Mirroring Emotion System – On-line Synthesizing Facial Expressions on a Robot Face

Vinicius Silva
Industrial Electronics Department,
School of Engineering, University of Minho,
Guimaraes, Portugal
a65312@alunos.uminho.pt

Filomena Soares and João Sena Esteves
Industrial Electronics Department, R&D Centre Algoritmi,
School of Engineering, University of Minho,
Guimaraes, Portugal
[fsoares;sena.esteves]@dei.uminho.pt

***Abstract*—Social skills are an important issue throughout human life. Therefore, systems that can synthesize emotions, for example virtual characters (avatars) and robotic platforms, are gaining special attention in the literature. In particular, those systems may be important tools in order to promote social and emotional competences in children (or adults) that have some communication/interaction impairments. The present paper proposes a mirroring emotion system that uses the recent *Intel RealSense* 3D sensor along with a humanoid robot. The system extracts the user's facial Action Units (AUs) and head motion data. Then, it sends the information to the robot allowing on-line imitation. The first tests were conducted in a laboratorial environment using the software *FaceReader* in order to verify its correct functioning. Next, a perceptual study was performed to verify the similarity between the expressions of a performer and those of the robot using a quiz distributed to 59 respondents. Finally, the system was evaluated with typically developing children with 6 to 9 years old. The robot mimicked the children's emotional facial expressions. The results point out that the present system can on-line and accurately map facial expressions of a user onto the robot.**

Keywords*—*Facial Expressions; Intel RealSense; Zeno robot; Mimicking Emotions.

I. INTRODUCTION

Human-Robot Interaction (HRI) is an important topic in the scientific community. The general idea lies on robots collaborating with humans, autonomously performing tasks and effectively communicating their "intentions". When face-to-face, people use a wide variety of sensory and motor modalities to communicate. Faces are the most noticeable social part of the human body. Following this trend, the face has received the most attention in HRI research since it is crucial in the communication of emotions from the early stages until the last stages of human life.

Researchers have used a variety of facially expressive robots in their work. These robots offer an extensive range in their expressivity, facial degrees-of-freedom (DoF), and visual appearance.

The work developed by Mazzei [1] consisted of a first stage in developing the humanoid robot FACE to allow children with Autism Spectrum Disorders (ASD) to deal with expressive and emotional information. FACE is a female android actuated by 32 servo motors moving its artificial skin. This allows human facial expressions to be re-created. Posteriorly, the system was tested with 5 children with ASD and 15 typically developing children. The evaluated emotions were happiness, sadness, anger, disgust, fear, and surprise, defined as the six basic emotions [2]. The results demonstrated that happiness, sadness and anger were correctly labelled with high accuracy for both children with ASD and typically developing children.

In [3] it is presented EDDIE, a robotic head with 23 DoF, where actuators are assigned to the particular Action Units (AUs) of the Facial Action Coding System (FACS). The system was evaluated by 24 participants: 8 children from 5 to 8 years old and 16 adults from 25 to 48 years old. The study consisted of a multiple-choice test in which people should build a correspondence between six shown facial expressions to 10 given answers. The recognition rate for the average of all emotions was 57%. Further developments led to a facial mimicry system combining facial expression analysis and synthesis on a robot [4].

Similar to EDDIE, Kismet [5] is able to engage humans in expressive social interaction. It has 15 DoF and it was designed with the possibility to process a variety of social signals from visual and audio channels, and deliver social signals to the human with whom it was interacting. The values of the recognition rate were higher than those obtained with EDDIE. The average value for all six basic emotions was 73%.

SAYA [6], a tele-operated android robot used in the role of a teacher, is capable of express human-like facial expression and perform some communicative functions with its head and eye movements. The face has 19 DoF for generating facial expressions. In order to evaluate the designed facial expressions, the system was initially tested by 24 adults that watched videos of SAYA performing each of the six basic emotions. The results showed a high recognition rate, 97.3%, for all the six basic emotions.

Most of the reviewed systems have fixed heads, preventing head movements that are particularly important to convey emotional states [7]. Only Kismet and SAYA have moving heads. FACE and SAYA have human-like faces. EDDIE and Kismet are expressive, but hardly resemble human faces. In addition, some systems do not operate on-line; they are either remotely operated (SAYA) or sequentially operated (FACE).

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Generally, researches resort to animators to generate precise and realistic facial expressions on their robots or they use quite expensive, closed-source software applications for the same purpose. These applications usually operate offline, preventing the possibility for mimicking emotional states on-line. Additionally, the mimicry system used in EDDIE uses a conventional 2D camera to produce a video stream from which the user's AUs are automatically extracted and mapped to the robot, mirroring the user´s facial expression.

The present work describes a framework for facial expressions synthesis in a robotic platform to be used with children. A human-like face and a head with pitch, yaw and roll capabilities are required, so that reasonably natural expressions and movements may be obtained. In order to accomplish this goal, an experimental setup was designed and implemented using the new *Intel RealSense* 3D sensor (instead of a conventional 2D camera), a computer, and a *Zeno* model R-50 robot from *RoboKind* (www.robokind.com). The system is able to synthesize human emotions on-line on the robot through facial expressions and head motion. This system extracts the user's facial AUs and, after processing them, it sends commands to the robot allowing on-line imitation. At a first stage, the system was evaluated in a laboratorial environment in order to check its functioning. Posteriorly, tests were conducted in a setting with typically developing children with the purpose of detecting some constraints of the system.

This paper is organized in four sections. Section II describes the proposed system; Section III shows the preliminary results obtained; and the conclusions and future work are addressed in Section IV.

II. Proposed System

In this section it is described the proposed system that allows a humanoid robot called ZECA (ZECA is the Portuguese name for *Zeno* robot) to mirror the facial expressions from a human user.

A. Experimental Setup

The system implemented in this work (Figure 1) consists of an *Intel RealSense* sensor, a computer, and the robot ZECA.

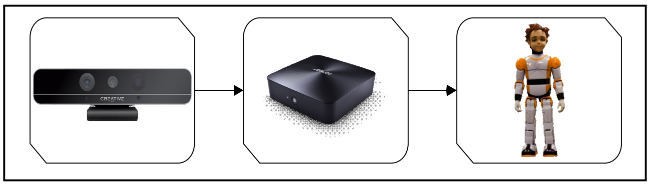

Figure 1. Experimental setup. Starting from the left: *Intel RealSense* (model F200), computer and ZECA robot [8].

Intel RealSense is a platform for implementing gesture-based Human Computer Interaction (HCI) techniques [9]. It contains a conventional RGB camera, an infrared laser projector, an infrared camera, and a microphone array. A grid is projected onto the scene by the infrared projector and the infrared camera records it, computing the depth information. A microphone array is also available, allowing performing background noise cancellation. Intel announced two models with distinct specifications [10].

The present work uses the *Intel RealSense* model F200, which is a front facing device dedicated to analyse the human face and hand. This device, along with the required Windows software, *Intel RealSense* SDK, was used to obtain the face data from the user.

ZECA (Figure 1) is a humanoid child-like robot with 34 degrees of freedom: 4 are located in each arm, 6 in each leg, 11 in the head, and 1 in the waist [11]. The major feature that distinguishes this robot from the others is the ability to express emotions thanks to servo motors mounted on its face and a special material, Frubber, which looks and feels like human skin [11].

B. System Description

Figure 2 shows the block diagram of the developed system. The face data (the user facial Action Units, AUs) obtained from the *Intel RealSense* sensor is filtered. Then, the data is normalized, generating a data package that is sent to the robot for actuation of the face servo motors. An application developed in C# runs on the computer, computing the user face data and establishing the communication with ZECA. A *Java* application runs in the robot in order to actuate the servo motors on the face, replicating the user facial expressions.

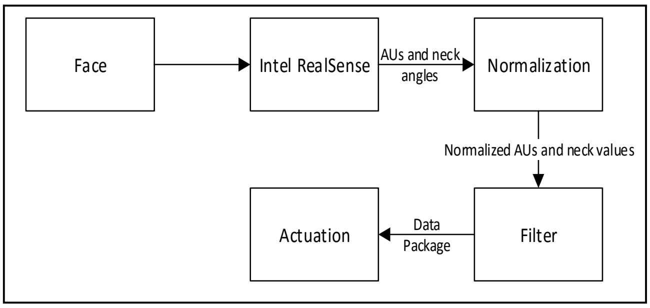

Figure 2. System block diagram. First the AUs and neck angles are obtained and normalized. Finally, the values are filtered and sent to the robot.

C. Face and Intel RealSense

Intel RealSense is able to calculate the scores for a few supported facial expressions as well as detecting up to 78 facial landmarks using the depth information. The user must be in front of the *Intel RealSense* as shown in Figure 3. The effective range for face tracking is 35 cm to 120 cm.

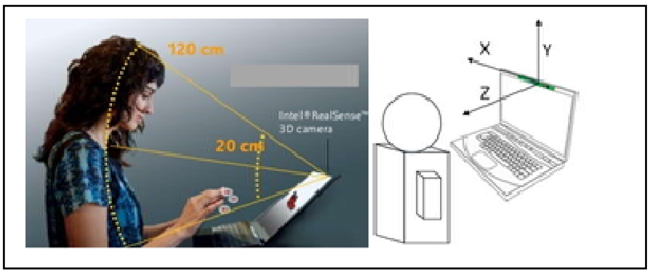

Figure 3. On the left: the recommended user position. On the right: the *Intel RealSense* coordinate system [12].

C. Obtaining the Action Units (AUs) and Head Motion

Commonly, an emotion is experienced by a person when reacting to a certain event. Emotions are normally characterized as negative (sadness, anger or fear), positive (happiness or surprise) or neutral. Developed by Paul Ekman and Wallace Friesen in 1978, the earliest method for characterizing the physical expression of emotions is the Facial Action Coding System (FACS) [13]. This system associates the action of the muscles to the changes in facial appearance. The measurements of the FACS are called Action Units (AUs) which are actions performed by a muscle or a group of muscles. There are a total of 46 AUs from which 12 are for the upper face, 18 are for the lower face and AUs 1 through 7 refer to brows, forehead or eyelids [14].

The *Intel RealSense* sensor along with *Intel RealSense* SDK can provide up to 78 facial landmarks, and a total of 16 facial AUs [10]. However, since the system is still under development, some facial AUs are detected with low accuracy and some AUs are not yet available. To solve this problem, certain facial AUs were obtained through facial landmarks. Table 1 lists the facial AUs used in this work, distinguishing those provided by *Intel RealSense* from the ones obtained through facial landmarks.

TABLE I. SELECTED FACIAL ACTION UNITS

Facial action units	*Intel Realsense*	Facial landmarks
Eye brow raiser	✔	
Eye brow lower	✔	
Eyelids		✔
Eyes up	✔	
Eyes down	✔	
Eyes left	✔	
Eyes right	✔	
Mouth open		✔
Lip stretcher	✔	
Lip depressor		✔

In order to obtain the facial AUs from landmarks, 10 facial landmarks were selected. Figure 4 shows the selected and labelled facial landmarks for geometric features extraction. Table II lists the significance of the selected 10 facial landmarks. These geometric features were determined by calculating linear distances between couples of landmarks.

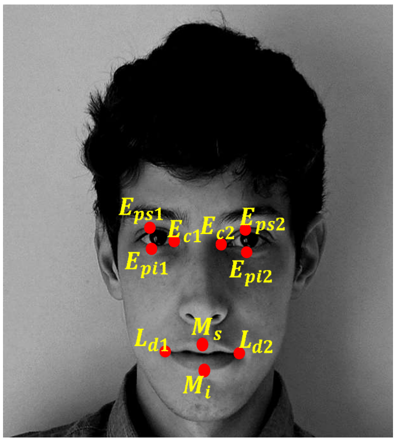

Figure 4. Selected facial landmarks.

The following equations (1 to 5) show how the linear distances between couples of landmarks were obtained, whereas x and y indicate, respectively, the horizontal and the vertical components of a point in the image space. Table II details the variables used.

$$Lip\ depressor_{right} = \sqrt{(E_{c1_x} - L_{d1_x})^2 + (E_{c1_y} - L_{d1_y})^2} \tag{1}$$

$$Lip\ depressor_{left} = \sqrt{(E_{c2_x} - L_{d2_x})^2 + (E_{c2_y} - L_{d2_y})^2} \tag{2}$$

$$Eye_{right} = E_{ps1_y} - E_{pi1_y} \tag{3}$$

$$Eye_{left} = E_{ps2_y} - E_{pi2_y} \tag{4}$$

$$Mouth\ Open = M_{s_y} - M_{i_y} \tag{5}$$

TABLE II. FACIAL LANDMARKS SIGNIFICANCE

Facial Landmark	Significance
E_{c1}	Eye corner
E_{c2}	Eye corner
L_{d1}	Lip depressor
L_{d2}	Lip depressor
E_{ps1}	Eye palpebrale superius
E_{ps2}	Eye palpebrale superius
E_{pi1}	Eye palpebrale inferius
E_{pi2}	Eye palpebrale inferius
M_S	Mouth superius
M_I	Mouth inferius

The facial AUs obtained from *Intel RealSense* are normalized in a 0 to 100 intensity scale, where 0 means that the AU is not present and 100 means that the AU is definitely present.

The facial AUs that were obtained through facial landmarks are normalized, using equation (6), to the 0 to 100 scale.

$$N = \frac{W - min_v}{max_v - min_v}(B - A) + A \tag{6}$$

where:

N – Normalized Facial Feature value
W – Facial Feature value to normalize
min_v – Minimum value from the normalized set
max_v – Maximum value from the normalized set
$[A, B]$ – Range for value (W) after normalization

The minimum and maximum values for each of these AUs were experimentally found. A performer was asked to execute a wide range of extreme facial movements while seated in front of the *Intel RealSense* sensor. For example, in order to find the maximum value of the AU Eyelid, the person opened the eyes as much as possible. The minimum value of the AU is zero, corresponding to the closed eyes.

The *Intel RealSense* SDK can return the user head angles, called Euler angles [15]. These angles determine the head pose in terms of rotation along the three axes. These angles are used in order to establish the pose of the head of ZECA, using its servo motors as illustrated in Figure 5.

D. Mapping and normalization of facial AUs and neck angles

An AU is linked to actions of a muscle or group of muscles. Therefore, each AU was associated to a servo motor or a group of servo motors responsible for a facial movement on the face of ZECA (Figure 5). This association is shown in Table III. Due to the robot mobility limitations, it is necessary to delimit the movements of the neck. For example, the maximum range for the second servo (Figure 5) is 0-30º [16]. This was taken into account. Posteriorly, all facial AUs were converted to a 0-1 scale. The conversion to this scale was made according to the API (Application Programming Interface) of the robot which only accepts numbers between 0 and 1 for each servomotor.

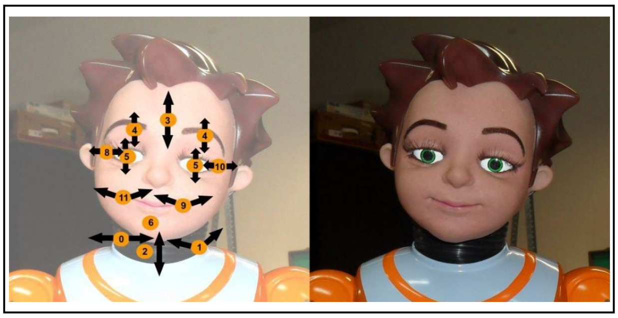

Figure 5. Mapping of the servo motors on the face and the neck of ZECA [16].

TABLE III. MATCHING OF THE AUS AND THE SERVO MOTORS OF ZECA

Facial AUs	Servo motors of ZECA
Eye brow raiser	Servo Motor 4
Eye brow lower	Servo Motor 4
Eyelids	Servo Motor 3
Eyes up	Servo Motor 5
Eyes down	Servo Motor 5
Eyes left	Servo Motor 8 and Servo Motor 10
Eyes right	Servo Motor 8 and Servo Motor 10
Mouth open	Servo Motor 6
Lip stretcher	Servo Motor 11 and Servo Motor 9
Lip depressor	Servo Motor 11 and Servo Motor 9

E. Filter

In order to smooth out short-term fluctuations due to rapid facial movements, a moving average filter with 10 samples was applied for each AU value. The number of samples was obtained experimentally. In Figure 6 it is possible to see the effect of this filter in one AU value of a facial expression (in this case, the eyebrow movement AU value).

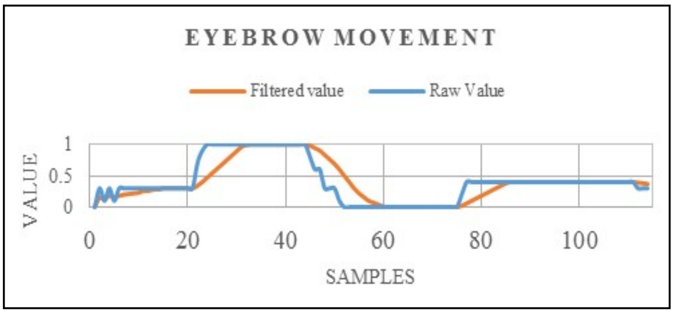

Figure 6. Eyebrow movement.

F. Communication protocol

The *Intel RealSense* subsystem is connected to the robot ZECA through a local network, communicating via a TCP/IP socket. A client application that runs on the computer transmits the data to the robot allowing it to actuate. The AUs data package consists of 8 AUs values and the 3 Euler angles values, Figure 7.

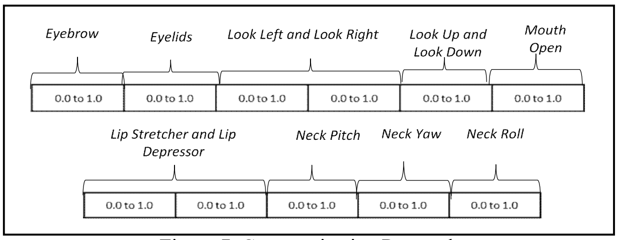

Figure 7. Communication Protocol.

III. RESULTS

The overall system was first tested in a laboratory environment to verify its correct functioning using the software *FaceReader* (section A). Then, a perceptual study was conducted in order to test the similarity between expressions of a performer and the robot (section B). Finally, the system was evaluated in a school environment with children in the 1st cycle, where the robot mimicked the child emotional facial expressions (Section C).

In https://www.youtube.com/watch?v=vXYJ7szyY8s it is possible to see a video of the robot imitation performance.

A. System Evaluation using FaceReader

In a first stage, the software *FaceReader* was used to automatically analyse the synthesized facial expressions. *FaceReader* is a professional software from *Noldus* [17] for automatic analysis of the six basic emotions (happy, sadness, anger, fear, disgust, and surprise), as well as classifying neutral and contempt states. It also provides gaze direction, head orientation, person characteristics (e.g. gender and age), and a detailed analysis of the facial AUs. This software can analyse from live video, recorded video, or images. Therefore, a video of ZECA mirroring the emotions of a performer was used. This video was subjected to the *FaceReader* software analysis.

Figures 8 to 10 present the examples of the facial expressions associated with happiness, surprise, and fear, respectively, registered for the robot and the performers. The *FaceReader* results are presented in each legend in terms of performance matching.

A video presenting some of the performed tests may be seen in the following link: https://youtu.be/qt_4nJpXPz8.

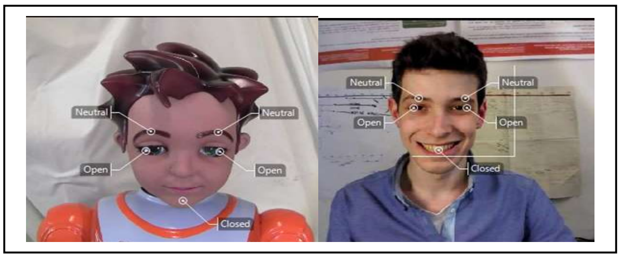

Figure 8. Happiness facial expression: match of 54% for the robot and 85% for the performer.

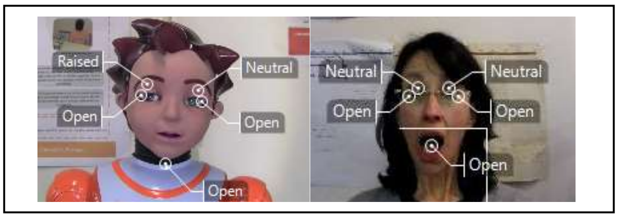

Figure 9. Surprise facial expression: match of 77% for the robot and 87% for the performer.

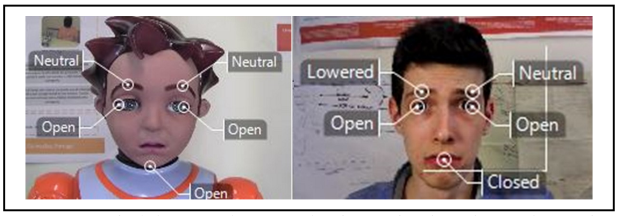

Figure 10. Fear facial expression: match of 69% for the robot and 62% for the performer.

Despite of the high recognition rates for the above facial expression, anger was really hard to be recognized using this software, even though most of the AUs necessary to represent that expression were present. Most probably, they were not marked enough for the software to recognize them. Moreover, the software *FaceReader* is prepared to recognize facial expressions in human faces. In this case, the software was run on a non-human face, a robot face, which may be harder for the software to recognize.

B. Perceptual Study – Quiz

In order to test the similarity between facial expressions of a performer and the robot, a perceptual study was conducted using side-by-side comparison or "copy synthesis" [18], [19]. Thirty-one children between 6 and 9 years old and 28 adults between the ages 18 and 52 participated in the study (total sample: 59 participants). The synthesized expressions on a simulated/physical face were shown side-by-side with the performer's face to the participants. In this perceptual study, the participants had to select, among the robot facial expressions, the most similar to the performer's facial expression. Figures 11 and 12 present the results obtained with children and adults, respectively.

The facial expression with the highest similarity is surprise, with a score of 100% in adults and children. Happiness and sadness have similar matching scores in children and adults: 87% for children and 96% for adults. The facial expressions with the lowest matching score for children are anger and fear, with 55% and 58%, respectively. The matching scores of these facial expressions in adults were higher, with 93% for both expressions.

C. Perceptual Experiment

A perceptual experiment was conducted to evaluate the proposed system. This is a common method for evaluating synthesized facial expressions [20], [21]. In this perceptual experiment, three emotions were considered: happiness, sadness (since they are opposite emotions, they are more easily identifiable) and the neutral state. It was also considered the head motion as it gives more emphasis to the emotional states, making it easier to distinguish the facial expression [7].

The tests for the perceptual experiment considered 32 typically developing children from the 1st cycle with 6 to 9 years old. The tests were performed in a school environment in a closed room.

The experimental setup may be seen in Figure 13, with the camera placed in the chest of the robot. The child sat in front of the robot, looking at ZECA and performed the emotions happiness, sadness and neutral, requested by the researcher. The researcher showed a photograph corresponding to each emotion in order to serve as a clue. Sadness was performed in two different ways, with and without the head bowed. A supervisor person reported the results for each of the expressed emotions, Figure 14.

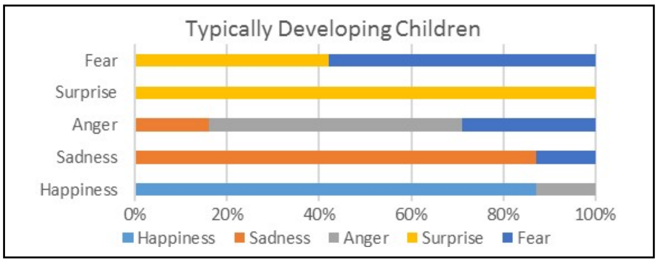

Figure 11. Matching Results – Children.

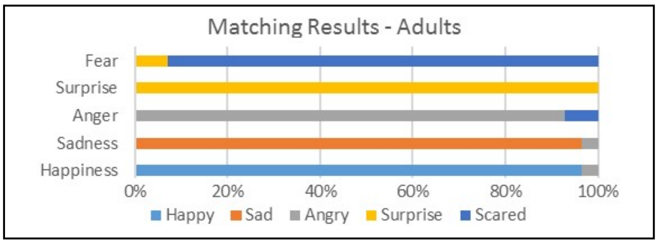

Figure 12. Matching Results – Adults.

Figure 13. Experimental setup: ZECA and *Intel RealSense.*

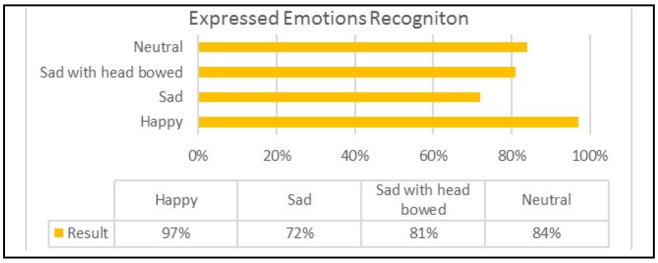

Figure 14. Recognition of the expressed emotions.

The happy emotion had the highest matching score (97%) and the neutral state obtained a mark of 84%. Regarding sadness, it was better determined considering head bowing (81%) compared to the expression without head movement (72%). The relatively high overall scores of the expressed emotions suggest that the system can map facial expressions of a user onto a robot, accurately and on-line.

IV. CONCLUSION AND FUTURE WORK

This paper described a solution for facial expression synthesis on the humanoid robot ZECA. It uses the recent *Intel RealSense 3D* sensor for extracting the user's facial Action Units (AUs) and it sends the data to ZECA, allowing on-line imitation.

The overall system was first tested in a laboratorial environment. The emotions happiness, sadness, surprise, fear, anger and neutral were analysed. The software *FaceReader* was used to automatically analyse the synthesized facial expressions on the robot when mimicking the performer. All except anger had a match higher than 50%. Even though most of the AUs necessary to represent anger were present, the emotional state was not correctly recognized. Most probably, in the robot face the AUs were not marked enough for the software to recognize them. Additionally, it may be difficult for the software to recognize facial expressions in a non-human face as it is prepared to work with human faces.

The perceptual study allows concluding that surprise obtained the highest similarity, with a score of 100% in adults and children. Happiness and sadness have similar matching scores in children and adults: 87% for children and 96% for adults. Anger and fear were the facial expressions with the lowest performance for both children, with 55% and 58%, respectively. On the other hand, these facial expressions had a better matching rate in adults, with 93% for both expressions.

A perceptual experiment was conducted with children from 6 to 9 years old to evaluate the proposed system. The overall scores of the expressed emotions matching (97% for happiness, sadness: 72% without head movement and 81% with head bowing, and 84% for the neutral state) indicate that the proposed system based on the *Intel RealSense 3D* sensor can map facial expressions of a user onto a robot, accurately and on-line.

The next step is to endow the robot of emotional knowledge, i.e., make it able of automatically recognizing the six basic emotional states. The final goal of the project is to work with children with autism spectrum disorders, promoting social activities of recognizing and mimicking emotions.

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