals. The "hot" command tells the robot it is in the right direction and must drive forward. The "cold" command tells the robot it is in the wrong direction and must turn around itself until it receives a new hot command.

- Game space: a room with some paper cylinders arranged on it. One of these cylinders is the goal. The others are obstacles labeled with number (Fig. 8).
- Number of players: one or more (plus the robot)
- Objective: to lose as few points as possible while trying to get the robot to the target.
- Dynamics:
  - Place the robot on the opposite side of the target cylinder (The goal is labeled with an "x").
  - Using the "hot" and "cold" commands previous trained, the user needs to guide the robot to the goal avoiding the other cylinders
  - Every time the player knocks a cylinder he/she loses the number of points scored on it.
  - If more than one player plays the game, the one that loses the least points wins.

Guide the robot using EMOTIV Insight is not an easy task, at least in the first contact with this technology (see section V). This obstacle was considered during the game design.

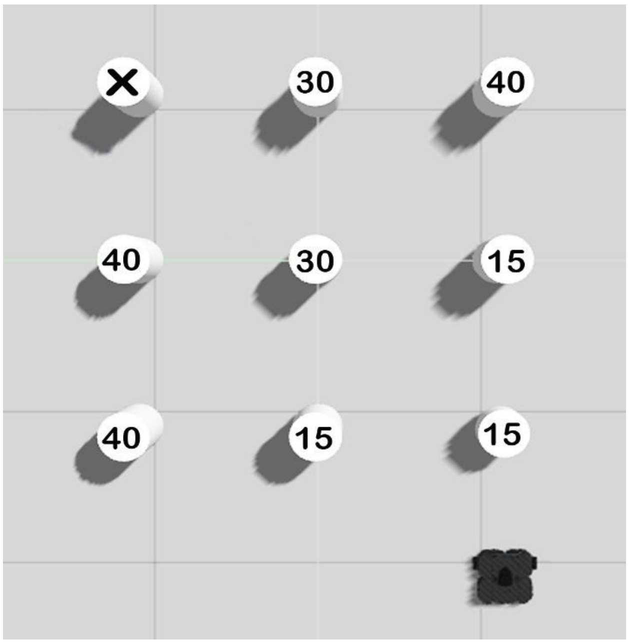

Figure 8. Game space prototype

IV. MATERIALS AND METHOD

As mentioned before, this research proposes a Hot and Cold game where the player needs to conduct a wheeled robot to a goal, avoiding obstacles, using EEG signals. The system uses a Turtlebot3 Waffle, an EMOTIV Insight five Channel Mobile EEG and a computer to establish the communication between the EEG headset and the robot.

The EMOTIV Insight (Fig. 9) is a commercial, low-cost device for reading cerebral signals with five channels capable of measuring activity from all cortical lobes of the brain.

The EMOTIV site describes its equipment as follows: "Based on unique and highly efficient methods, EMOTIV has developed a system for users to train direct mental commands where the user trains the system to recognize thought patterns related to different desired outcomes, such as moving objects or making them disappear. […]. [It] measures 6 different cognitive states in real time – Excitement (Arousal), Interest (Valence), Stress (Frustration), Engagement/Boredom, Attention (Focus) and Meditation (Relaxation)." [3]

Figure 9. EMOTIV Insight headset.

EMOTIV has an SDK for different programming languages that can be used to acquire the EEG signals and "trigger commands" based on the data collected through these readings.

The EMOTIV Control Panel allows one to create user profiles to save the practice of several actions. For this, it is necessary to practice concentration on thought patterns such as *neutral*, *action one*, *action two*, and so on (Fig. 10). To play the Hot and Cold game, two actions, labeled "hot" and "cold", were trained. Using these two actions the user can control Turtlebot3 [26] to drive forward (hot) or spin around itself (cold).

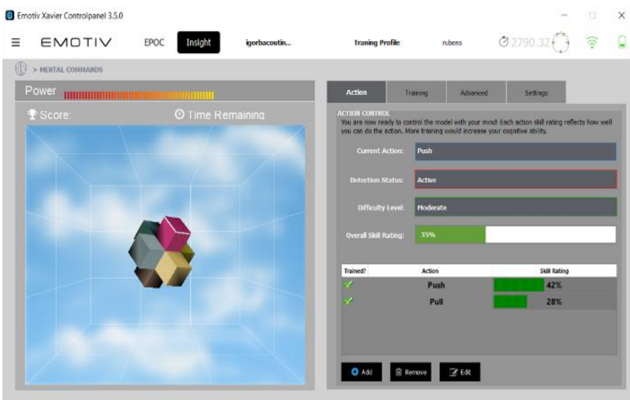

Figure 10. Emotiv action training interface.

A customized web page was created to show the sensor contacts, the current detected action, and the metrics for the user's mental performance in the Turtlebot3 control (Fig. 11).

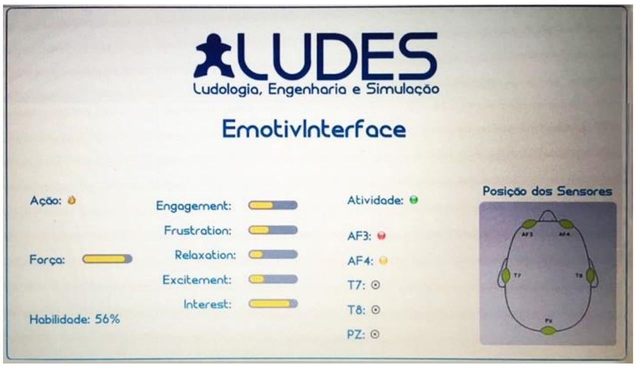

Figure 11. Hot and Cold Game EMOTIV interface.

The Turtlebot3 Waffle (Fig. 12) is a wheeled robot produced by ROBOTIS [27].

Turtlebot3 Waffle comes equipped with a Dynamixel XM430, a high-performance actuator used to control the Turtlebot3 wheels movement, and with 2 sensors: a laser distance sensor (LDS-01) and a video camera (Intel Realsense R200). To control its actuators and acquire data from its sensors, Turtlebot3 Waffle uses a single-board computer (Intel Joule 570x) and a control board (OpenCR1.0).

The Turtlebot3 software uses ROS [28], a flexible open-source framework for developing software to robots. ROS uses, among other ways of communication between its processes, a publisher-subscriber architecture. In ROS, the three central elements of this architecture are named: *nodes*, *topics*, and *messages*.

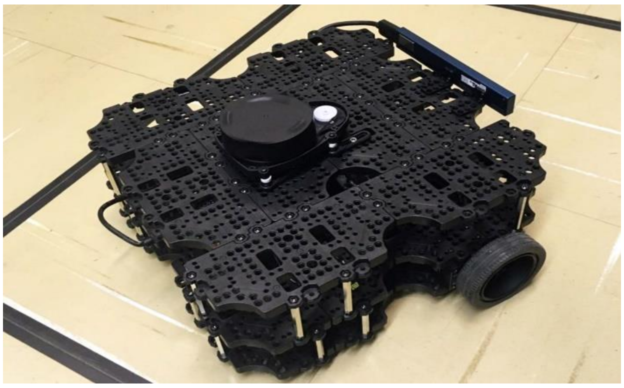

Figure 12. Turtlebot3 Waffle.

Nodes are, basically, C++ or Python programs that generate or acquire data. The nodes exchange data with each other through messages published in topics (Fig. 13). A node can publish messages on topics or subscribe to topics to receive messages posted by other nodes. A publisher node has no information about which subscriber nodes will access its published messages. The same way, a subscriber node has no information about the source of the messages it receives from a specific topic.

Turtlebot3 has a sort of "native" nodes to control its actuators and acquire data from its sensors, as well as a collection of nodes to perform a variety of tasks such as SLAM (Simultaneous Localization and Mapping).

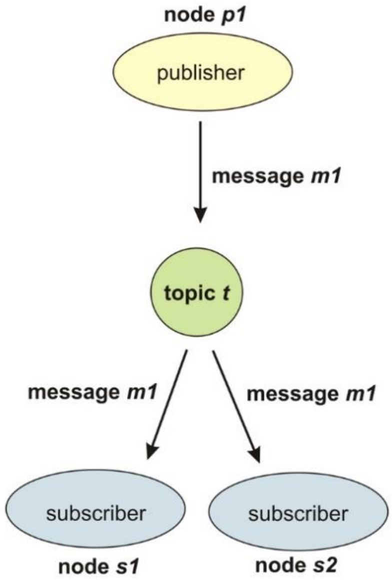

Figure 13. ROS nodes communication Diagram

To perform personalized tasks, one can develop nodes that, through the publisher-subscriber architecture, use the information provided by the Turtlebot3 native nodes about the data generated by its sensors, and control the Turtlebot3 actuators using the native nodes designed for this purpose.

Therefore, in order for the Turtlebot3 to assume the necessary behavior to perform the "Hot and Cold" game, two ROS nodes were developed (based on ROS nodes already available): one responsible for generating "hot" and "cold" messages from the data provided by the EMOTIV webserver and another responsible for controlling the movements of the Turtlebot3 in response to the "hot" and "cold" messages received (Fig. 14).

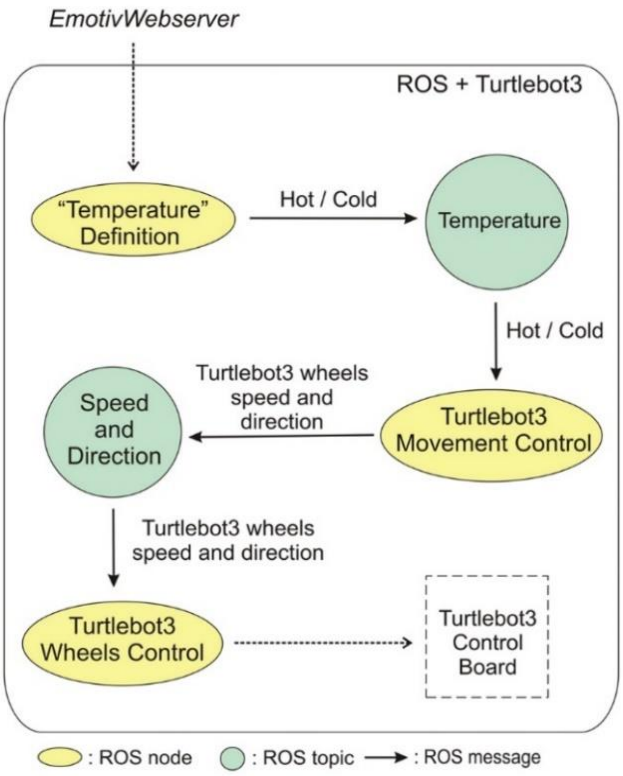

Figure 14. "Hot and Cold" game ROS nodes.

The internal communication between the EMOTIV Insight and the Turtlebot3 was performed using a common HTTP protocol. The schematic presented in Fig. 15 shows a summary of this system.

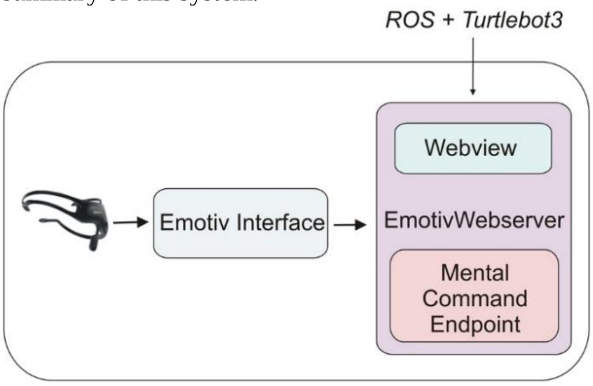

Figure 15. EMOTIV Insight and Turtlebot3 Comunication

With the technological environment properly prepared, an experiment was performed to test de BCI based Hot and Cold game, as described in section V.

V. RESULT AND DISCUSSION

The experiment to test the Hot and Cold Game based on BCI was carried out in 3 steps.

In the first step, a keyboard was used to verify the correct robot response to the hot and cold commands. A hot command, triggered by the “h” key, said to the robot it was in the right direction and should move forward. The cold command, triggered by the “c” key, said to the robot it was in the wrong direction and should spin around itself until a next hot command was trigged. The robot control tests using the keyboard showed it was responding properly to the commands received and performing the expected actions.

In the second step, the robot control actions were trained within the EMOTIV environment. During this training, for each desired action, the user must focus his/her thought on something, and the EMOTIV readings regarding this specific thought will then be linked to that singular action

Two healthy adult subjects with no experience using EMOTIV, a 29 years old male (Subject one) and a 47 years old male (Subject two), carried out the training of the two necessary actions to play the Hot and Cold game. Both subjects had some difficulties to achieve the appropriate skill rating for each action. “This skill rating is calculated during the training process and provides a measure of how consistently the user can mentally perform the intended action.” [29]

Subject two reached better marks then subject one, as shown in Table II. Based on these results, subject two was chosen to carry out the third step: controlling the robot with the EEG signals.

TABLE II. HOT AND COLD GAME ACTIONS SKILL RATING

Subject	Skill Rating	
	Action 1 (hot)	*Action 2 (cold)*
1	66%	61%
2	72%	67%

With the EMOTIV headset placed at his scalp, subject two started trying to make the robot respond to his mental commands (Fig. 16). The robot responded with a low response delay (less than one second) when a trained command was identified by EMOTIV. But, the elapsed time between the player thinking about the desired action and his thought matching the trained one was quite long, sometimes exceeding 20 seconds.

The experiment showed that the communication between EMOTIV and Turtlebot3 was satisfactory and the difficulties found to control the robot were related to the player's ability to concentrate on the thought that matched the desired action. These difficulties, however, as mentioned before, can be considered in the game design as one of the challenges to be overcome by the player.

Another point to be considered, as mentioned by [22], is that, in the real environment, the position of the robot, relative to the player (near, far, facing the player, facing away from the player) may have some influence on the player's thoughts when trying to make the robot to execute a particular action. For example: making the robot walk forward (hot) when it is facing away from the player suggests the effect of pushing the robot. The same action, when the robot is facing the player, suggests the effect of pulling it.

Figure 16. Hot and Cold Game Testing

The variants of position, distance, angle, occlusion, among others, are distinct in the real world from those in a simulation. This suggests that training to control robotic devices in the real world should preferably be performed in it, with all its challenges. Therefore, the use of games to perform the necessary training to control these devices could help to make this task more enjoyable, increasing the user’s engagement in his training process.

Finally, this study also showed that the combination of ROS and EMOTIV SDK enables the development of EEG-based BCI systems in a quite friendly manner.

VI. Conclusion and Future Work

The bibliographical review presented in section II indicates the existence of few studies on the control of robots with EEG and even fewer studies on games adopting this association of technologies, especially using off-the-shelf low-cost EEG devices such as EMOTIV Insight with a 5 channels headset. So, the EEG based Hot and Cold Game presented in this paper may contribute with new knowledge in this research area by aggregating some hands-on experience.

We observed in our tests that the training of different EEG commands is not an easy task. Therefore, developing games where few commands are necessary, as in the Hot and Cold game presented here, may help people with motor disabilities, or lack of limbs, in their first steps when learning to control robotic devices designed to aid them in their daily chores. Such an approach may contribute to making this learning process more playful.

New features, such as image recognition, could be incorporated into the game, allowing the robot to identify the target when it is located, among other objects arranged in the game area that could make the game more exciting.

Lastly, more tests, with a larger number of subjects, and in the actual game space (including the obstacles) need to be performed to enable the necessary adjustments. This way we hope to improve the gameplay of the BCI based Hot and Cold game proposed in the research.

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