Visual computing tool for training recognition and production of facial expressions by children with autism

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***Abstract*—Individuals with ASD can present limitations in several activities, including recognizing and producing emotions. This work presents a computational tool elaborated for training the recognition and production of facial expressions, developed based on a study about the state-of-the-art of the field. Besides the training activities, the tool collects and analyze data about the user during the activities. The usability of the tool was validated through experiments performed with autistic children, supervised by a multidisciplinary team. These experiments were recorded in both 2D and 3D videos, being the first database of this kind presented in the literature, from our best knowledge. The results show a tendency about the difference in recognizing positive and negative expressions.**

I. Introduction

Autism spectrum disorder (ASD) refers to a group of complex neurodevelopment disorders, characterized by a disruption in the fundamental processes of socialization, communication, and learning of the individual [1]. According to a recent paper published by the Centers for Disease Control and Prevention (CDC), the prevalence of the disorder was estimated to be one in forty-five children in the USA [2]. Matson and Kozlowski [3] and Hansen et al. [4] demonstrate that the number of diagnosed cases of autism has been growing in the latest years. They also argue that this growth is related to several factors, among them the changes in diagnostic criteria and the growing awareness of the general population about the disorder.

Among the limitations presented by individuals with autism, we can mention the difficulty in recognizing and producing facial expressions. Ekman and Friesen [5] suggests that the skills to recognize and produce emotions using the face are inherent in the human race. The emotions expressed through the face have an important role in communication and interaction between humans. Picard et al. [6] arguments that since the first months of life, infants already interact through facial expressions, using them as essential clues for communication.

Although autism does not have a cure [7], therapeutic approaches have been applied to overpass the limitations presented by those individuals, providing a higher quality of life and preventing the aggravation of the disorder [8]. Technological resources have been successfully explored in approaches for autistic individuals who are able to use computers, tablets, and similar devices [9], [10]. With the help of these technological resources, therapeutic initiatives have been developed to improve the characteristics where these individuals present limitations, including the assertiveness to recognize and produce facial expressions.

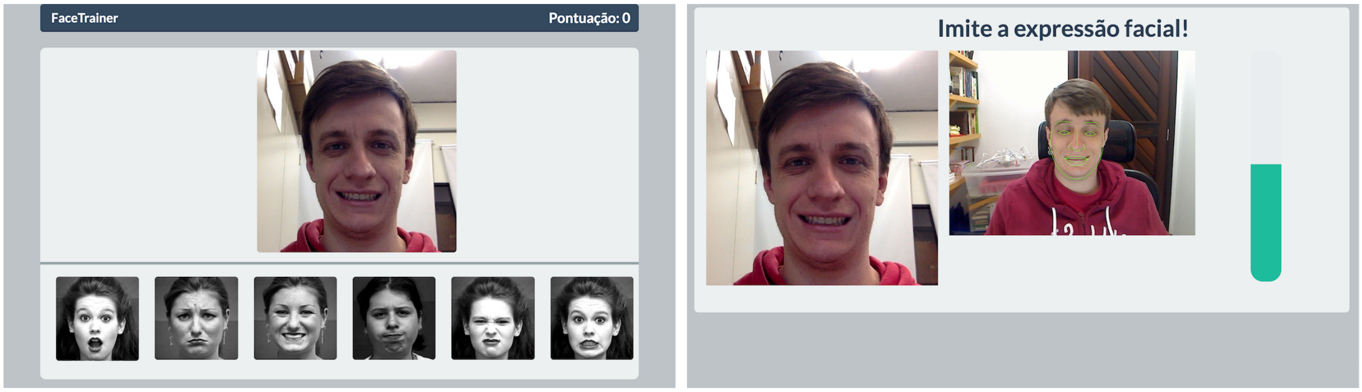
This article summarizes the work published in the dissertation[1] [11], which presents the development of a visual computing tool for training the recognition and production of facial expressions by individuals with autism. This paper is organized as follows: Section II presents a literature review of existing works in the area; Section III details the specification and design of the tool; Section IV explains the technological stack used; Section V describes the methodology defined for the usability experiment; Section VI discusses the results obtained. Finally, Section VII concludes with contributions and final remarks.

II. Literature Review

Several studies (e.g. [13]–[19]) proof that it is possible to train the abilities to recognize and produce facial expressions in individuals with autism using computer-based interventions. These interventions strengthen the association between the mental state and the facial expression, improving the formulation of the Theory of Mind [20]. Based on the motivation to investigate and catalog the state-of-the-art, a literature review on the subject was developed in Section 2 of the dissertation [11].

As the first step of the review, systematic searches were carried out for over two years, resulting in a total of twenty-one articles found describing computational tools with similar purpose. These twenty-one papers [15]–[17], [21]–[38] were evaluated under six criteria defined by the author: target audience; methodology for training facial expressions; form of

[1]M.Sc. Dissertation



(a) Example of facial expression recognition activity - Facial expression images obtained from [12]

(b) Example of facial expression production activity

Fig. 1. Screenshots of two training activities included in the developed tool

interaction with the tool; graphic interface; facial expressions and functionalities to evaluate the patient outcomes.

After the analysis of the articles based on the defined criteria, conclusions about the comparison were drawn. As for the target audience, it can be verified that most of the computational tools aim at level one autistic children, who have less difficulty to learn (compared to other levels of autism) and are at the best age to execute this type of training [39]. In the methodology for facial expression training, it was observed that the production of facial expressions was explored in recent work (e.g. [13], [15]), adding an extra exercise to train the skills related to facial expression.

On the criterion of graphical interfaces, it was shown their evolution over the years, including the fact that new tools use components that are friendly to autistics, such as caricatured images [40] and 3D graphics [36]. Evaluating the facial expressions used in the tools, it was noted that the six basic facial expressions defined by Ekman and their variation are the most used. Analyzing the functionalities for evaluating the patient outcomes, it was found that only one of the tools [32] has an interface for monitoring the patient's progress. Also, only two studies [21], [31] that record participants data (e.g. videos, audios, gaze tracking) for further evaluation of patient outcomes by healthcare professionals were found in the literature.

Based on the results of the review, improvements aiming the development of future tools were proposed in four of the six criteria evaluated during the comparison. These improvements were:

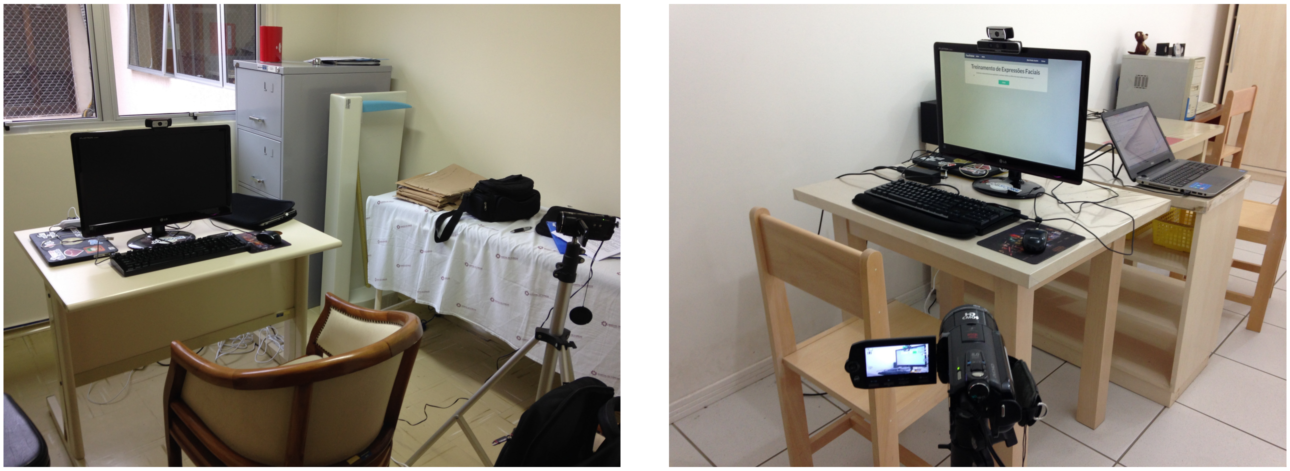
- Inclusion of new concepts discovered by the area of psychology in the context of facial expressions, such as compound facial expressions [41] and facial expressions tailored for the target audience;
- Inclusion of the production of facial expressions as part of the training, allowing the participant to train facial expressions by producing them on their face;
- Use of web technology, allowing portability and simplified access to the tool, as well as facilitating studies with participants from different geographic regions;
- Inclusion of functionalities to obtain and analyze data to evaluate the participant outcome. Among the data to be collected, we can cite correct and wrong answers given during activities, the video footage of participants during experiments and the gaze tracking while the participants evaluate facial expressions.

III. Proposal

To start the development of the visual computing tool, specification work was carried out in partnership with healthcare professionals from the two participants centers, Center for Neuropediatrics at the Clinical Hospital of UFPR (CENEP-HC) and the Association of Autistic Friends (AMA) of Jaraguá do Sul. The involvement of professionals from different areas aims at helping the exchange of expertise to define a specification that is best tailored for the target audience. To define the functionalities and interfaces to be implemented, software development best practices were considered, as well as the improvements pointed out by the literature review.

Grouping similar functionalities, the funcionalities of the tool can be divided into two modules: a) training module, where the user will perform the activities to practice their skills in the recognition and production of facial expressions; b) administration module, where the professional responsible for the application of the tool defines activities, levels, and analyzes reports based on data collected from activities.

The training module includes two types of activities: recognition and production of facial expressions, which are exemplified in Figure 1. In recognition of facial expressions, a multimedia content (e.g. image, audio, or video) associated with a facial expression is presented, along with six faces demonstrating each of the six basic facial expressions. The users must understand the content and recognize facial expression associated with it, and them choose the same facial expression in the images presented below. If he/she chooses the wrong answer, an error message is displayed, encouraging



(a) Experiment setup at CENEP (b) Experiment setup at AMA of Jaraguá do Sul

Fig. 2. Images of the experiment setup at the two participant centers

him to try again. Once the user chooses the correct facial expression, a congratulation message is displayed, and the next activity is presented.

In the activity of production of facial expressions, the users should produce facial expressions on their face. The interface of this activity consists of two frames: in the first, an image of a certain facial expression is displayed, while in the second one the live image of the user's camera is displayed. In the user's camera image, tracking points from facial features will overlaps their face if it is being tracked correctly. A thermometer is also presented on the right side, which grows when the algorithm recognizes that the facial expression produced is correct. If the algorithm recognizes the produced expression as correct, the activity is considered to be answered, and the user is redirected to the next activity.

In addition to the features for training the recognition and production of facial expressions, the tool provides an interface that allows healthcare professionals to monitor and evaluate the patient outcome in real time. The patient progress can be visualized individually, with all the performed activities (and their recorded data). Four types of data for each activity can be accessed using this interface: gaze tracking data, correct and wrong answers given (until finishing the activity), the time taken to resolve it, and the video (with audio) of the participant. The tool can also analyze and compile data extracted from a set of users, making possible to do statistical tests and comparison between results obtained from different participants.

IV. Technology

The tool was developed for the web platform, using JavaScript and HTML5 for building controls and user interaction. The server side code was written in Ruby, using the framework for web application development Ruby On Rails. To perform facial expressions recognition in real time, the clmtrackr[2] library was used. The library is open source, and its implementation is based on the work of Saragih et al. [42]. The library works by tracking face landmarks through constrained local models, which are adjusted using Regularized Landmark Mean-Shift.

When face landmarks are located, the library uses logistic regression to calculate the probability of the obtained landmarks to be similar to each of the six basic facial expressions. The facial expressions models were trained using the MUCT [43] database, which contains images of the six basic facial expressions on faces of varying age, gender, and illumination. Finally, the probability of the face found to present certain facial expression is returned. Gaze tracking was implemented using a Google Chrome extension developed by xLabs[3], which provides gaze tracking data on the browser using as input only a webcam image.

To record the participant while using the tool, the RecordRTC[4] library was used. The library allows the collection of three different types of data: a) audio; B) video; and c) the user's screen. The library is open source, and presents its implementation in JavaScript, allowing videos to be recorded through the browser and sent to the server.

V. Experiments

To evaluate the usability of the developed tool, an experiment was carried out with the target group of the tool, children with autism. In the experiment, ten participants had to complete a set of training activities, while an observer take notes about their interaction with the tool. Those observational notes will later be reassessed and validated, based on the recordings of the experiment. In addition to the notes, the functionalities to evaluate the patient outcomes will be used to obtain metrics and data about the participants and their

[2]https://github.com/auduno/clmtrackr
[3]http://www.xlabsgaze.com
[4]https://www.webrtc-experiment.com/RecordRTC/

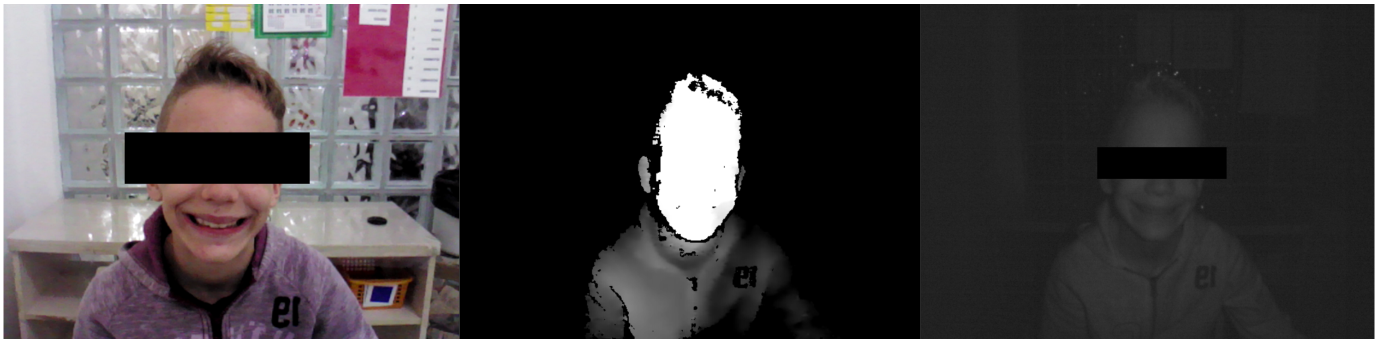


Fig. 3. Example of images of the participants obtained from the activities of producing facial expressions using the Intel RealSense camera.

performance. The experiment was developed in partnership with two centers: HC-UFPR Neuropediatrics Center (CENEP-HC) and AMA of Jaraguá do Sul. Figure 2 presents images of the experiment setup on both centers.

The experiment was approved by the ethics committee of the Health Sciences sector of UFPR under the number CAAE 55205016.0.0000.0102. It was monitored and supervised by a healthcare professional at CENEP, and accompanied by a educator responsible for the child at AMA.

Thirty-eight activities were defined to be executed by the participants during the experiment: a) four introductory activities, where users should match geometric forms and cartoonized facial expressions to understand the mechanics of the interfaces; b) twelve activities to recognize a facial expression in a displayed image (images obtained from the CAFE [44] database); c) six activities to recognize a facial expression from a video; d) six activities to recognize a facial expression in a social situation described by an audio; e) six facial expression production activities.

The computational tool was installed in an Apple-branded Macbook Pro. The notebook has 16GB of DDR3 RAM and 2.7GHz Intel Core i5 processor. The notebook was docked on a twenty-five-inch LG E2350V monitor. As the front camera for interaction with the tool, a Logitech C920 webcam was utilized, which was attached above the monitor. To record the experiment, a Canon Vixia HF S10 camcorder was used. All the facial expression production activities were also recorded using an Intel RealSense 3D Camera (Front F200) camera.

VI. Results

Analyzing the collected usability data, it was observed that users were able to perform the activities without any major problems with the functions of the tool or with the interfaces. The primary activities involving geometric forms helped users to understand the interface, and all users were able to perform the recognition activities without assistance.

In the production activities, however, it was noticed that users were able to understand and practice the desired expressions, but they weren't able to complete the activities (from the sixty production activities executed, only nine were completed successfully), due to problems in the algorithm to recognize the facial expressions. The algorithm presented difficulties in tracking the user's face and in recognizing facial expressions produced with less intensity. These problems are related with the fact that the algorithm was trained to recognize facial expressions using a database that contains only stereotyped frontal facial expressions [43].

Examining the data extracted using the features for evaluating the patient outcomes, it was observed that happiness, sadness, and anger were the expressions with the smaller amount of errors in the recognition challenges, being recognized correctly in 77,50%, 60% and 55% of the challenges respectively. The expressions of surprise, disgust and fear were the ones with the smaller rates of correct answers, being recognized correctly on the first answer in only 50% (surprise), 35% (disgust) and 12,5% (fear) of the activities. Also, it was observed that there was no relationship between the participants' age and their performance, which reinforces evidence [45] that the facial expression knowledge does not improve with age for individuals with autism.

Analyzing the time to finish each challenge, it was verified that positive expressions (happiness) were recognized quickly when compared to two negative expressions (fear and disgust), being confirmed by a Kruskal-Wallis Test [46] (p-value < 0.01). However, the same difference wasn't confirmed between sadness (negative expression) and happiness (positive expression). The first test result is similar to previous literature findings [47], [48] about the smaller accuracy and more time taken to recognize negative expressions when compared to positive expressions.

Evaluating the 2D videos recorded by the tool, we discovered autism-related behaviors, such as stereotyped movements and echolalia, which reinforces the importance of extracting and using these videos for the future evaluation of the participant. The gaze tracking data obtained was also analyzed, but no conclusions could be obtained due to the lack of accuracy. Observing the videos of the activities where the gaze tracking data had a small accuracy, it was discovered that the lack of accuracy is associated with strong head movements by the participant during the activities (i.e. moving it far away from the camera or out of the camera point of vision). These movements worsened the tracking of the participants' eyes, therefore generating problems to extract the gaze tracking data.

The production activities were recorded in three formats (depth, infrared, and RGB), resulting in a multimodal database of videos of children with autism producing facial expressions, with a total of 62GB in videos. Color images have been recorded in YCbCr format, with a resolution of 640x480 pixels, 30 FPS. Depth images were recorded at 640x480 pixels resolution, 30 FPS. The infrared images were recorded in Y8 format, with a resolution of 640x480 pixels, 30 FPS. All files have been saved in the .rssdk format, which allows different types of videos to be stored synchronously, helping in a future evaluation. Figure 3 presents examples of the three types of images obtained during the activities of producing facial expressions.

VII. Final Remarks

This article summarized the work published in the dissertation [11], which presented the development of a visual computing tool for training the recognition and production of facial expressions by children with autism. Before developing it, a literature review on the subject was executed, providing more information about the existent initiatives and proposing improvements. Based on these improvements, the tool was developed. To validate its usability, an experiment was carried out with children with autism, which resulted in positive findings. The experiment also demonstrated a tendency to the fact that positive expressions are recognized more quickly and assertively than negative expressions.

The results of the literature review of the dissertation were published in an article in the 43rd SEMISH [49]. Also, we are preparing an article containing details on the experiments performed and their results for submission to an international journal of high impact. Future work will include extending the tool with more activities and using the collected multimodal database to improve methods to recognize facial expressions of individuals with autism.

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