Social Robots for Reinforcing Attention and Forming Emotional Knowledge of Children with Special Educational Needs

A. Lekova, T. Tanev, S. Kostova, P. Dachkinov, V. Vassileva-Aleksandrova, O. Bouattane

***Abstract* — Emotional child-robot interaction helps catching quickly child attention and enhancing information perception during learning and verbalization in children with Special Educational Needs (SEN). This will improve the pedagogical rehabilitation for these children and also develop their emotional knowledge and memory in play-like activities mediated by emotion-expressive social robots. The designed by us EEG-based portable Brain-Computer Interface (BCI) measures and features the brain electrical activity in real time in order to analyze the correlated attentional or emotional states of a child. Different BCI outputs can assist special educators in assessment of the emotional and cognitive performance of a child or can be used directly as inputs for robot control. BCI is a new technology for human-robot interaction and it can evolve into technology for self-regulatory training of attention and emotional skills via neurofeedback exposed on a robot. Since the attention or emotional responses of children with SEN make robots to act, these skills are naturally reinforced in the play. Two research protocols based on this idea are presented. They describe the procedures for conducting custom scenarios for robotic intervention with a portable brain-listening headset. The proposed BCI is used to translate the human brain activity, head motion and eye movement during the process of expressing emotions into robot commands. Then, they are wirelessly transmitted to the robot sensors, modules and controllers by a new designed BCI-Robot framework. This study marks a first step towards the way of utilizing the advantages of educational theater in Social Robotics in order to transfer the emotional talent of an actor to an emotion-expressive robot.**

***Index Terms*— Brain-computer interface, Children with SEN, Educational theater, Emotion understanding, Human-robot interaction, Neurofeedback, Pedagogical Rehabilitation, Social robots**

I. INTRODUCTION

Emotions reading is a critical element of the social intelligence because it is the way we make sense of other people's behavior and decide on our own next moves. Emotions play the central role in day-to-day living and emotional regulation has an impact on the intensity, duration, and expression of emotional reactions [1]. Recent neuroimaging findings have indicated that emotions have a significant influence on the cognitive processes in humans, including perception, attention, learning, memory, reasoning and problem solving [2]. Attention is a key factor for human cognition and a link between the brain and behavior. Because there is great public interest in neuroscience, more details about the modulation of attentional and emotional networks in the brain are provided in Section II [3], [4]. In the same section, a new explanation why emotional events capture attention and enhance cognitive processes [5] is provided, too

Conclusions from our past projects such as METEMSS [6] revealed that positive emotional events during the play with humanoid and non-humanoid robots can unlock unexpected potential skills in children with Special Educational Needs (SEN), quickly and automatically capture attention and facilitate perceptual process. Our results are consistent with those shown in the literature, for example authors in [7] prove that emotions facilitate language learning. However, our past results from [6] revealed that children with SEN face difficulties in guessing others' emotions and paying attention to own or other people's feelings. That is why they cannot handle simplest social situations and an early intervention for formation of emotional knowledge and memory through experience is critical, and what is more practice is very important. Some explanations from behavioral studies about the abilities for emotion and face recognition in individuals with autism [8], [9] describe these impairments with deficiency in emotion processing or misinterpreting facial expression due to different brain activity in parietal, temporal and occipital regions in right hemisphere. Technologies can help in recognizing changes in emotions that a child is experiencing. They can be captured by external observation such as tracking of body postures and facial expressions, or physiologically. Novel approaches in emotion recognition include the use of information technologies and specifically the use of brain aware devices and Brain-Computer Interface (BCI) which bypass the conventional channels of communication (i.e. muscles) and to

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provide direct communication and control between the human brain and the physical devices. BCI translates different patterns of brain activity into commands in real time [10]. Recently, portable, non-invasive and affordable EEG commercial devices for “gaming” or “well-being sustainability” have emerged [11]. They record the brain activity and measure the change in brain pulse voltage by electrodes on the scalp. We use low resolution devices “EPOC” or “Insight” (Fig.1.) by EMOTIV bioinformatics company [12]. The EPOC/INSIGHT electrode locations (INSIGHT ones are discriminated by red circles) are shown on Fig.1.a according to the 10-20 international EEG system (Fig.1.b), recommended by the International Federation of Societies for Electro-encephalography and Clinical Neurophysiology [13]. Although both devices have low resolution and are with a few electrodes, they provide high-quality output neural signals [14]. If machine learning techniques are implemented in BCI, the emotions can be captured and recognized based on the spatial and temporal resolution of the neural activity. For instance, arousal and valence scores can be used for discriminating the current emotions. The current version of EMOTIV hardware and software offers three different kinds of detection algorithms, based on extensive scientific studies in order to develop accurate machine learning algorithms to classify and grade the intensity of different conditions. EMOTIV measures 6 different mental states (performance metrics) in real time: Excitement (Arousal), Interest (Valence), Stress (Frustration), Engagement/Boredom, Attention (Focus) and Meditation (Relaxation).

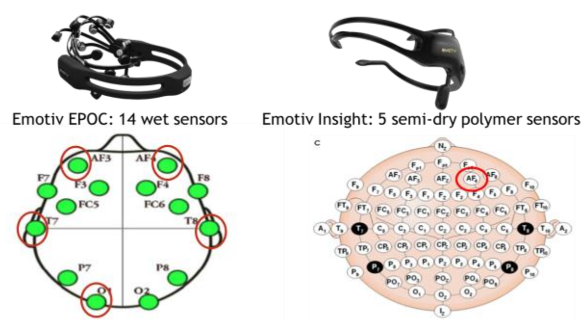


Fig. 1. EMOTIV BCI technologies and electrode locations according to the 10-20 international EEG system.

In the current study, we have developed a BCI to be used in daily life and out of laboratory environment for learning through play/art in a pedagogical scenarios mediated by socially assistive robots. BCI measures and features in real time the brain electrical activity in order to analyze the correlated attentional or emotional states of a child. It is used either for monitoring, or for attention and emotional training based on imitation or a neurofeedback. The robots are controlled by BCI and this integration of both technologies engages the children with SEN and reinforce their attentional or emotional responses. We explained this with the robot intervention which encourages exploration and play, and it is attractive for teaching daily living skills, organizing sensorimotor system and understanding social opportunities in communications. The knowledge can be gained by observation, however a deeper learning can occur when learners perform the actions themselves [15]. The mediation aspect of the robot is the core in social robotic studies [16] where the memory, emotion and learning are involved in Robotic Intervention Scenarios (RIS) [17]. Since the body is involved in the process of the “learning by experience”, the perceived stimuli are transformed into a more stable memory and cognitive representations because the notion of the body includes not only the body itself but also the senses, the mind and the brain [18].

Directed by the neuroscience implications how to strengthen the memory traces and neuronal excitation of the brain we include more modalities in RIS, such as touch, audio, 3D objects, movements and the emotional impact of the educational theater. It provides a safe environment to the children and uses creative tools to address critical problems in a bizarre way - very emotional, strange or unusual. In the frame of our current project for pedagogical rehabilitation in special education [19] the robotics researchers collaborate with the actors from the Educational Theater “Tsvete” [20]. The actors have long experience in puppet therapy [21] and that is why we have attempted to transfer the emotional and social talents of the actors into the world of robots in order to improve the pedagogical rehabilitation for children with SEN and to develop their emotional knowledge and memory by play-like activities mediated by social robots. An approach for tracking the actor behavior and transferring it to the emotion-expressive robot in order the latter to have similar to the actor’s qualities is presented in Section V.

Recently, the robots have appeared on the theater stages to educate and promote social changes in behaviors [22] and to evaluate their use in public and private settings by studding the interactions with care robots [23]. There is also a term “robot puppeteering” where one or several puppeteers control the head, arms and legs of a robot, such as Loren the Robot Butler in the movie “Teach me how to Dougie”. However, these results cannot be used for educational purposes because the puppeteers or human-robot interactions take place in the theater, unaffordable for repetitive needs of learning for children with SEN. To the best of our knowledge, we have marked a first step towards transferring the advantages of educational theater into the social robotics and augmenting a socially assistive robot with the emotional and social talent of an actor. Thus, we want to develop child-robot interactions that catch quickly the child attention and enhance the information perception during learning. We implemented in RIS the actors’ way for performing, understanding and responding to emotions in order the child to experience the emotion-generative process together with the robot and thus to develop the child’s episodic memory.

In the Gross ‘‘modal model’’ of emotion [1], the generation of emotions is a special sequential “situation-attention-appraisal-response” process which occurs over time. Any case of deficiencies in these stages requires emotional regulation strategies. Another and more intuitive emotional regulation is through neurofeedback – a biofeedback that uses real-time displays of brain activity (most commonly EEG). The neurofeedback rehabilitation is effective for training attention or emotion self-regulation of the brain function. An emotional experience can be processed as a healthy or unhealthy one. The emotional regulation strategies which we take into account are “cognitive reappraisal” involving healthy changing of an emotional response based on reinterpreting the meaning and assigning a non-emotional meaning to a situation [24]. Since we consider the training of the emotional experience by cognitive reappraisal is not sufficiently studied for children with SEN, thus we present our goal to implement the ‘‘modal model’’ of emotion [1] in the safe world of robots and our hypothesis to place the child’s neurofeedback in the play-like robotic interventions. For understanding the emotions experienced by the child and the level of attention, the play-like activities for controlling the robots are personalized according to the current child’s brain activity correlated to the attentional or emotional states, which are translated into input commands to the humanoid or non-humanoid robot. Thus, the robots express the attention or emotions of the child and this is helpful in the pedagogical rehabilitation, since children with SEN avoid direct eye contact or do not understand their own emotions. Thus, the correlated brain activity is tracking and copying on the programmable robots in order to assist special educators in monitoring the progress in skills learning. For understanding the child level of attention we monitor human eye movements based on EEG brain activity during blinking. There is a variation in the alpha waves of the EEG spectrum in the frontal and occipital lobes. The time of blinking and its rate can indicate how engaged people are with what they are looking at and how important this is for them [25]. Children with ASC blink differently than typically developing children. In [25] the researchers found that typically developing children blinked less before something emotionally was expected to happen because they anticipate it, while children with autism react to the physical event after it has already happened because they can’t anticipate it.

Since the research in the pedagogical rehabilitation is conducted according to a plan (a protocol), we designed two research protocols. They describe the procedures for conducting custom scenarios for robotic intervention by using a low resolution and portable brain-listening headset. The protocols consist of the procedures for conducting the experiments, i.e., what and how it will be done in the study. A protocol also describes the target groups, the length of the study, the materials and the related methods. The first protocol describes how to reinforce children to pay attention or learn emotional knowledge by imitation and the second protocol describes a game with the robots where the child learns about its own emotions based on a neurofeedback exposed on a robot. A special attention in this study is devoted to healthy emotional reactions of the children. The research protocols have been submitted to the Ethics Committee for Scientific Research (ECSR) to the Institute of Robotics of Bulgarian Academy of Sciences (IR-BAS) for approving that emotional reactions are helpful and they happen in the right situations. Some of our experimental sessions, based on emotional situations proposed in [26] and adapted by us for using in the world of robots, can be seen in Section III (Fig.2. and Fig.3). The feeling of satisfaction and enjoyment learned from the emotional lesson is checked at the end of the session. The ECSR criteria for banning a child to participate in the experimental session are presented in details in Section V. These protocols have been approved from the ethic committee of IR-BAS and can be tested by other researchers. We propose an additional research protocol describing how the emotional talent of an actor in expressing emotions can be tracked by external (inertial data) or physiological (neural data) observations, respectively, and recorded.

In the proposed robotic intervention scenarios, an innovative BCI-Robot framework containing EMOTIV brain headset for tracking, processing and translating motion or EEG data into robot commands has been developed. A new designed BCI-Robot framework is used to transmit online and wirelessly commands to the robot sensors, modules and controllers. Three types of BCI-robot software frameworks are instantiated: (1) EMOTIV-NAO software framework translating the correlated brain signals in time to NAO eye sensor commands in scenarios for assessing child concentration and attention, (2) EMOTIV-BigFoot software framework, where the score for joint attention of a child is translated into commands to control the movement of the non-humanoid robot BigFoot for training in real time, (3) EMOTIV-EmoSan software framework, where the emotions experienced by the child switch the corresponding robot intervention scenarios for cognitive reappraisal. A different BCI software framework for motion capturing is proposed and the corresponding algorithms for transferring the head and eye movements of the actor to the robot are presented. In the present study we prove that emotion-expressive robot fulfils the motions of the actor’s head.

The paper is organized as follows: Section II presents related works about neuroscience implications for pedagogical rehabilitation and the assistive technologies used. Section III presents the research protocols for reinforcing the attention and emotional knowledge of children with SEN with examples for robotic intervention scenarios. Section IV presents three applications of the BCI-Robot wireless framework containing an EMOTIV brain headset, as well as the BCI software framework for motion capturing correlated with the head movements exposed on the EmoSan robot. The approach for tracking the actor behavior and transferring it to control system of the emotion-expressive robot, as well as the results based on data from two actors, are discussed in Section V. Conclusion follows.

II. Related Works

A. Neuroscience implications for learning, memory, cognition and behavior

At the end of the eighteenth century Franz Joseph Gall, a German physician and neuroanatomist brought together biological and psychological concepts in the study of human behavior [27]. He proposed the radical new ideas that all behavior originated from the brain, that different parts of the brain control specific aspects of our behavior and that the center for each mental function grew with use, such as a muscle bulks up with exercise. Scientists assume, in the words of neuroscientist Marvin Minsky [28] (p. 287) that “the mind is what the brain does” and if we want to understand the mind, we should look to neuroscience and the brain for the real answers. Minsky [28] also writes on p. 163 that “our culture wrongly teaches us that thoughts and feelings lie in almost separate worlds. In fact, they are always intertwined. And really, there are actions in the mind with which we set up thoughts and fantasies that move our own emotions, arousing hopes and fears through self-directed offers, bribes, and even threat”. The last proves that there are schemes for self-control, stimulating acts and thoughts that directly change the brain's chemical environment. Minsky proposes to regard emotions not as separate from thoughts in general, but as varieties or types of thoughts, each based on a different brain-machine that specializes in some particular domain of cognition. Emotions are universal and cannot be felt without thought, however reasoning processes engage cortical regions of the brain, while brain structures linked to emotions are often subcortical, such as the amygdala, ventral striatum, and hypothalamus.

The emotional reaction is usually caused by our thoughts (Fig. 2), however it can be triggered unconsciously (Fig.5.) without understanding why it is happening [26]. For example, the fear evolves to protect ourselves and the control relies on controlling/changing our thoughts by coping statements or by asking whether the threat is true or unreal. Emotions are affected by culture, too. According to many theories, like cultural syndrome [29], culture allocates attention to inner feelings and thoughts very differently. Cultural contexts encourage or suppress emotional expression.

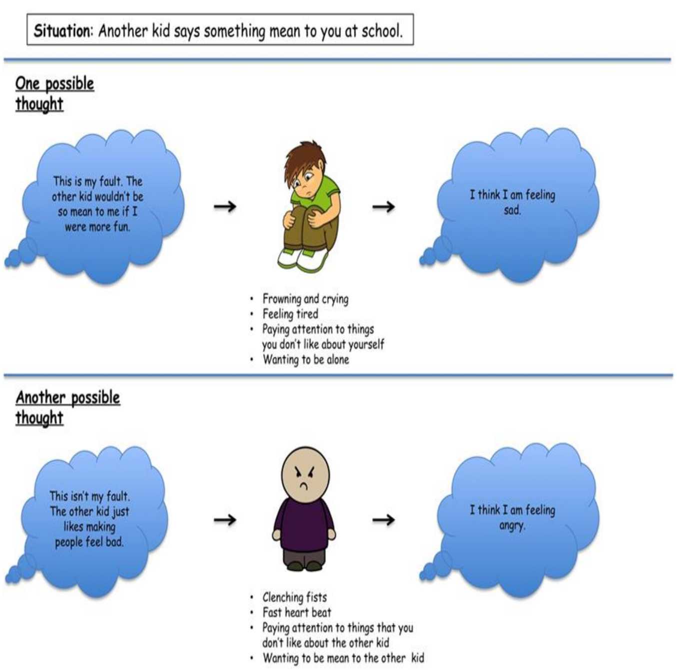


Fig. 2. A person can have different thoughts about the same situation (adapted from Fig.1 in [26])

In [30] the researchers evaluate the brain activations which are associated with the application of two different emotional regulation strategies - cognitive reappraisal and expressive suppression. An EEG device “Emotiv EPOC” is used to measure the brain electrical activity of the participants during a session of inducing sadness in a virtual reality environment. In the control group, authors found significant activations in several right frontal regions that were related to the induction of negative emotions. For the group practicing emotional regulation strategies, they found significant activations in the limbic, occipital, and parietal regions. A survey with similar results obtained through clinical neuroimaging systems, which is consistent with the findings for brain activation associated with regulation of emotions is presented in [30]. To summarize, the neural structures involved in emotional processing form two systems - a ventral emotion system and a dorsal emotion system. They have a role in the decrease of negative emotions and form a complex network that is responsible for processing responses to emotional events involving the ventromedial prefrontal cortex, the dorsolateral prefrontal cortex, the orbitofrontal cortex, amygdala, insula, hippocampus, and cingulate cortex.

By education we enhance learning and neuroscience explains the mental processes involved in the development, plasticity, learning, memory, cognition and behavior [31]. Future educational practice should be transformed taking into account some of the key insights from neuroscience [32]: (1) Learning outcomes are not solely determined by the environment but biologically, i.e. biological factors play an important role in accounting for differences in learning ability between individuals, (2) Understanding of specific learning difficulties (e.g. dyslexia) and uncovering why certain types of learning are more rewarding than others, (3) The brain changes constantly as a result of learning, and remains ‘plastic’ throughout life, (4) Self-control in acquisition of knowledge and mastery benefit future learning and the neuroscience has a key role in investigating the means of enhancing the brain power by neurofeedback, (5) Some insights from the neuroscience are relevant for the development and use of adaptive digital technologies that have the potential to create more learning opportunities inside and outside the classroom.

The learning is structural changes in the brain and the key of these changes is the neuroplasticity. Neuroplasticity can be defined as the ability of the nervous system to respond to intrinsic or extrinsic stimuli by reorganizing its structure, function and connections [33]. Learning means that one has created a strong enough memory trace to keep it and adding more modalities, such as touch, audio, manipulation of 3D objects and movements in robotic intervention might strengthen the memory traces of the learners. This helps neurologically the Emotion and Attention systems in the brain to interact, resulting in emotional association of information from short-term memory to long-term memory. A neuroscience explanation for this is that the amygdala and prefrontal cortex cooperate with the medial temporal lobe in an integrated manner that affords (1) the amygdala modulating memory association; (2) the prefrontal cortex mediating memory encoding and formation; and (3) the hippocampus for successful learning and long-term memory retention [2]. Thus, emotions could be used for modulating the selectivity of attention, as well as motivating action and behavior. More understanding how the cognition and emotion are effectively integrated in the brain, how emotions enhance perception and attention, and anatomical basis for cognitive-emotional interactions can be seen in [4]. A new explanation as to how emotional events easily capture our attention is given in [5], i.e., as a novel pathway formed from the amygdala, the brain's emotional center, and the thalamic reticular nucleus, a key node in the brain's attentional network in the upper surface of temporal lobe. This amygdalar pathway formed unusual synapses with more large and efficient terminals than pathways from the orbitofrontal cortex.

Recent studies report the role of amygdala–frontal connectivity during regulation of emotions [30], [34]. Successful control of affect depends on the capacity to modulate negative emotional responses through the use of cognitive strategies, such as cognitive reappraisal. These strategies involve frontal cortical regions in the modulation of amygdala reactivity. The authors in [34] use psychophysiological interaction analyses of functional magnetic resonance imaging data and show that brain activity in specific areas of the frontal cortex (dorsolateral, dorsal medial, anterior cingulate, orbital) covariates with amygdala activity and this limbic-frontal circuitry is important for the regulation of emotions.

B. Assistive technologies for pedagogical rehabilitation

We have chosen to use the EMOTIV EEG brain tracking device [12] because the Emotiv technology allows to detect the facial expression, current cognitive and mental states, and periodic brain rhythms using the row EEG data stream. Inertial sensors are mounted in the headset and provide motion data streams. Four simple periodic rhythms recorded in the EEG are identified by frequency (Hz) and amplitude – *theta, alpha, beta* and *gamma*. EMOTIV EPOC (Fig.1.a) has 14 EEG sensors. Eight of them are positioned around the frontal and prefrontal lobes and they pick up signals from facial muscles and the eyes. The sensors induce noise in EEG signals and most EEG systems filtered or ignored artefacts when interpreting the brain signals. The EMOTIV detection system also filters these signals out, however, it also uses these signals to classify which muscle groups are responsible for the artifacts. Thus, the so-called "smart artifacts" induced in pure EEG signals are diverted and classified to map the activation in different muscle groups and eye movement into events that are used for detecting the facial expression and blinking [35].

The accuracy of EMOTIV has been validated by several independent studies presented in [12]. In one of the studies [14] the authors compare EPOC to a research-grade Neuroscan system and conclude that an adapted EPOC system can produce valid auditory Event Related Potentials (ERPs) in children. It is important to adapt the EPOC system since passive auditory ERPs have been proved useful for considering auditory and visual processing in attention deficit hyperactivity disorder (ADHD) and specific language impairments. Thus these authors encouraged us to use EMOTIV EEG devices out of laboratory environment. Another conclusion from [14] states that the children have "noisier" EEG (and ERP) responses, contaminated to a greater degree by electrical noise generated by movement and resulted in artefacts in EEG signals. According to authors [14], the reason for this is that the children have difficulties in keeping still during the long test sessions and the laboratory EEG settings are intimidating for them.

Systems with BCI feedback for rehabilitation have been reported to be effective for training attention's self-regulation in children with Attention Deficit Hyperactivity Disorder (ADHD) [36], [37] or for neurofeedback training and speech therapy in order to enhance learning and speech ability in patients with a diagnosis of ASC [38]. ADHD affects approximately 10% of children in the world and conventional therapy (including medications, psychotherapy, behavior therapy, training, etc.) and health coverage systems for ADHD is insufficient. Novel approaches in attention training include the use of information technologies and specifically the use of biofeedback treatments as effective for training the attention's self-regulation in children with ADHD. The neurofeedback relays on the neurophysiological self-regulation skills and provides visual feedback to the users about their performances in specific cognitive tasks. The EEG based systems try to train the individual to a particular profile of EEG, not individualized but based on group dynamics [38], [39], [40], [41] and [42]. For example, the study [38] examines neurofeedback training and speech therapy in order to enhance learning and speech ability in patients with a diagnosis of autism spectrum disorder. A single case pre- and post-intervention study is adopted. The training incorporates video feedback in order to increase the 4-7Hz band (using arousal protocol) on T4-P4 (electrodes' location can be seen in Fig.1.). The results of the formal interview, EEG and self-reports show significant reduction in signs and symptoms, and enhancement in performance [38].

Nowadays, the brain-controlled mobile robots have received a great deal of attention because they can improve the quality of life [10]. The scientific implication of robotic intervention scenarios aims at understanding the thoughts and facial expression by a child during the process of experiencing of emotions. There are a lot of training and evaluating classifiers in the literature designed for the task of detecting the emotional state of a person by observation of her/his EEG data. Machine learning techniques in [43] are used to classify emotional states in high/low arousal and positive/negative valence (Fig.3). Since EMOTIV currently measures 6 different cognitive states in real time and two of them are Excitement (Arousal) and Interest (Valence), emotions can be mapped out on a chart (Fig.3.) modeling the range of arousal (high to low) and valence (pleasure to displeasure) that is experienced during a particular emotion. Authors monitor EEG signals in four locations in the prefrontal cortex: AF3, AF4, F3 and F4 according to 10-20 international EEG system [13]. Beta waves are associated with an alert or excited state of mind, whereas dominant alpha activity is associated with brain inactivation. Consequently, the beta/alpha ratio is a reasonable indicator of the arousal state of a person, while the valence in [43] is estimated by computing and comparing the alpha power a and beta power b in channels F3 and F4, given in (1).

$$valence = a_{F4}/b_{F4} - a_{F3}/b_{F3} \quad (1)$$

Other EEG features about emotions detection can be found in [44], [45] and [46]. In [46] human emotions are accessed by simultaneous recording of EEG and Eye-Tracker devices.

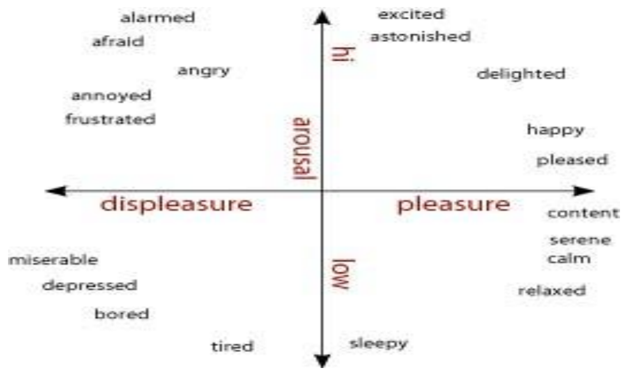


Fig. 3. Valence–arousal circumplex chart (adapted from Wikipedia)

The scientific implication of our experiments to transfer the techniques for learning through art in RIS will be to promote brain plasticity from stimuli based on sensorimotor modalities that actors use but in a low-priced way. Our findings are consistent with the results from the European Project CREATIONS [18] which suggest that embodied learning may lead to learning outcomes of a higher quality after interdisciplinary connection of science with different forms of Art. The project data were collected from thirteen theatrical performances which were organized by secondary school students (500 subjects). However, the educational theater is an expensive therapy because the effective learning needs doses of practice over time according to the neuroscience. This is the reason why we have asked the actors from theater "Tsvete" to record their own expressions of emotions in different interactive robotic scenarios for emotional regulation because a theatric interactive robotic scenario is difficult to be designed by the robotic scientists.

III. Materials and Methods

A. Hypothesis and relevance of the materials and methods

Our hypothesis consists of the following: 1) Feeling, understanding and expressing emotions are enhanced in the robotic vs human special educator conditions because the robotic intervention engages and encourages the exploration and play; 2) Theater techniques for expressing emotions with exaggerated mood induction, narrating by theatrical intonation and using more movements in showing emotions will reinforce the attention and learning; 3) Brain neuroplasticity and neuronal excitation of children with SEN will be increased based on practicing daily life behaviors mediated by socially assistive robots and integrated with BCI in order to track the correlated attention and emotional state of the child; 4) A neural proof that robots reduce the stress in the children during play-like activities because they are their friends not teachers; 5) The assistive technologies support special educator in a non-intrusive learning assessment in an entertaining and playful environment by systematic measuring technique, based on quantitative measures; 6) The pedagogical rehabilitation needs time and it is repetitive, therefore if the artistic talents of the actors are transferred on robots these limitations could be overcame.

Materials: Assistive robots: humanoid robot NAO [47], non-humanoid robot BigFoot [48] and emotion-expressive robot EmoSan [49]. The NAO robot is especially designed to not scare the kids. Our past and current projects have proven this for children with SEN more than 3 years old. The children like also the non-humanoid robot BigFoot very much because it has fun movements. The intelligent sensors used for assessing the personal behavior are: MS Kinect sensor [50] and EEG-based brain-aware headset – EMOTIV [12]. This headset is harmless wearable device complying with the requirements of the Low Voltage Directive 2006/95/EC, the EMC Directive 2004/108/EC, the R&TTE Directive 1999/5/EC, and carries the CE and C-Tick marks accordingly.

Participants: 5-14 years old children of both genders.

Recruitment of participants: Recommended by a pedagogue. The individuals in all groups had previously been diagnosed by a licensed clinical psychologist or doctor.

B. Methods

The experimental conditions for testing the proposed robotic intervention scenarios are described in details in the research protocols. Here we present the developed BCI-robot software frameworks and the research solutions: (1) How to use the commercially available EEG portable EMOTIV headset with few electrodes for assessment of child attentional and emotional states in daily life; (2) How to integrate BCI with programmable robots in order to assist therapists in child eye-tracking; (3) A new acquisition protocol for detecting eye blinking based on neural oscillations in only two frequency ranges is designed and the acquisition of neural data is robust to drying up of EEG electrodes or head movement; (4) A BCI framework for emotion capturing and facial expression and analysis in real time is designed (Fig.8), (5); A new acquisition protocol for emotional robot-driven interaction based on EMOTIV mental and cognitive detection is designed; (6) A robot capable of imitating the movements of the human head is designed; (7) Tracking and transferring head movements expressing emotions from an actor to a robot is performed; (8) A BCI-robot software framework for self-regulatory training of attention and emotional skills via neurofeedback exposed on the emotion-expressive robot is designed (Fig.6).

To make the assessment more consistent and safer, the children attention and engagement is monitored by external or internal observation of head and hand pose changes in time through a computer vision-based approach or by inertial sensors. Head and hand poses are key elements of human behavior analysis. Many techniques for computing head poses have been reported and the advantages of depth image irrelevant to light, rotation angle and scale can be exploited. The

MS Kinect sensor we use for recording the changes in pose is external to the child since the wearable sensors require careful calibration and may cause discomfort for the child.

In preparing the intervention scenarios we have been directed by the good skills presented in [24] and [26] which describe how to distinguish the helpful emotions and how to practice "cognitive reappraisal". We transfer these intervention scenarios in the safe world of robots and our modification of Fig.2 is shown in Fig. 4. When the emotion is helpful the robot listens to what it is telling to do. When an emotion is unhelpful then there are some good skills that a child has to learn and practice in the scenario. The robot changes its own thought after a "cognitive reappraisal" and the child practices this change correspondingly by imitation. For instance, if the robot feels angry or sad and the emotion is not helpful then different activity or exercising, such as gymnastics, dancing, etc., can help. When the emotion "fear" is unhelpful in the current situation (Fig.5), another useful skill to be practiced is "approaching your fear accompanied by Robi – a friend".

Experimental conditions: The children participate solely (in individual sessions and in 5-6 minutes per game). During the session Robi plays 5 games with the child designed for understanding the Shapes, Emotions, Shopping, Transport, Body Sounds/ Acoustics. Data analysis concerns brain activity correlated with eye blinking and its rate index, and shoes how engaged child is, what is looking at and how important this is for it. During the game for "playing with robots through emotions" Robi searches and shows pillows which correspond to the emotion experienced by the child. At the same time, the emotion-expressive robot EmoSan imitates the emotion in order to show it to the child. The child is able to control the BigFoot robot by head nodding/shaking in guessing what emotion Robi understands and EmoSan experiences, respectively. Then, the EmoSan robot is controlled via neurofeedback until the child feels the right emotion. The child neurofeedback is always exposed on the humanoid or non-humanoid robots under the supervision of the special educator. Thus, the child can pay attention to its own emotions and through the mediated robot can understand what he/she feels and how responds. The educational theater "Tsvete" respects the European culture, where the expression of emotions is encouraged. This directed our RIS towards learning from practice to handle situations when a child or a robot feels happy, sad, scared or angry.

In the game for "playing with robots through emotions" a child can learn emotional knowledge by imitation or by neurofeedback (Fig. 8.). The play enhances the learning of emotions because they are neural inputs to control of the play scenarios and thus reinforces attentional or joyful emotional responses of the child. The play also facilitates the assessment of emotional state and cognitive processing of a child by the special educators. In the Emotive Control Panel the therapist may monitor the Performance Metrics tab containing two graphs, which can be customized to display different combinations of emotional states and time scales. By default, the top chart is configured to plot 30 seconds of data for the Engagement, Frustration, and Instantaneous Excitement detections. The bottom chart default is a display of 5 minutes data length for the Long-Term Excitement detection. The plotted values are the output scores returned by the Performance Metrics detections.

Possible emotional situations and reactions in the world of robots are illustrated in Fig. 4. The special educator explains how the child should change its emotional response and by monitoring the child's behavior physiologically- or by a vision-based sensor she/he can assess the progress in reinterpreting the meaning of the situation. The child observes a situation with the three robots which may cause different thoughts and emotional reactions. Based on the emotion experienced by the child, which is tracked by BCI, the interactive scenario is adapted in order to personalize his/her attention or emotional knowledge. For example, the EmoSan robot can have different thoughts about the same situation which leads to different kinds of changes in: 1) what the face and head do; 2) what it pays attention to and thinks about; and 3) how EmoSan wants to act. If EmoSan gets angry when Robi does something mean to it (the bottom part of Fig. 4.), the anger can inform Robi not to be mean anymore. If Robi and BigFoot notice that EmoSan is sad without friends, the sadness can help them to see that EmoSan needs their love and support. However, sometimes these identical emotions can be unhelpful if they happen in the wrong situations. Another example is as follows: if EmoSan gets angry with Robi because it has hurt EmoSan by accident. This might lead to deterioration of their friendship.

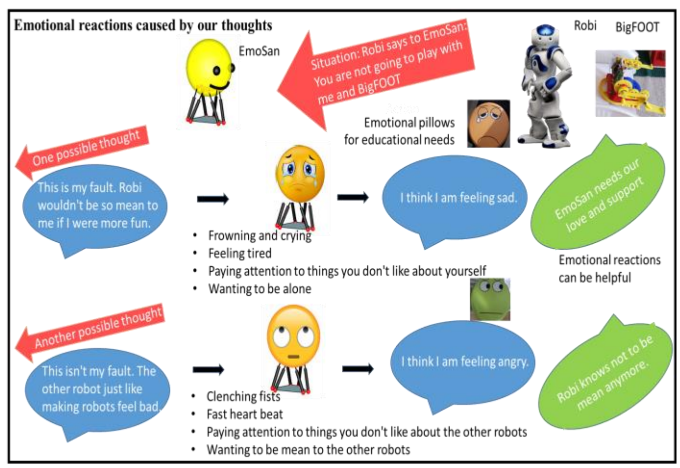


Fig. 4. A child can have different thoughts about the same situation. Different thoughts can then lead to different kinds of changes in body, attention and action. (Figure is adapted from [26] to the world of robots)

The technologies used during the experiments (sensors, interfaces and robots) help the special educator to monitor and record the children emotions in quantities measures. For more consistent assessment we use Microsoft Kinect sensor for extracting 3D poses by external observations from an image sequence integrating RGB and depth information. Thus, the special educators can monitor the sessions online and can be prompted in assessing specific behavior based on the head and hand pose changes. These data could be later analyzed offline in order to prove whether the games mediated by humanoid and non-humanoid robots enhance attention and emotional skills of children with SEN. An additional approach, which helps special educator to evaluate the child's concentration and emotional engagement in real time, is the usage of the led sensors in the eyes of the Robi robot. The robot blinking duplicates the child's blinking by one of the BCI-robot frameworks - EMOTIV-NAO Software Framework.

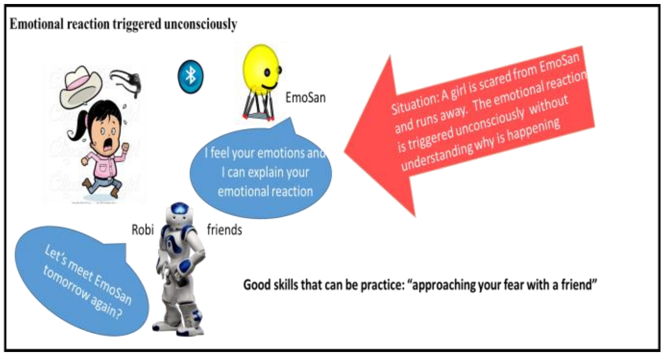


Fig. 5. A child has an emotional reaction triggered unconsciously

IV. BCI-Robot Software Frameworks

Three types of BCI-Robot wireless framework for training or assessment (Fig.6.) in the pedagogical rehabilitation of children with SEN have been developed and deployed on the three robots: 1) EMOTIV-NAO Software Framework (ENSF) translates the correlated brain signals in time to NAO eye sensor commands in scenarios for assessing child concentration and attention; 2) EMOTIV-BigFoot software framework (EBSF), where the child head motion is translated into commands to control the movement of the non-humanoid robot BigFoot in real time for training child's attention on a specific emotion; 3) EMOTIV-EmoSan software framework (EESF), where the child's current emotion directs the corresponding scenarios for cognitive reappraisal. A BCI software framework for human motion capturing during expressing of emotions is proposed at the end of this section.

We have designed, developed and deployed our own scenarios on humanoid robot NAO for training of listening, understanding and speaking skills of children with communicational disorders in a playful learning environment for orientation in space, shapes, colors and emotions. In order to understand the current child emotions and the level of attention, the child's brain activity is translated into commands to humanoid robot Robi and to non-humanoid robot EmoSan. ENSF translates the correlated brain signals in time to robot eye sensor commands. In the EBSF the child head motion is translated into commands to control the movement of the non-humanoid robots BigFoot. By ENSF and EESF the child can understand its own emotion by imitation and usage of toys that are familiar to the child. For instance, Robi shows to the child commercially available emotional pillows, or EmoSan nods/plays the current child's emotion.

The "Insight" or "EPOC" headsets (Fig.1) used in the framework has 5, respectively 14 wireless channels, which record human brainwaves with 128 or 250 samples/sec per channel, resolution: 14 bits with 1 LSB = 0.51μV, frequency response: 0.5-43Hz. Digital notch filters at 50Hz and 60Hz are built-in. Then, we pre-process EEG signals by using 4th order Butterworth high pass filter with cut-off 4Hz and by FFT transformation we extract the different brain rhythms (δ, θ, α, β, γ). Artefacts in EEG signals arising from head movements are categorized by automatically detecting their presence through inspection of the gyroscope waveforms. The artefacts in EEG signals coming from the head movement are removed using the measurements of the EMOTIV gyroscope sensor. The gyroscope channels, capturing the *X, Y* head-movements, provide two gyroscope signals for the lateral and vertical rotation around the neck and axis passing through ears. Each 0.5ms we put trigger markers in the EEG recordings and we base our analysis on the imported short epochs. Any epoch with contamination excessing an experimentally defined threshold is excluded (Fig.7.a).

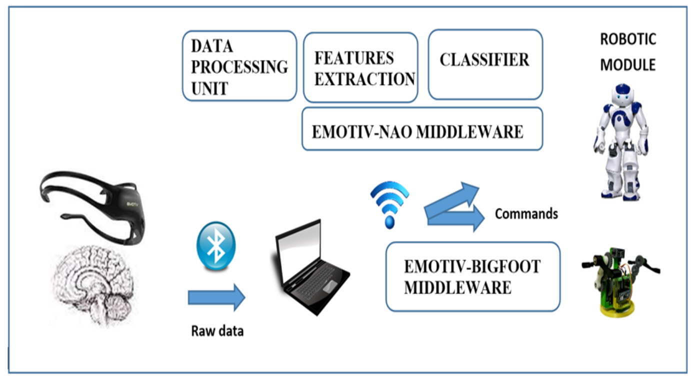
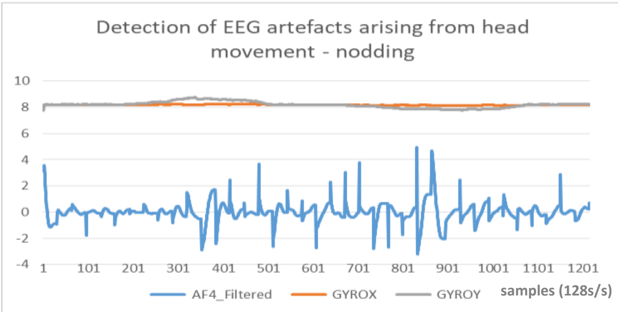


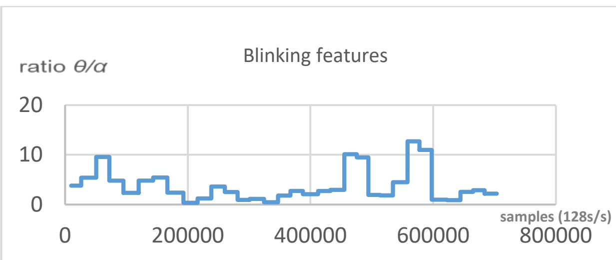
Fig. 6. BCI-Robot wireless framework for training or assessment

A. *Brain activity correlated with eye blinking exposed on the NAO robot*

The EMOTIV-NAO Software Framework translates the correlated brain signals in time to robot commands for changing led sensors mounted in the eyes. A new acquisition protocol, describing how to extract brain activity correlated with blinking, is experimented and appreciated by the therapists as a useful monitoring tool for the engagement (attentional or emotional) of the child. The different frequency bands are individually analyzed and combined together. In order to control the NAO led sensors, we analyze manly the electrodes on the forehead AF3 and AF4 where the BCI is robust to electrode drying up. Thus, we imitate the blinking on NAO in time via wireless interface. All 5 electrodes are used when we detect performance metrics in order to reprogram the robot to adapt the attentional or emotional play scenarios for the current child. Children without autism seem to be able to anticipate what is coming next based on facial expressions, body language and wordplay. Things are different for children with autism. Without understanding the social context in which actions happen, children with autism may often be reacting, after the fact, to physical events that have already happened" [25]. The ENSF provides a way to monitor the attention and emotional engagement by measuring blinking on the NAO's eyes because children with autism avoid eye contact and measuring it on NAO assists the special educator remotely to evaluate this indicator.



a) Analyzing physical and physiological signals in detecting artefacts



b) Blinking features - ratio $\theta_{AF4}/\alpha_{AF4}$

Fig. 7. Blinking activity at the right hemisphere

The proposed new acquisition protocol for blinking detection extracts averaged signals in θ and α and evaluates output score - a ratio between their powers in time as a classification for close or open state. We have found the AF4 electrode at the right side of the forehead as most promising, marked with a red circle in Fig.1.b. After extracting the eye-blinking features for *open_state* and *close_state* (2) we experimentally defined the value of threshold *Thr* to 5. The θ and α power of blinking activity at AF4 is shown in Fig. 6.b. This figure shows that both θ and α powers increase, however the θ power increases slightly faster than α at the moment of blinking and it is significantly higher. The ratio gets bigger at the moment when the person blinks.

$$open\_state \quad if \;\; Ratio = \theta_{AF4}/\alpha_{AF4} < Thr \qquad (2)$$

Then, the current state and its duration is mapped to eye blinking parameters in ALLeds Python module in order to control NAO's eye-LEDs on the robot. The protocol has been experimentally tested and it has proved to be feasible and not require a training phase. The eye blinking is translated in real time using Python scripts in order to control the intensity of the NAO's eye-sensors.

B. Brain activity correlated with emotions exposed on the Robi, EmoSan and BigFoot robots

The newly designed emotional robot-driven interaction protocol is based on EMOTIV SDK mental and cognitive detections. Six different emotional and sub-conscious dimensions are measured in real time [35] – Excitement (Arousal), Interest (Valence), Stress (Frustration), Engagement/Boredom, Attention (Focus) and Meditation (Relaxation). In the designed play these performance metrics control Robi in recognizing and bringing the emotional pillows in the room that corresponds to current emotional state of the child, who wears the EMOTIV headset (Fig.8). Handling the EMOTIV event *engine_PerformanceMetricEmoStateUpdated*, we map the raw scores for excitement, relaxation, stress and boredom to the corresponding "Naomark" (landmark) stuck on the emotional pillow. Then, Robi explains how it feels and asks the child to guess the emotion that Robi is experiencing. The child responses by head nodding for "No" or by head shaking for "Yes". If the answer is "No" BigFoot goes forward like a spider. Otherwise, it performs left or right funny rotations. In case of a wrong guess, EmoSan prompts the child by playing this emotion.

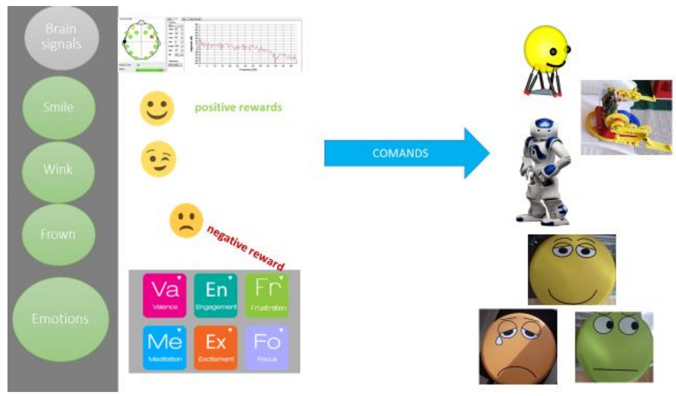


Fig. 8. Brain-robot game for learning emotional knowledge by imitation or by neurofeedback

In the designed ENSF, the performance metric scores for the current child emotional activity over time are the inputs to the NAO module to move the robot – *ALMotion*. The scores switch the NAO module for recognizing the corresponding landmark - *ALLandMarkDetection*. In the designed EESF, the EMOTIV performance metric scores correlated to the child emotions over time are the inputs to the EmoSan module in order to express the correlated emotion and drive the corresponding lesson for cognitive reappraisal. Monitoring the child behavior physiologically or by vision-based sensor can help in assessing how the child reinterprets the meaning of the situation and how it changes its own emotional responses. The emotional reactions presented in Fig.4. and Fig.5. involve changes in: 1) what your body does; 2) what you pay attention to and think about; and 3) how you want to act. It is important to pay attention to an emotional reaction you have experienced and try to figure out which emotion you feel and why in order to respond to it in healthier ways. The EMOTIV gyroscope measurements during the child head nodding or shaking are translated to robot commands and used as inputs to the BigFoot or EmoSan robot controllers. The captured human head motion is exposed on the EmoSan robot. The eyes and lips of the EmoSan robot are under development.

C. Motion capturing correlated with head movements exposed on the EmoSan robot

The BCI software framework for motion capturing has been designed, developed and tested. The artistic skills of the talented actors from the theater in expressing emotions have been utilized as their motions have been captured and recorded. The corresponding algorithms for transferring the head motions of the actor to the robot have been developed. The experimental conditions for testing the communication protocol based on the EMOTIV headset for tracking the movements of the actors begin with a calibration of the EMOTIV and Kinect sensors. During the session 3D coordinates of head and neck are extracted to label the Emotiv row data. Then the actor starts playing a sequence of head and face postures for 6 emotions: fear, joy, surprise, sadness, disgust and anger. Here, the goal is to transfer these motions to a socially assistive robot. We consider the technical and artistic challenges of tracking and translating movements expressing emotions from an actor to a robot in order to stimulate the attention and establish emotional contact with a child. For this reason, we propose a software framework for motion capturing and transferring the movements of an actor head to a robot. The technical challenge was what kind of motion-tracking device to be used and how the robot to be designed in order to be capable of imitating the movements of the human head to a great extent. In this study we use the 9-axis inertial motion sensor (3-axis gyroscope, 3-axis accelerometer, 3-axis magnetometer) embedded in the Emotiv brainwave headset. The sensors' output signals (with resolution 64 samples per second) are tracked, recorded and analyzed online by a custom Emotiv SDK application. These signals are processed and transferred to an emotion-expressive robot head dubbed EmoSan, which we have designed and developed. The movements of this robot are realized by a parallel kind of mechanism based on the Gough-Stewart platform (Fig.9). It has 6 degrees of freedom and it was proven to fulfil the motions of the human head [49]. The robot motion capabilities are revealed through the analysis of the workspace, which is graphically illustrated in [49].

V. Results and Discussion

The designed robotic intervention scenarios are based on a continuous feedback from the special educators in the Day Care Center for Children with Disabilities "Zdravets" situated in the town of Bansko. We integrated several assistive innovative technologies in the work practice of the special educators for reinforcing the learning, such as intelligent sensors, robots and brain aware devices. Our research findings are based on the pilot experiments. The practitioners found that the BCI-NAO software framework for exposing on the NAO robot the brain activity correlated with the child's eye blinking is very useful for the assessment of the child's activity. The director of the center asked for more support in developing a very simple play where the child can understand its own emotion by imitation. We have discussed the possibilities and this has resulted in the proposed brain-robot game for "playing with robots through emotions" where NAO mimics the emotions by toys that are familiar for the children in "Zdravets", such as "emotional pillows". They are used by NAO to interact with the child in assistance with the non-humanoid robots EmoSan and BigFoot according to the research protocols described in Section III. The developed games for "orientation in space, shapes and colors"; "emotional reactions in the world of robots" and "playing with robots through emotions" comply with several criteria for ceasing the participation of a child with SEN in the experimental session. They are as follows: 1) if a child is reluctant to participate, the parent can decide to withdraw his/her consent for the participation of the child during or after the data collection; 2) the play with robots could be ceased by the therapist; 3) the interaction between robots and children must be safe; 4) the child communicates with each robot in the presence of a teacher; 5) if the child is anxious, the activity will be terminated immediately

The research protocol for tracking and recording the movements of actors by the EMOTIV headset have been approved by the Ethics Committee for Scientific Research, too. According to the experimental conditions we have recorded the data from two actors - a female and a male. We have collected data for from 6 emotions performed by the two actors: fear, joy, surprise, sadness, disgust and anger. Each one was repeated 3 times with duration of 30 seconds. Because the EPOC resolution is 64 samples per second, we collected 36 files with about 1950 records in each one. After processing the data, we have proved that the sensors and interfaces used in the experimental sessions help to monitor, measure and analyze the actor's head and face movements for expressing emotions and these movements could be transferred to the robot actuators or eye and lip sensors.

In order to capture the motion of the human head the data from the 9-axis inertial motion sensor embedded in the Emotiv brainwave headset have been used. The algorithm for processing the raw data from the inertial sensor is beyond the scope of this study and will be presented in a further paper. The processed data give the orientation and position of the Emotiv headset (i.e. the human head) with respect to the earth coordinate system $\{O_e\}$ (Fig.9). The body coordinate system $\{O_b\}$ is attached to the Emotiv headset and it moves with the headset. The origin of the earth coordinate system $\{O_e\}$ is a fixed point on the ground and its axes are also fixed. At this stage we use the angular rate about the x, y and z axes of the sensor frame from the tri-axis gyroscope to obtain the orientation of the body frame, while the data from the tri-axis accelerometer are used to determine the displacement of frame $\{O_b\}$ starting from a known position.

The obtained orientation of the Emotiv headset is given by a 3x3 orientation matrix **R**. Then, any point (position vector) of the Emotiv headset (the human head, respectively) given in body coordinate system $\{O_b\}$ can be expressed in the earth coordinate system $\{O_e\}$ as follows

$$\mathbf{P}^e = \mathbf{R} \cdot \mathbf{p}^b + \mathbf{O}_e\mathbf{O}_b \ , \tag{3}$$

where $\mathbf{P}^e$ is a position vector of a point attached to the human head (Emotiv headset) expressed in the earth coordinate system $\{O_e\}$; $\mathbf{p}^b$ is the same point given in the body coordinate system $\{O_b\}$; $\mathbf{O}_e\mathbf{O}_b$ is the vector connecting the origins of the earth coordinate system $\{O_e\}$ and body coordinate system $\{O_b\}$.

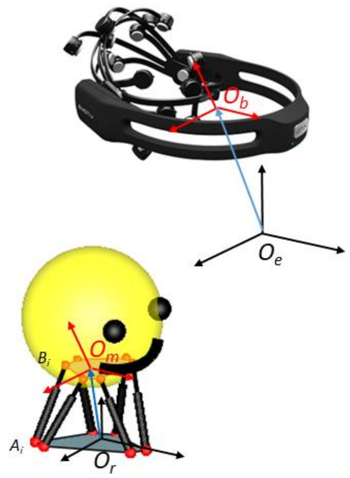


Fig. 9. Schematic arrangement of the coordinate systems of the Emotiv brainwave headset and the robot

Thus, we can trace the orientations of the human head and the positions of a point from the head with respect to the earth coordinate system {O_e} during the motion. The next step is to transfer the path (set of positions) and set of orientations to the robot, i.e., to establish a robot control algorithm. The dimensions of EmoSan robot are similar to the size of the human head and neck. Then, without loss of generality, we could set the earth coordinate system {O_e} to coincide with the coordinate system {O_r}, the latter is attached to the base of the robot and it is fixed. Similarly, the coordinate system {O_m}, attached to the moving platform of the robot, coincides with the body coordinate system {O_b} of the Emotiv headset. The motion of the moving platform of the robot is realized by the length variation of the six legs which connect the two platforms (the base and the moving platforms) of the robot. In order to control the robot, the lengths of the six legs have to be obtained. At every given time moment, the orientation and the position of the moving platform correspond to a particular set of leg lengths. Since the orientation of the robot head should correspond to the orientation of the human head (Emotiv headset), the orientation matrix is the same as in eq. (3). The joints of the base and the moving platforms are arranged at points A_i and B_i, respectively (Fig. 8). We need to obtain the coordinates of points B_i with respect to the base coordinate system {O_r}, i.e,

$$\mathbf{B}_i^r = \mathbf{R} \cdot \mathbf{B}_i^m + \mathbf{O}_r\mathbf{O}_m , \qquad (4)$$

where $\mathbf{B}_i^m$ is a point (position vector) from the moving platform given in the coordinate system {O_m} and its coordinates are known from the robot design; $\mathbf{B}_i^r$ is the same point expressed in the base coordinate system {O_r}; $\mathbf{O}_r\mathbf{O}_m = \mathbf{O}_e\mathbf{O}_b$ is the vector connecting the origins of the coordinate system {O_r} and coordinate system {O_m} ($\mathbf{O}_r\mathbf{O}_m = \mathbf{O}_e\mathbf{O}_b$).

Then, the leg lengths are as follows:

$$L_i = \left\| \mathbf{B}_i - \mathbf{A}_i \right\|, \quad (i = 1..6) , \qquad (5)$$

where $\mathbf{B}_i = \mathbf{O}_r\mathbf{B}_i$ and $\mathbf{A}_i = \mathbf{O}_r\mathbf{A}_i$ are vectors expressed in the base coordinate system {O_r}.

Linear actuators (DC motors) are used to vary the lengths of the legs. Therefore, the control of these motors ensures that the desired lengths of the actuators are achieved which will correspond to the given position and orientation of the moving platform. Following this algorithm, the robot head will reproduce the captured motion of the human (actor) head.

In addition to the robot head motion, the transfer of the movements of face muscles to the EmoSan robot eyes and lips is to be performed and this task is still under development. Tracking facial expression is used to transfer the actor's emotional features on the robot. This is important, because children with autistic spectrum conditions (ASC) frequently misinterpreted happy faces as neutral faces, and confused neutral faces with negative facial expressions (sad and angry) [9]. During our past recordings, together with head motion we tracked the facial expression and emotional grades of an actor, provided by Emotiv technology. The three BCI-Robot software frameworks have been tested separately for their feasibility during pilot experiments with typically-developing children. They will be tested together and experiments with children with SEN will be conducted soon.

Conclusion

The main contributions of the proposed study are two research protocols for reinforcing the attention and emotional knowledge of children with SEN by means of robotic intervention scenarios, where an innovative BCI-Robot framework containing EMOTIV brain headset for tracking, processing and translating motion or EEG data into robot commands has been developed. The first protocol describes how to reinforce children to pay attention or learn emotional knowledge by imitation and the second protocol describes a game with the robots where the child learns about its own emotions based on a neurofeedback exposed on a robot. These protocols have been approved from the ethic committee of IR-BAS and can be tested by other researchers. We propose an additional research protocol describing how the emotional talent of an actor in expressing emotions can be tracked by external (inertial data) or physiological (neural data) observations, respectively, and recorded. An approach for tracking the actor behavior and transferring it to the emotion-expressive robot in order the latter to have similar to the actor's qualities is proposed. Data from two actors have been tracked, recorded, processed and transferred to the robot control system. Also, the developed interface could be applied for direct transfer of the human motion to the robot in online mode. We have proved experimentally that the proposed BCI-Robot framework is capable to mimic the human head motion and eye movement during the process of expressing emotions. The proposed software frameworks, connecting the EMOTIV BCI with the Python API (for NAO robot) or Arduino API (for BigFoot and EmoSan robots), are sufficiently general and can be used for different cognitive tasks and with other robots.

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https://www.researchgate.net/profile/Omar_Bouattane/contributions