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Contributions to development of mobile support applications for persons with autism spectrum disorder

- PhD THESIS summary -

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ABSTRACT

Autism represents a neurodevelopmental disorder that is characterized by problems in expressing feelings, integrating socially, and having repetitive behaviors. A recent report of Centers for Disease Control states that 1 of 44 children were identified with ASD (autism spectrum disorder). Studies have shown that boys have four times more chances to develop autism than girls. Though autism can be diagnosed as early as age two, the majority of children are diagnosed after the age of four.

Drawings are an important part of a child's life and drawing interpretation is very useful to find out what the child is feeling. In this context, thesis describes an android application called *PandaSays* that was developed based on the drawing's interpretation, as an improved eHealth system dedicated to autism, to help parents and tutors communicate better with their children and to understand their emotional state. The algorithm used in the android application interprets the children's drawings and identifies their affective state. Recent studies tried to predict the affective state of the child using humanoid robots or using images of facial expressions. There is no application that uses drawings to evaluate the affective state of a child. By means of this solution, drawings will become a gate to the child's affective state and behavior. Another important aspect of the application is that the parent does not have to go to a psychologist to interpret his/her child's drawings, the application does that for him, as the dataset is already validated by a certified psychologist. The solution incorporates a machine learning algorithm that detects the affective state of the child ("happy", "angry", "sad", "insecure", and "fear") from what he/she draws. The application's dataset contains 1453 drawings. The output is sent further to one of the robots: Marty, Alpha1P or Alpha 1E. The robots will execute a specific action, depending on the state previously received from the machine learning algorithm. The role of funny and friendly robots as being integrated in complex solutions has been proved to be useful in improving interaction with children.

A Music Module was also integrated in the application, as many studies demonstrated that music therapy is helpful for children diagnosed with autism. Based on the music therapy effectiveness, the android application contains five classical music songs, that will be played according to the affective state of the child. Having integrated a module to communicate with humanoid robots, the solution has become a useful teaching tool in schools or autism centers. For choosing the best robot model to incorporate in the application, a comparison between MobileNet neural network, VGG16 (Visual Geometry Group from Oxford), ResNet (Residual Neural Network) and Feedforward Neural Network was made. In parallel it was used AutoML Vision Edge from Google. The code was written in Python 3 and the following libraries were used: sklearn, tesnorflow and matplotlib (for displaying graphics). Because of the small dataset, transfer learning was applied, using ImageNet, as weights.

Moreover, *PandaSays* mobile application conforms to the accessibility guidelines, and can be used also by children diagnosed with aphasia or children that have speech impairments. The application contains a Text-To-Speech module, where the child can write something, and it will be said out loud. This module has sign language integration, to help children that have auditory or speech impairments.

A robust set of experiments has been done in order to validate the proposed innovative solution. The thesis ends with personal conclusions, a list of publications and future work.

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LIST OF ABBREVIATIONS

Abbreviation	Stands for
ASD	Autism spectrum disorder
ADOS	The Autism Diagnostic Observation Schedule
ACSA	Autistic child Sensor and Assistant System
SMOTE	A synthetic minority over-sampling technique
RISTA	Robot-mediated Imitation Skill Training Architecture
ROI	Region of interest
ReLU	Rectified Linear Unit
MVVM	Model-View-ViewModel
AR	Augmented reality
SMO	Sequential minimal optimization algorithm
BLE	Bluetooth Low Energy
EDR	Enhanced Data Rate
LE	Low Energy
MAC	Media access control
OS	Operating system
PRP	Pose, Record & Playback
RFCOMM	Radio frequency communication
RS-232	Recommended Standard 232
TCP	Transmission Control Protocol
IP	Internet Protocol
VGG	Visual Geometry Group from Oxford
ResNet	Residual Neural Network
sp	scalable pixels
API	Application Programming Interface
ADHD	Attention Deficit Hyperactivity Disorder
CARS	Childhood Autism Rating Scale
FFT	Fast Fourier Transform
LED	Light Emitting Diodes

CHAPTER 1. INTRODUCTION

1.1.Background and Research Motivation

Autism represents a neurodevelopmental disorder that is characterized by problems in expressing feelings, integrating socially, and having repetitive behaviors. There is no solution to entirely cure autism spectrum disorder, but early detection (from six months to three years) helps children develop different skills such as social skills and communication and helps control their repetitive behavior [1].

Drawings are an important part of a child's life and drawing interpretation is very useful to find out what the child is feeling. The important part of the drawing action is that the child can draw starting at six months of age. In order to predict the drawing, the parent or tutor has to visit a certified psychologist that is specialized in Drawings Interpretation. In this context, the thesis will describe in its chapters an android application called *PandaSays [2] that was developed based on the drawing's interpretation, as an improved eHealth system dedicated to autism, to help parents and tutors communicate better with their children and to understand their emotional state.* The algorithm used in the android application interprets the children's drawings and identifies its affective state, as will be more detailed in the following chapters.

There is no application that uses drawings to evaluate the affective state of a child. As we will detail further in this thesis, drawings will become a gate to the child's affective state and behavior. Another important aspect of the application is that the parent does not have to go to a psychologist to interpret his child's drawings, the application does that for him, as the dataset is already validated by a certified psychologist.

The PandaSays [2] application is also designed to help children diagnosed with aphasia, or children that have speech impairments. The application's dataset contains 1453 drawings. The output is sent further to one of the robots: Marty, Alpha1P or Alpha 1E. The robots will execute a specific action, depending on the state previously received from the machine learning algorithm. In the application was also integrated a Music Module, as many studies demonstrated that music therapy is helpful for children diagnosed with autism. As the application has integrated a module to communicate with humanoid robots, it can be used as a teaching tool in schools or autism centers. Moreover, *PandaSays* mobile application conforms to the accessibility guidelines, and can be used also by children diagnosed with aphasia or children that have speech impairments.

1.2.The main objectives of the thesis

The main objective of the thesis is to develop an android application that can help parents and tutors to communicate better with their children diagnosed with autism, aphasia, or a speech impairment. To create this application and to fulfill and validate this research, the following secondary objectives were realized:

1. Research all the existing applications and devices used to help children diagnosed with autism.
2. Realize a critical analysis of the solutions that help in providing diagnose, interaction, help and evaluation of the autistic children, finding the weaknesses and the gaps that can be covered by the new innovative research described in this thesis.
3. Understand the concepts and the strategies behind the evaluation of the emotional states of the children with autism.
4. Investigate all papers related to humanoid robots, being used as a tool to help children diagnosed with autism.
5. Consider drawings as a gate to children's understanding and develop an android application based on machine learning techniques that can help parents and tutors to reach the emotional state of the child.

6. Design and establish the application's flow.
7. Create a database of drawings and divide them into 5 classes, representing the following states: "happy", "sad", "angry", "insecure" and "fear".
8. Validating the database by a certified psychologist, having the main specialization the drawing interpretation.
9. Increase the dataset of drawings.
10. Choose the best robotic solution that will be integrated in the final application.
11. Find the best model to evaluate the affective state of the child from its drawings with high accuracy, making a comparison between VGG16, MobileNet, ResNet and Feedforward Neural networks. The methods applied were transfer learning, image augmentation and k-fold cross-validation.
12. Establish a connection between the application and a robot via Bluetooth protocols.
13. Find the best device to execute the connection of the robot. The robots will have the goal to improve the emotional state of the child by moving accordingly.
14. Test and validate the algorithms and the robot's interaction with children diagnosed with autism and further in Autism centers.

1.3.Thesis Structure

The thesis is divided into six chapters, starting with Introduction.

Chapter 2: This chapter presents an analysis of the algorithms used to diagnose autism and continues with the existing solutions for detecting autism. The chapter starts with the presentation of tests-based solution for autism spectrum disorder and continues with the presentation of wearables dedicated for diagnosing autism. The third section presents the algorithms used for predicting autism spectrum disorder and continues with solutions for autism analysis based on eye-tracking and game-based solutions. Moreover, a comparison between existing solutions is made and are presented their advantages and weaknesses.

Chapter 3: In this chapter, PandaSays android application is presented. The first section makes an introduction about the drawing interpretation and its importance for helping predict the affective state of the child. The next section illustrates the PandaSays application with its main features: *Drawing Module* (where children can draw), *Drawing interpretation module* (where the drawing is interpreted by the Machine Learning algorithm), *Label Recognition Module* (where an photo taken is analyzed), *Text-to-Speech Module* (where the child can write something and is read out loud), and *Communication with the Robot module* (where is presented the application's communication with the robot).

In the fourth section it is presented a comparison between VGG16 and MobileNet neural networks. The algorithms are applied on different datasets. A new dataset is gradually improved, and more drawings are added. The fifth section introduces the analysis of Feedforward Neural network for the integration in PandaSays application. The next section talks about the safety considerations of using the application. Further there are discussed the data and methods used in the android application, and the updated comparison between VGG16 and MobileNet is included, as the dataset was improved.

Chapter 4: This chapter begins with a robust analyze of the robot-based solutions for behavioral support and understanding for children diagnosed with autism spectrum disorder, focusing on the details of the applications and research that have been realized using humanoid robots. The next section of this chapter presents the PandaSays mobile application in the context of its performance tests using Deep Convolutional Neural Networks and Residual Neural Networks. Next, is presented the updated machine learning model, with the new dataset of drawings. The chapter continues with the introduction of the humanoid robot used - Alpha 1P and its features. Further it is explained the

communication between the robot and the application and is realized a comparison between the times on different devices. Another section of this chapter is represented by the Accessibility module, exposing the importance of accessibility for children diagnosed with autism and the applicability in the *PandaSays* android application.

Chapter 5: This chapter introduces the music feature and the related work around this subject. The next section presents the Music module of the PandaSays application and its connection with the Drawing Interpretation Module. The chapter continues with accessibility applicability on the new music feature. Further, it is presented a case study using the robot Marty, where the child, diagnosed with autism interacts with the robot. Next, there are introduced the Alpha 1E and Alpha 1P humanoid robots' application flows and the comparison of connection times between the robots and the android application.

Chapter 6: This chapter presents the conclusions of the thesis, all contributions resulted from the research and future work.

CHAPTER 2. A critical analyse on the technologies and methods used for development of applications dedicated to persons with autistic spectrum disorder

2.1. Tests based solutions for autism

In this chapter there are presented the existing tools for monitoring autism spectrum disorder. This section is structured in 7 sections. After the introduction, Sections 2-6 present the current tools used for predicting and helping children diagnosed with autism and making a comparison with PandaSays application, exposing the advantages and weaknesses of those solutions, and comparing them with the PandaSays application's features.

There is no specific solution to cure autism, but fast detection (from six months to three years) helps children learn different skills such as communication and social skills and helps control their repetitive behavior. In the present, there are several screening tests that are administered by professionals, service providers and parents [1]:

- Observation tool - Autism Diagnostic Observation Schedule (ADOS-2)
- Modified Checklist for Autism in Toddlers (M-CHAT)
- Ages and Stages Questionnaires (ASQ)
- The Childhood Autism Rating Scale (CARS)
- Screening Tool for Autism in Toddlers and Young Children (STAT)

The advantages of PandaSays application consists of a fast drawings interpretation that eliminates the need of going every day to a psychologist and determining the parent or the tutor to understand the emotions of the child.

2.2. Wearables dedicated to ASD diagnose and communication

People diagnosed with autism have difficulties in expressing their feelings and showing empathy towards other people; they cannot easily understand other people's emotional states [3]. In the present, there are no reliable sensors that can measure the affective state. MIT Media Laboratory has developed systems for communicating affective states information presented in the table below:

Table 2.1 Advantages and weaknesses of Wearable devices

Wearable devices	Advantages	Weaknesses
The Galvactivator [4]	• Notices the person's skin (who wears it) energy and links its values to an LED display. • Can measure emotions.	• The child diagnosed with autism might respond differently to every device, some might become aggressive or frightened. • High price of acquisition. • Low access to the device. • Time consuming – the data must be gathered after the child was monitored and further sent for a more rigorous analysis.
Expression glasses [4]	• Device designed for facial recognition that	• Low data of expressions gathered.

	utilizes pattern recognition to point out expressions such as interest or confusion.	• The child diagnosed with autism might respond differently to every device, some might become aggressive or frightened. • High price of acquisition. • Parents or caregivers can access this device mostly in certain facilities that have them and many devices are not for sale. • Time consuming – the data must be gathered after the child was monitored and further sent for a more rigorous analysis.
Emotiv Insight [5]	• Analyses states such as degree of attention, focus, interest, relaxation, excitement, affinity, engagement, and stress.	• The child diagnosed with autism might respond differently to every device, some might become aggressive or frightened. • High price of acquisition. • Low access to device. • Time consuming – the data must be gathered after the child was monitored and further sent for a more rigorous analysis.
Empatica [5]	• Designed to capture excitement, stress, or emotions. • Monitors heart rate and motions. • Can be wear by children.	•High price of acquisition. •Low access to device. •Time consuming •Requires professionals' evaluation.

An advantage of PandaSays application is that requires only an android device and internet to be able to download for the first time the machine learning model, so the drawings analyzer can start working. Humanoid robots are optional, but currently there are three options in the application, with different price ranges.

2.3. Algorithms used in ASD analysis

Machine learning algorithms were utilized to analyze the complete set of scores from the first module of ADOS available at the "Autism Genetic Resource Exchange" (AGRE) for 15 people without ASD and 612 people with autism [6]. The analysis claimed that eight of the 29 structures

present in the first module of ADOS were enough to diagnose autism spectrum disorder with 100% accuracy. A group of families that have one or more children diagnosed with autism represents the input for machine learning classification algorithm. There were 16 classifiers, and for each algorithm it was applied a 10-fold cross validation. The validation consisted in testing the classifier on ADOS data collected from people diagnosed with autism.

From the 16 classifiers, it was chosen ADTree (Alternating decision tree) algorithm, because succeeded in classifying correctly all 612 individuals from the AGRE who already were diagnosed with autism by ADOS first module and 15 with no autism, as diagnosed by AGRE and Boston AC. Clusters Evaluation refers to finding the cluster configuration that best fits the data. For the evaluation of results, the following methods were applied: univariate analysis and multivariate analysis. There were 27 ASD phenotype features as input features; Repetitive Behavior Scale-Revised (RBS-R) had the best validation indices scores. The algorithms can be used to determine other disorders characterized by social impairments, communication deficiency, aphasia, abnormal behavior.

Most of the algorithms presented in this section are more suitable for making analysis on data gathered from screening tests. As the PandaSays android application has a dataset of images, it was more appropriate to use Convolutional Neural Networks to train the model.

2.4. Solutions for autism analysis based on eye-tracking

Individuals diagnosed with autism have difficulties in creating eye contact or carrying on it.

Eye-tracking devices are helpful in diagnosing autism, as they gather the atypical gaze movement, one of the biomarkers, necessary in diagnosing autism. As other devices, they present some limitations when it comes to diagnosing autism spectrum disorder (Table 2.2):

Table 2.2 Advantages and weaknesses of Eye-tracking devices

Eye-tracking devices	Advantages	Weaknesses
Arabic screening system [7]	• Helps to gather eye-gaze data utilizing remote eye tracking. • Helps with autism diagnosis as gaze movement is an autism biomarker.	• Data applied only to Arabic countries. • High cost of devices. • Are available mostly in special clinics or medical facilities. • They detect autism spectrum disorder after the age of 8, and the requirement to help children with autism is to diagnose this disease as early as possible.
Tobii X120 Eye Tracker [7]	• Helps diagnosing autism, using Region on Interest. • Separates individuals with autism from individuals without autism. • High accuracy of autism prediction – 88,6%.	• High cost of devices. • Are available mostly in special clinics or medical facilities. • They detect autism spectrum disorder after the age of 8, and the requirement to help children with autism is to diagnose this disease as early as possible.

2.5. Solutions for ASD Diagnoses

Parents are unable to capture all their children's actions, behavior, and symptoms that are diagnosed with autism. A proposed system was developed for finding the possible symptoms, using long term patients records [8]. In this study are applied machine learning algorithms and they developed an autism diagnosis tool that uses *Confabulation theory*.

Other algorithms used to find the appropriate symptoms regarding autism are: CARMRMR (CARMRMR takes *min (k+1, m)* scan of the total symptom database, where *k* represents the largest frequent symptom set and *m* is the number of symptoms in the directory), SMOTE - A synthetic minority over-sampling technique, representing a technique that generates synthetic examples, because it operates in "feature space", rather than "data space", and so it avoids overfitting.

2.6. Game-based solutions for ASD patients

Game based solutions for diagnosing autism have the advantages of being interactive and developing the children's social skills, however, these solutions present the following weaknesses, detailed in the table below:

Table 2.3 Game-based solutions – advantages and weaknesses

Game-based solutions	Advantages	Weaknesses
Precision-level circles game [9]	• Captures levels of autism. • Available on phones and tablets. • Can be monitored by parents. • Low cost.	• The child can get bored or not interested in the game. • The game has just three colours, that might not be of interest for the child or even get annoyed.
Virtual Reality-based driving system [10]	• High level of interactivity. • Teaches driving.	• Not suitable for children. • Designed for individuals that are at least 18 years old. • High cost of acquisition.
Gesture patterns during smart tablet gameplay [11]	• Gathers complex information about children's motor patterns. • Available on tablet	• Does not detect affective states.
Autism Barta [12]	• Designed to screen autism for children. • Assesses the child's condition and uploads the data into database.	• The questionnaire is based on M-CHAT screening tool, which requires medical professional for evaluation. • High cost

PandaSays application can help with autism diagnosis, by gathering data about the child's emotional state, and does not require special training. The application provides a User Manual module, where is explained how the application functions.

2.7. Conclusions

Autism is a neurodevelopmental disorder and is not fully curable. The hardest part in helping individuals diagnosed with ASD is teaching them to express their emotions towards others and to

socialize with other people. Therefore, ASD should be diagnosed as early as it can be. Autism diagnosed at an early age (< 2-5 years) can help those children develop normally and integrate faster in society when they grow up. Machine learning algorithms contribute to establishing a system for detecting ASD from an early age. Most used algorithms were SVM (Support Vector Machine), decision trees as ADTree (Alternating decision tree).

Wearables are used as systems for communicating affective information to help measuring the affective state.

Robots have a significant role in giving guidance to children with ASD on how to express their feelings or intentions and how to interact with others.

Drawings are useful in obtaining information about the children's affective state and can help diagnose autism from an early age, starting at six months. Drawing interpretation is an important part of the PandaSays application. The application does not require special training, as screening tools do, and a high procurement cost, as other devices presented in this chapter and can be used not only by children diagnosed with autism, but also by children with speech impairment or aphasia.

Based on this chapter, the following article has been published:

"L. Popescu and N. Popescu, "A critical analysis of the technologies used for development of applications dedicated to persons with autism spectrum disorder," 2020 19th RoEduNet Conference: Networking in Education and Research (RoEduNet), Bucharest, Romania, 2020, pp. 1-5, doi: 10.1109/RoEduNet51892.2020.9324880., WOS:000654265900029."

CHAPTER 3. PandaSays - an innovative machine learning based solution for predicting the affective state of children with autism

3.1. Drawing based analyze – a window to children understanding

Early detection of autism (from 6 months to 3 years) can help children to accumulate different skills such as social and communication skills and can help with monitoring their repetitive behavior. This research is focused on children between 2-8 years. The existing studies concluded that children could express their feelings through their drawings. Parents try to understand their children and try to understand what they really need or why sometimes they are upset. Some parents might be certified psychologists, but most of them have normal jobs and cannot interpret their children's drawings.

Drawings can inform how a child interprets the world he notices around him. A simple drawing, that at first glance can appear as insignificant scribbles, can express a child's social behaviour, the relationship between his parents or tutors and other relatives, level of intellect and perception, areas of interest, and if a child is feeling sad, insecure, frightened or introvert.

3.2. Mobile Application details

"PandaSays" is a mobile application designed for children with autism and for their parents, relatives, or tutors to help them improve their communication. The application uses machine learning for evaluating the affective state of the child from what he draws.

The application does not diagnose autism, but helps children already diagnosed with ASD to learn to communicate more efficiently and to increase their social skills. The drawings were gathered from children with ages between 3-8 years old from the following countries: Romania, United Kingdom, Germany, and Spain. In this way it can be proved that the treated problem is universal and the children from all over the world can be emotionally evaluated based on how they express their feelings when playing with lines, shapes, and colors.

The application initially had 4 modules but has been extended later as it will be described in chapters 5 and 6: *Drawing Module, Label Recognition Module, Text-to-Speech Module (*a feature created also for children that are susceptible to aphasia or they have other speech problems*), and Communication with the Robot module.* The application is written in Java and Kotlin Programming languages and follows the MVP architecture (Model-View-Presenter). Python programming language was added further to make connection with the Robot module. The architecture is now MVVM (Model-View-ViewModel), separating the logic from the views, and adding it to the ViewModels. Communication with the Alpha 1P/1E is realized through Bluetooth Communication Protocols and Raspberry PI and the code is written in Python (version 3.9).

3.3. PandaSays Mobile Application Introduction

"PandaSays" [2] is an android mobile application, build up for children with autism and for their parents or tutors to help them make their communication better and try to express what they feel. The application consists in four modules: Label Recognition Module, Drawing Module, Text-to-Speech Module and Communication with theRobot module. The dataset has five classes, representing the children's emotional state. The classes are "happy", "sad", "insecure", "fear", and "angry". The android application detects the affective state of the child from what he is drawing.

Currently, PandaSays application has incorporated in it a custom TensorFlow model, built with MobileNet Convolutional Neural Network. In Figure 1, the output of the model prediction is displayed, the drawing having the result of "insecure" state, with 75% accuracy.

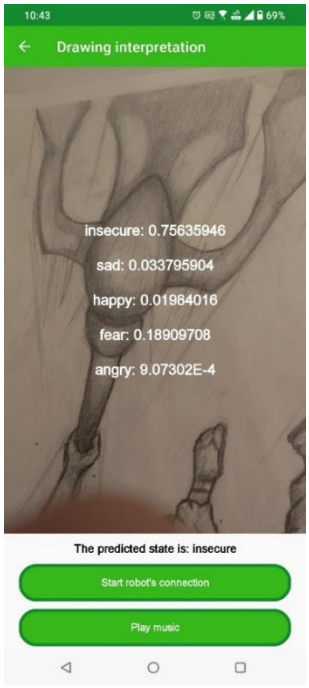

Fig.1. Output of a drawing representing “insecure” state

For the drawings database it is used Firebase Storage. The problem is a multiclass one.

3.4. Comparative discussion between VGG16 and MobileNet, as Convolutional Neural Networks

VGG has two architectures: VGG16 (with 16 layers), and VGG19 (with 19 layers). VGG16 replaces the large kernel sized filters (11 and 5 in the first and second convolutional layer) with 3x3 kernel-sized filters, with stride of 1 and uses same padding and MaxPool layer of 2x2 filter of stride 2. For training the model, in order to predict children’s states from their drawings, it was used VGG16. The dataset was divided into 25% for testing and 75% for training. It was used average pooling, and an “input_shape” = (224, 224, 3). It included a single pretrained convolutional block, to reduce computation time and improve prediction accuracy with small data. The number of epochs was 30, and the batch size 16. Keras [13] data augmentation has been applied by adding the following parameters: "zoom_range”, “height_shift_range", "width_shift_range", "shear range", "horizontal_flip", and "fill_mode". The model trained with VGG16 is underfit, because training loss is decreasing, and its performance is better than the validation set.

MobileNet, with a lightweight architecture, has 30 layers and is based on depthwise separable convolutions - it performs a single convolution on each color channel (Red, Green, Blue) rather than making a combination of all three and applying flattening. The networks are 32 times smaller and 10 times faster than VGG16, although they return the same results.

The accuracy of the model trained with MobileNet was 58%. Figure 5 shows that training loss continues to decrease until the end of the training, so the performance is good, and test loss decreases to a point and begins to grow again, which signifies that the model is starting to overfit.

3.5. Feedforward Neural Network

For applying the feedforward propagation, we maintained the same Keras augmentation to images and we created a new sequential model with four layers. A rectified linear activation function (ReLU) was applied to the first three layers. On the output layer, containing five classes, was applied a Softmax activation function.

The model was trained using Keras library functions (model.fit()). The batch size was 32 and thenumber of epochs was 20. The metrics obtained were loss = 1.5597 (Figure 2) and accuracy = 28.3333%. The accuracy has a significant drop in comparison with the Convolutional Networks which was 58%.

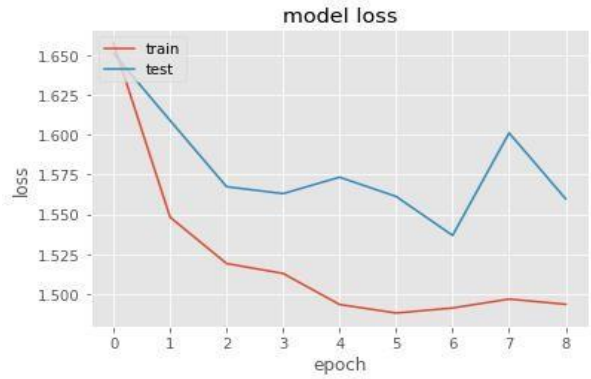

Fig.2. Feedforward Network model loss

3.6. Safety considerations

PandaSays mobile application offers the possibility to upload a drawing, before accessing the Drawing interpretation module. First an alert will be displayed, asking if the user wants to upload a drawing. By clicking “No”, the user is sent directly to the Drawing interpretation module and by clicking “Yes”, the user remains on the same Menu screen, where a drawing can be uploaded.

In Figure 3 it is displayed the “Upload flow”. The user clicks on the button “Take a picture of your drawing”, next the “upload” icon will be clicked. After the “upload” icon is clicked, the machine learning algorithm will start detecting if the drawing contains faces or body parts, and if it does contain any of those, the drawing will not be uploaded into the database of drawings.

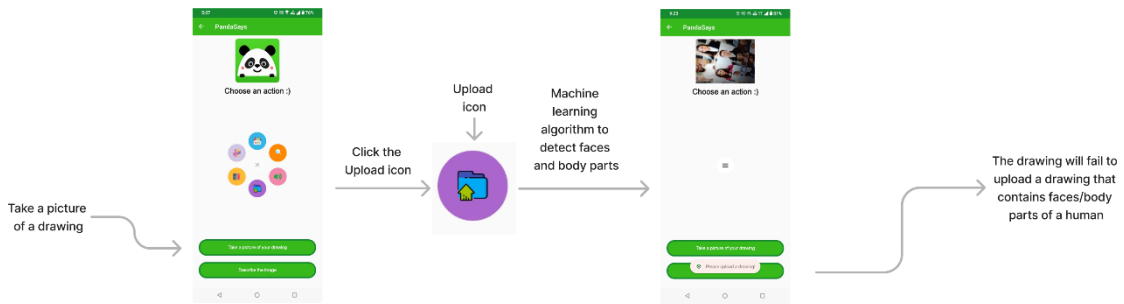

Fig.3. Upload flow

3.7. Data and methods used in the mobile application

As database for the PandaSays application, it was chosen Firebase Database, used for storing a large set of images, but also to give the users the opportunity to upload their own drawing. The dataset of drawings contained at first 597 images. The classes with the number of drawings are: happy (167 images), sad (152), insecure (81), fear (102), and angry (95). The dataset has increased almost three times since the beginning of the application's development.

For training the model, it was used initially AutoML Vision Edge [14], which is a Google product that helps building the machine learning model. The model is trained in Google Cloud.

As expected, the "happy" class was labeled correctly with 80.6% accuracy, and the "insecure" class had the lowest accuracy - 21.4%. The model has been tested with an image, representing an "angry" state with 60.8% accuracy, as shown in Figure 4.

Fig.4. Firebase AutoML Predictions results for angry state

A Convolutional Neural Network model has also been built, that has a total of 426,340,605 parameters and 426,340,605 trainable parameters. Five convolutional layers were used for the model creation. Then Keras data augmentation has been applied by adding the following parameters: "rescale", "shear_range", "zoom_range", "brightness_range", "height _shift_range", "width_shift_range" and "horizontal_flip". The validation dataset and the test dataset represented 20% of the total set of images from the entire labeled data. The highest accuracy was approximately 50% for the test data with a number of 10 epochs. The accuracy will be improved, as will be shown in the next chapters. Further, Transfer Learning was used to predict the model: VGG16 and MobileNet convolutional neural networks.

3.8. Conclusions

Drawings are a dominant tool for gathering data about children's affective state and by knowing the child's affective state they can play a significant role in helping children with autism integrate easier in society and start building connections with others from childhood.

As it was presented in the previous sections, "PandaSays" was developed as a mobile application destined to children with autism and their parents as a virtual friend for improving their communication. The application is a work in progress, and it will be improved further as it is shown in the next section. The dataset is not very large at this moment, and this is reflected in the accuracy of model prediction. The image dataset will be increased to at least 3000 images for better accuracy in prediction, and other machine learning algorithms will be applied.

The machine learning model is overfitting, and the next step would be to use a resampling technique as k-fold cross validation, to estimate accuracy on unseen data.

Studies have demonstrated that robots help children socialize better and can express easier what they feel. The current mobile application will predict the emotional state of children diagnosed with autism. After the state is predicted, the output will be sent to the robot (Marty, NAO or ALPHA 1P, 1E Ubtech Robots) and then, the robots will perform some actions in order to make the child feel better. If he is sad or angry, for example, the robot will start dancing.

To program Alpha 1P robot, a client-server communication will be established using Bluetooth Communication Protocol and Raspberry Pi 4.

Another module that will be introduced is an augmented reality one. For implementing this module, it will be used ARCore and OpenGL, for rendering 2d and 3d vector graphics. ARCore was created by Google for developing augmented reality applications [15].

The results of the research presented in this chapter have been published in:

- *"L. Popescu and N. Popescu, "Machine Learning based Solution for Predicting the Affective State of Children with Autism," 2020 International Conference on e-Health and Bioengineering (EHB), Iasi, Romania, 2020, pp. 1-4, doi: 10.1109/EHB50910.2020.9280194. WOS:000646194100068"*
- *"A-L. Popescu and N. Popescu, "Neural networks - based solutions for predicting the affective state of children with autism," 2021 23rd International Conference on Control Systems and Computer Science (CSCS), Bucharest, Romania, 2021, pp. 93-97, doi: 10.1109/CSCS52396.2021.00023."*

CHAPTER 4. Detecting the affective state of children with autism using mobile application and robot interaction

4.1. Introduction

Chapter 4 is structured as follows:

- Related work section, where there are presented relevant studies that helped the research.
- Third section: "Solution details and Performance Tests Using Deep Convolutional Neural Networks and Residual Neural Networks", where PandaSays application is described, including performance tests by using deep convolutional neural networks and residual neural networks.
- Forth section: "PandaSays Application - The Updated Machine Learning Model" – presents an update of the machine learning algorithm.
- Fifth section: "Alpha 1 series Bluetooth Communication Protocol" presents the Alpha 1 series Bluetooth communication protocol, emphasizing the whole strategy for establishing the Bluetooth serial communication between Raspberry Pi and Alpha 1P robot, using a SPP (Serial Port Profile) application.
- Sixth section: "Comparison of the Communication Times from Candidate Devices" displays the comparison between Raspberry Pi 4, Native Alpha 1P Android App, and BlueSPP Android App, underlying the evaluation results based on their connectivity time.
- Seventh section: "PandaSays Mobile Application and Accessibility Integration" exposes the accessibility features used by the application.
- The last section: "Conclusions".

4.2.Robot - based solutions for behavioral support and understanding

Humanoid robots are used as a teaching tool to help children diagnosed with autism communicate better and learn new things, as reading, mathematics, foreign languages and so on.

In the paper "Humanoid Robot NAO as a Teaching Tool of Emotion Recognition for Children with Autism using the Android App" [16], Mohd Azjar Miskam and his colleagues, describe how they used the interaction of the humanoid robot NAO with children that were diagnosed with autism, by playing a game. NAO robot executes a couple of emotional poses, developed with Choregraphe and shows them to children. The robot is controlled by an Android application, via WIFI connection. "Manage Behaviours", it is a button that, when is clicked, the user can play a pose they choose from the robot. Also, it has a "Refresh" button to reset the connection with the robot.

The purpose of these behaviors is to teach the child how to interpret emotions and start learning to use them. NAO robot displays the following emotions: angry, happy, tired, scared, shy, disgusting, sad, and loving.

A pre-test demonstrated that the child recognized the emotions shown by the robot. Studies [17] and [18] have shown that several emotions such as anger, happiness, fear, sadness, when listening to music, arouse in those who listen.

J. M. Beer, in his paper [19] exposes how important music is as a therapy for helping children with autism. The aim of this paper was to use robots (they used NAO robot) in music therapy to help children with autism, taking in consideration the number of times the therapist intercedes to help the child engage with the robot and the number of times the child imitates a robot's dance movement [19].

Paper [20] illustrates how the use of humanoid robots in improving children's social skills, that are diagnosed with autism spectrum disorder. The study concluded that embedded reinforcement

theories and scaffolding have proved that robots are effective in motivating children and improve their learning and communication skills.

The paper “Developing therapeutic robot for children with autism: A study on exploring color feedback" [21] proposes to investigate the feedback received from therapy with children diagnosed with autism, by engaging with a robot that uses colors in different conditions. Four colors were used for gathering feedback: yellow, red, green, and blue. The child's favorite color was kept as a goal for the task, and the one that was disliked by the child was eliminated. For the experiment a Touch Ball was used that incorporated a sensor that calculates the three axial forces. The paper concluded that the feedback obtained from touching the device is more effective than the one resulted from the touching forces of the caregiver.

The advantages of the robot-based solutions are that they are using humanoid robots that help children diagnosed with autism to communicate better and also to be integrated in schools as a teaching tool. The major disadvantage of those solutions is that the cost of acquiring such a robot is very high.

4.3.Solution details and Performance Tests Using Deep Convolutional Neural Networks and Residual Neural Networks

PandaSays mobile application offers the possibility to draw and to upload a drawing. The image is interpreted by a machine learning algorithm. Studies have shown that drawings can reveal emotions and feelings [22]. The application’s purpose is to interpret the affective state of the child from what he draws, without the need of seeing a psychologist to perform this action.

The dataset contained at this moment 1279 drawings, divided into five classes, representing 5 affective states: “happy”, “fear”, “sad”, “angry”, and “insecure”. The whole training data set has been validated by a professional psychologist specialized in interpreting children’s drawings.

In our previous work [23] we made an analysis of Convolutional Neural Networks and Feedforward Neural Networks, in order to find the best model to predict the affective state of the children from their drawings with the highest accuracy. In the chapter, we concluded that MobileNet [24] neural network performed better than other neural networks. The new results will be presented further in this chapter. The dataset was split as follows: 80% for training and 20% for testing. For the image data processing, Keras ImageDataGenerator [25] has been used.

VGG16 (“Vision Geometry Group”) was used first to train the model. For the training, the fully connected output layers of the model are not added and for weights, the “ImageNet” was selected to be used. For compiling the model, it was used “Adam” (adaptive moment estimation) optimizer, which is one of the optimization algorithms that operates sparse gradients on noise, with a learning rate of 0.001; for loss it was used “categorical_crossentropy”.

The loss by applying VGG16 was 1.8508 and the accuracy had the value of 50.9375% (Figure 5). The number of epochs was 40 and the batch size was 16.

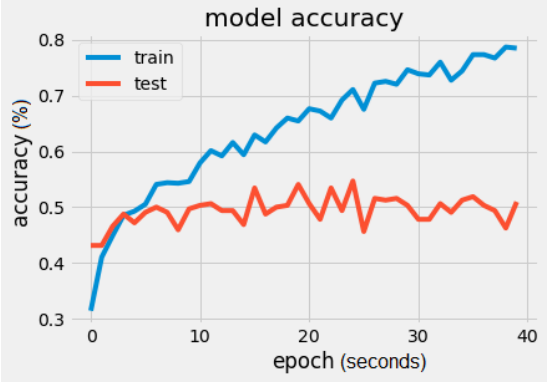

Fig.5. VGG16 model accuracy.

The “imagenet” dataset was utilized as weights for building up MobileNet model; the the number of epochs was 40 and the batch size was 16.

There is a significant difference regarding the trainable parameters between the VGG16 model and the MobileNet model. MobileNet has 5005 trainable parameters and VGG16 has 2,102,277. The metrics values were loss = 1.5260 and accuracy = 56.2500% (Figure 6).

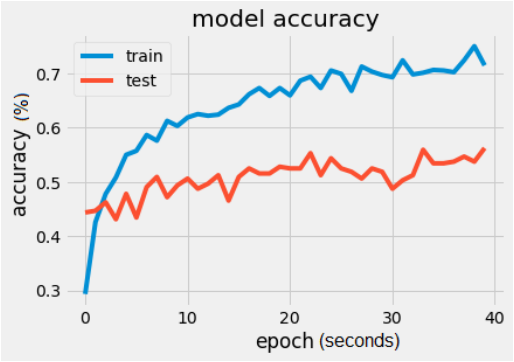

Fig.6. MobileNet model accuracy.

As shown in Figure 7, the main output can be observed, which shows that the drawing represents an “angry” state, with 92% accuracy, when using PandaSays app with the MobileNet model.

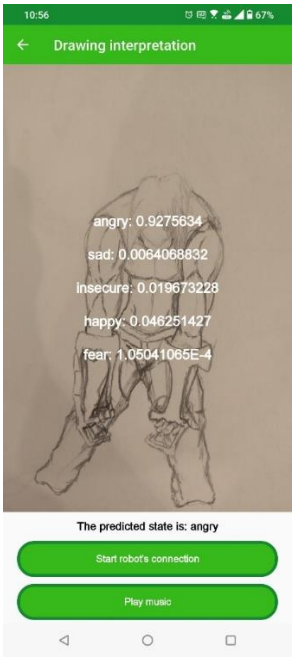

Fig.7. PandaSays drawing interpretation.

ResNet50 (Residual Neural Networks) from Keras was also used to train the model. For weight, it was chosen the "imagenet" dataset, as input tensor it was used the input of shape of (224,224,3), signifying the width (224 pixels), height (224 pixels) and the number of channels (3 – color channels), and a single pre-trained convolutional block was included (include_top = False).

The ResNet50 model's loss was 1.5041 and the accuracy obtained was 47.6562%. The highest accuracy is obtained by MobileNet neural network with 56.25%, followed by VGG16 with 50.93%. Although the smallest accuracy is obtained by ResNet50 neural network, its loss is the smallest, followed by MobileNet's loss of 1.5260%. For the PandaSays android application, it was chosen as the model built with MobileNet neural network because it obtained the best accuracy.

4.4.PandaSays Application -the Updated Machine Learning Model

In articles [23] and [26], we introduced PandaSays android application, that has a machine learning model to predict the affective state of the child from what he draws. For obtaining better accuracy, it was used transfer learning with Tensorflow library [27] and Keras [28]. It was chosen as the model trained with MobileNet [29] neural network to incorporate in the application.

The current database contains 1453 drawings (starting from 597 drawings). The dataset was divided into 25% for the testing set and 75% for the training set. The number of epochs was 30 and the batch size was 16. The accuracy of the model trained with VGG16 was 35% and was underfitting. The accuracy obtained by training the model with MobileNet, was 58%, which was smaller than the updated one - 84.583%. The accuracy obtained with Feedforward neural was just 28.3333%. The previous model from the application was replaced with the updated one, but also built with MobileNet. As weights were given the "imagenet" [30] dataset.

To evaluate the model, it was applied a K-fold cross validation, where K is equal to 10. The batch size was 32 and the model was trained for 50 epochs. The metrics gathered were accuracy and loss. The accuracy for 10 folds is shown in Figure 8. The train accuracy and loss are illustrated with the blue color and the test loss and accuracy are represented with magenta color.

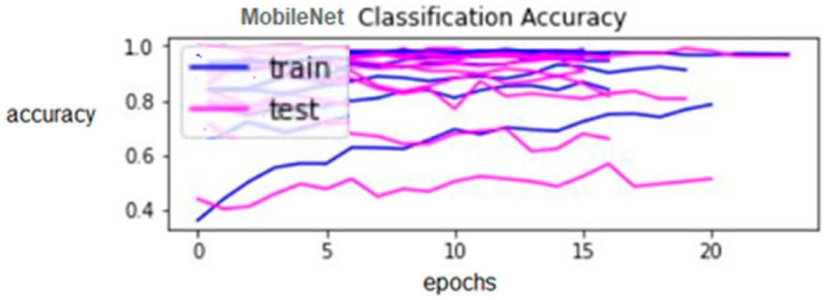

Fig.8. MobileNet model accuracy.

The standard deviation of the ResNet-50 model was 0.030, lower than the MobileNet's standard deviation (0.14). The mean accuracy of ResNet-50 model was represented by the value of 28.463%, which is smaller in contrast to MobileNet's one - 84.583%. The mean loss of MobileNet's - 0.3756 is higher than the ResNet-50's one, which is 1.555. VGG16 obtained a standard deviation of 0.085 and a mean accuracy of 59.867%. The standard deviation is smaller than the MobileNet's one (0.14) and also the accuracy. VGG16's mean loss obtained was 1.006 which is higher than MobileNet's and lower than ResNet-50's.

4.5.Alpha 1 series Bluetooth Communication Protocol

In this section the communication protocol will be introduced based on Bluetooth communication. Alpha 1 Pro robot can be programmed through Bluetooth using the Bluetooth Communication Protocol [31].

Alpha 1 Pro (1P) is a humanoid robot, programed using PRP (Pose, Record, and Playback), that can be useful for entertainment and education. The robot contains 16 high-precision servo joints, 3D visual programming software, and PRP (Pose, Record and Playback) functions that are controlled by an Android/iOS application.

In Figure 9, it is presented how the image is processed by the machine learning algorithm from the application PandaSays, how is uploaded into the Firebase database and how the output, representing one of the states: sad, happy, angry, insecure or fear, is sent to the robot to execute a specific action.

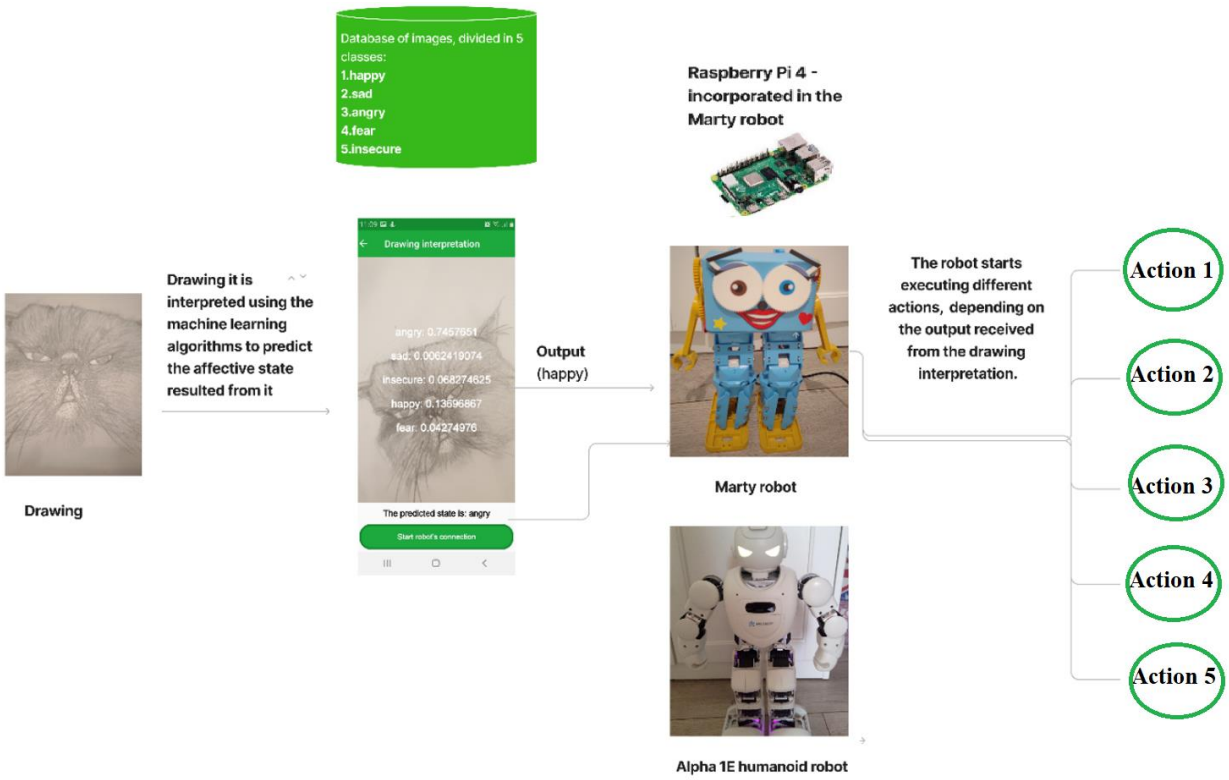

Fig.9. PandaSays Android application flow

4.5.1. Establishing Bluetooth communication with Python

To provide access to Bluetooth system resources on GNU/Linux computers, it will be used PyBluez [32] - a Python extension. The PyBluez module provides a high-level socket interface for establishing a connection between two Bluetooth devices. One acts like a client and the other one as server. In our case, Raspberry Pi is the server and Alpha 1P is the client. In order to obtain the information about the Alpha 1P robot, the command “info” will be used (Figure 10). The information is necessary to realize the client-server connection.

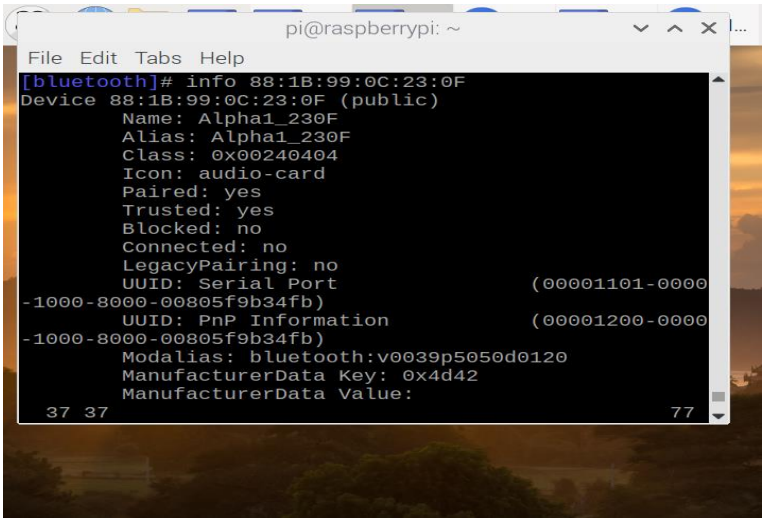

Fig.10. Get information about Alpha 1 Pro

4.5.2. Establish Bluetooth serial communication between Raspberry Pi and Alpha 1P robot, using a SPP application

For establishing a Bluetooth connection and for sending messages to Alpha 1Pro, it was used Samsung Note 9 android device and BlueSPP [33] mobile application. Figure 11 presents the communication between the server and the client.

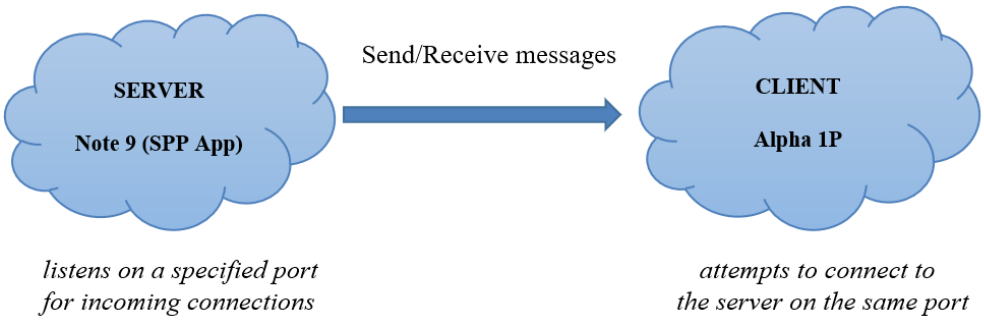

Fig.11. Server-client communication

According to the Bluetooth Communication Protocol document, the robot can perform several actions such as moving leg, arm, kick, move forward, backwards, and so on.

4.6. Comparison of the Communication Times from Candidate Devices

The BlueSPP android application is a Bluetooth Serial Port Profile communication software. The mobile device used was a Samsung S10+ Android phone. A digital watch was chosen for measuring the time. The connection with the Alpha 1P robot, using BlueSPP application, was made in 3.8 seconds. Table 4.1 displays the connectivity time comparison for the robot on every device presented. The best time was achieved by Raspberry Pi (3.23 seconds) through the Bluetooth version, followed by 3.8 seconds with BlueSPP application. The highest time for the connectivity was represented by the Alpha 1 native robot mobile application.

Table 4.1 Connectivity time results for Raspberry Pi, Alpha 1, and BlueSPP Android Apps.

Device/Application	Raspberry Pi/PyBluez Library	Alpha 1 Android App	BlueSPP Android App
Connectivity time (seconds) to Alpha 1P Robot	3.23	28.18	3.8
Bluetooth version	Bluetooth 2.0	Bluetooth 5.0	Bluetooth 5.0
Bluetooth version of Alpha 1P robot	Bluetooth 3.0/4.0 BLE + EDR		

Abbreviations: BLE = Bluetooth low energy; EDR = enhanced data rate.

4.7. PandaSays Mobile Application and Accessibility Integration

15% of the world population is represented by people with disabilities, on the report of the World Health Organization [34]. To help people with disabilities live a normal life and have access to digital services like a healthy person, it is very important that any software application is accessible.

There are two accessibility screen readers applications: “VoiceOver” - which represents a screen reader for iOS applications and “TalkBack” – screen reader for Android devices.

In Table 4.2 is presented a comparison between PandaSays mobile application and other applications designed for children with autism spectrum disorder. As can be noticed from the table, each application is focused whether on music therapy, or on improving communication using Text-To-Speech. PandaSays incorporates all those features in one single application and other features, as affective state prediction and robot module. Moreover, some applications designed for children with autism or with speech impairment are not accessible, which makes them not suitable for children that have visual, speech, or hearing impairment.

Table 4.2 Comparison between PandaSays android application and other android applications for autism

Android Application	**Advantages**	**Accessibility integration**	**Accessibility guidelines**	**Weaknesses**
PandaSays	• Drawing module • Affective state prediction from the child’s drawing • Music therapy integration • Augmented Reality module • Text-To-Speech module • Sign language module • Drawing validation using machine learning algorithms • Robot module • Contains no ads and no subscription plan.	Yes	• Follows the accessibility guidelines regarding title role, buttons’ roles, font, error messages, and images.	• Requires a large dataset of drawings to improve the machine learning algorithm for predicting the affective state.
Music Therapy for Autism [35]	• Contains Music feature. • Designed to improve social skills	Yes	• Has unlabeled images in the application. • The buttons are not announced as buttons.	• Does not follow the accessibility guidelines. • Is not backed up by a psychologist or research. • Contains ads.

Speech Blubs: Language Therapy [36]	• Text-To-Speech • Designed for children with autism to help them speak and learn new words. • Received "Social Impact award".	Yes	• The title of the new screen is not announced as "heading". • Contains unlabeled images.	• Requires a subscription plan. • Must improve its accessibility feature.

4.8. Conclusions

Humanoid robots play an important part in helping children diagnosed with autism. As several studies demonstrated, children are keener to interact with a robot than with their parents, doctors, or tutors. Robots can teach children how to express feelings, how to communicate better and how to relate with other children. Communication with the robot is one of the important parts in the PandaSays mobile application.

The contributions brought by this chapter are:

- In this chapter, it was exposed that the best trained model was MobileNet, obtaining an accuracy of 84.583%.
- Setting of a control method for connecting the robot Alpha 1 Pro with PandaSays android application, utilizing Bluetooth communication protocol.
- Developing a robot module that uses the robot's communication protocols to establish a connection with PandaSays android application, which will be utilized further to control the robot and send the machine learning response to it, in order to perform a certain action.
- Creation of the Python module for establishing client - server communication.
- Executing a configuration setup of the Raspberry Pi and robot's Bluetooth communication protocol, utilized to measure latency and connectivity time.
- The effectiveness of utilizing Raspberry Pi with PyBluez to create a client - server connection, exposed by the lowest latency (3.66 seconds) and by the connectivity time of 3.23 seconds, which was faster than the Bluetooth connection on other devices such as: Android Device, BlueSPP application.
- Highlight of the importance of humanoid robots in helping children diagnosed with ASD.
- The importance of accessibility in an application.
- Comparison between PandaSays android application and other android applications.

The results of the research developed and presented in this chapter have been published in the following papers:

- *"Popescu, A.-L.; Popescu, N.; Dobre, C.; Apostol, E.-S.; Popescu, D. IoT and AI-Based Application for Automatic Interpretation of the Affective State of Children Diagnosed with Autism.* Sensors *2022, 22, 2528. https://doi.org/10.3390/s22072528. WOS:000781611200001"*
- *"Popescu, A.-L.; Popescu, N. Drawing Interpretation Using Neural Networks and Accessibility Implementation in Mobile Application. Computation 2022, 10, 202, WOS:000894595500001. https://doi.org/10.3390/computation10110202.*

CHAPTER 5. Enhanced framework for persons with autistic spectrum disorder

5.1. Music-based therapy

In this chapter, it is presented the enhanced application flow with updates of PandaSays and the experiments that validates the solution. The current chapter is divided into 4 sections: Introduction, PandaSays mobile application - music feature, Case Study Using PandaSays Application and the robots Marty and Alpha 1P, and Conclusions.

Throughout the years, multiple studies have demonstrated that humanoid robots can help children diagnosed with autism and can improve their communication and learning skills. Moreover, schools have adopted humanoid robots as a teaching tool. Another important point is the use of Music Therapy for helping individuals improve their communication skills and overcome emotional challenges. Through music, therapists help children diagnosed with autism to improve their social skills and decrease anxiety [37]. Also, clinical studies show that music can be used as an alternative treatment for dementia, depression, autism, as will be shown further in this section.

The study "Music-Enhanced Emotion Identification of Facial Emotions in Autistic Spectrum Disorder Children: A Pilot EEG Study", presents a pilot study that exposes the use of music as a technique to improve emotion recognition for the children diagnosed with autism. The sessions were 15 minutes long. In the study participated 25 children, with the mean age of 8.8 years [38]. The participants were divided as follows: 14 into the experiment group and 11 into the control group. Images of facial expressions, representing four emotions: happy, sad, angry and fear, were presented to children. The images were shown accompanied by music. As a result, the accuracy of responses regarding emotion identification increased by 26% for the experimental group. Moreover, the emotional responses of the experimental group demonstrated a higher link with the emotional stimuli. The study concluded that music can be used to improve emotion detection in facial expressions and emotion induction.

Article [39] presents a desktop and smartphone application that have as features: playing songs and changing it according to the disposition. The application focuses on analyzing facial expressions and monitoring them. The aim of this application is to help patients with mood disorders or forms of neurological diseases, using music as therapy. Through a camera, the application captures the facial expression, interprets the state, and then communicates with the music module. The machine learning model was trained using SVM. The application's system design contains three steps: face detection, interpretation of the state and emotion prediction. An enhancement was brought to the model, using Active shape models (ASM). The music module contains 6 songs that correspond to the moods. The accuracy obtained was 60%. The hardest mood to predict was "disgust".

The paper "Effects of Music Therapy on Vital Signs in Children with Chronic Disease" investigated the implications of music therapy on hospitalized children's vital signs [40]. There were 377 music sessions, representing 177 active therapy and 200 receptive therapy. In the ICU department was noticed an improvement on the heart rate – was reduced by 17.9 beats per minute. In order to investigate the effects of music on oxygen saturation, heart rate and blood pressure, the protocols of the music therapy sessions were investigated. There were between two and four sessions per week. The oxygen saturation was bigger before holding the music therapy session. At SCU, the diastolic blood pressures were lower than before the music therapy session, and after the session they start to increase. The results concluded that the music therapy sessions led to an increase in oxygen saturation, and a decrease in the heart rate, helping children be more relaxed and to get away of anxiety.

Music therapy represents an important subject in helping children diagnosed with autism and helping them express their feelings. In this context, in the PandaSays application, the Music module was introduced, to create a more complex solution for children diagnosed with ASD.

5.2.PandaSays mobile application – music feature

In our previous article [41] and [42], we talked about the communication between the PandaSays mobile application and the following robots: humanoid robot Alpha 1P, from Ubtech company and Marty robot. The state resulted using the machine learning algorithm on a drawing, it is sent further to the robot, where some preconfigured actions will be performed by it, depending on the child's affective state. Numerous studies have demonstrated that music therapy can help children diagnosed with ASD communicate better and enhance their social skills. Because of the importance of music therapy, classical music was integrated into PandaSays mobile application, and, in this context, a new framework was developed.

5.2.1. PandaSays Music Module presentation

In Figure 12 is presented the PandaSays application flow with the Music module. The drawing is sent to the Drawing interpretation module, where it is obtained the affective state. Further, the user has two options: to reach the Music Module directly, where a classical music song will be played automatically, or select to go to the Robot Module. When the state it is sent to the Robot module, the robot will start to do different actions, depending on the output of the machine learning algorithm and play a song.

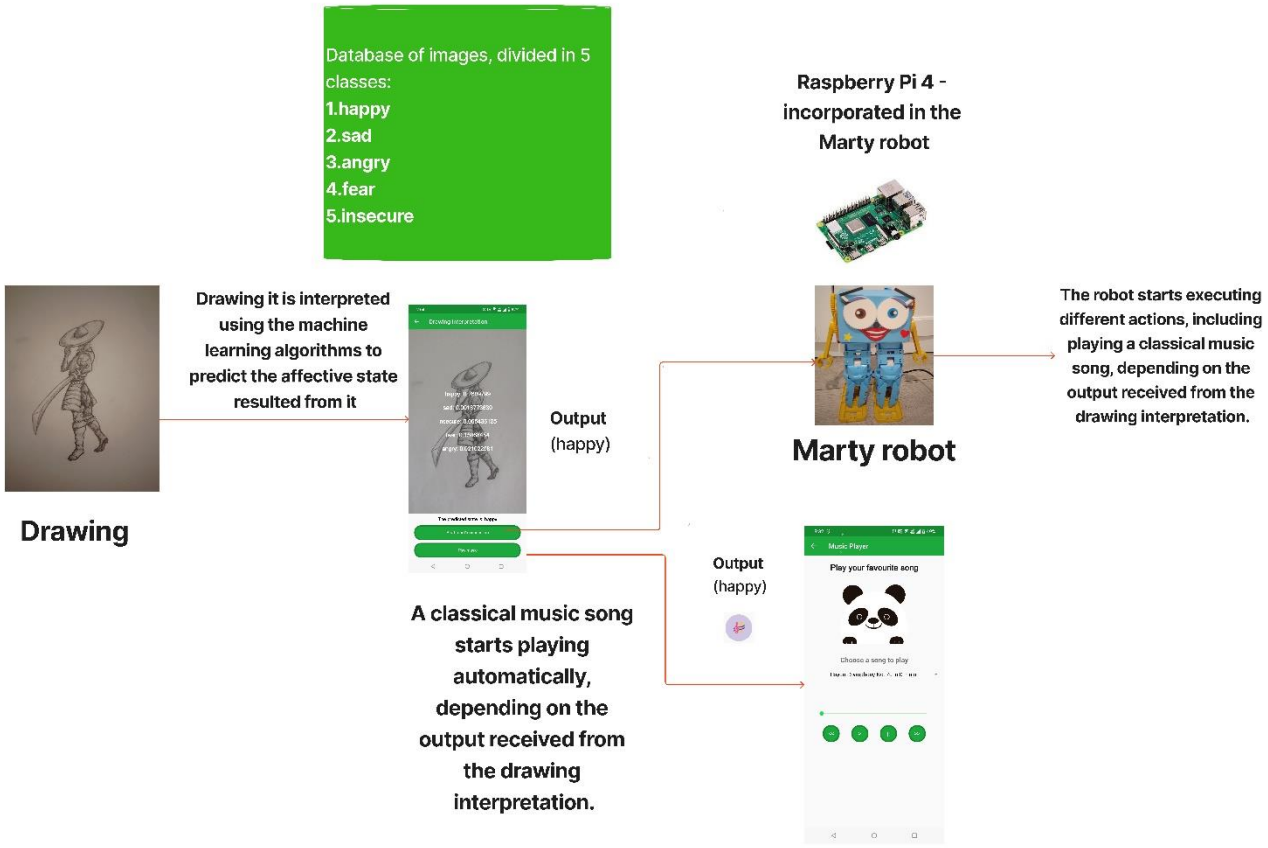

Fig.12. PandaSays app flow with Music module integrated

For playing specific song, module “pygame” was used. It was implemented a method “play_song”, that searches for available audio devices, that have Bluetooth activated, and when it finds one, will start playing a song, depending on the state received from the Drawing module.

5.2.2. PandaSays Music Module accessibility

The application continues to follow the accessibility rules and guidelines. The title “Play your favourite song”, has the role of “heading”, being the first element that is read when reaching the screen. The other elements on the screen are focusable and all have descriptions to help the user navigate easily into the application. Error messages are also shown to the user in case there is an error returned from the server, and the error message is clearly read by the accessibility service and the color is appropriate, following the accessibility guidelines.

5.3. Case Studies Using PandaSays Application and Alpha 1P and Marty robots

Mihnea was diagnosed with autism at the age of three, and now he is 8 years old. He is doing therapy, going to a special center for children diagnosed with autism. The child mostly does a scribbling and not a specific figure or element like a house, trees and so on. The PandaSays application’s prediction algorithm was tested on multiple drawings of the child. An important point to be mentioned that not every child diagnosed with ASD likes to draw, this cause can be linked to the motor difficulties or repetitive behaviors specific to ASD.

After the child finished his drawing, it is sent to be interpreted by the Drawing Interpretation Module from the application, as it can be seen in Figure 13. The algorithm predicted the first drawing as “insecure”, seen in picture (a), with 88% accuracy.

In section (b) of Figure 13, the result of the machine learning algorithm is the “happy” state, with 54% accuracy, having on the second position the state “fear”, with 40% accuracy.

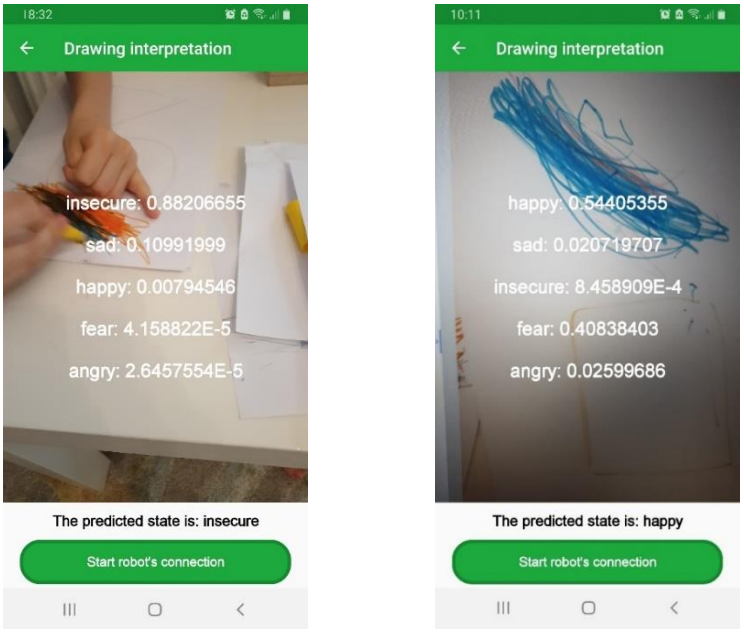

Fig.13. (a) “insecure” affective state prediction when child was drawing; (b) “happy” affective state prediction of the child’s drawing

After the algorithm has interpreted the drawing, the user has the possibility to make a connection to one of the robots incorporated in the application: Marty or Alpha 1P.

Andrei is six years old, and he started receiving therapy in Germany for two years. The child speaks German and very little Romanian language. We made an online meeting with Andrei, to observe his interaction with the Alpha 1P humanoid robot and with Marty. He was very excited and happy seeing the Alpha 1P dancing. Andrei likes to draw, and his drawing's interpretation is shown in Figure 14, where it can be noticed that his affective state is "happy" with 70% accuracy.

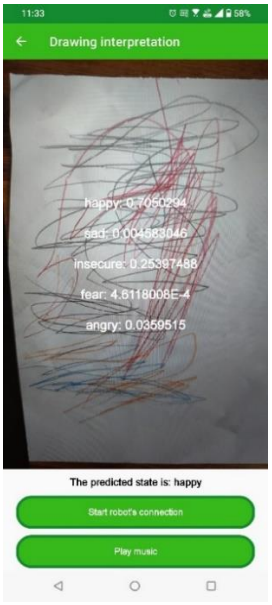

Fig.14. Drawing state prediction

5.4. Alpha 1E/Alpha 1P application flow

In chapter 4 we talked about the establishment of the Bluetooth communication between Raspberry Pi and Alpha 1P robot. In Figure 15, it is presented the application flow using humanoid robots as Alpha 1E and Alpha 1P. When clicking the "Connect to the robot" button, another application will be launched through an Intent, and the robot connection will be made through Bluetooth. The robots will start executing specific actions, depending on the output received from the Drawing Interpretation module. For creating the new application, "kivy" [43] library was used and Python version 3.9. The application does not have a design. Its main purpose is to create the robot's connection via Bluetooth so the robot can start doing some actions.

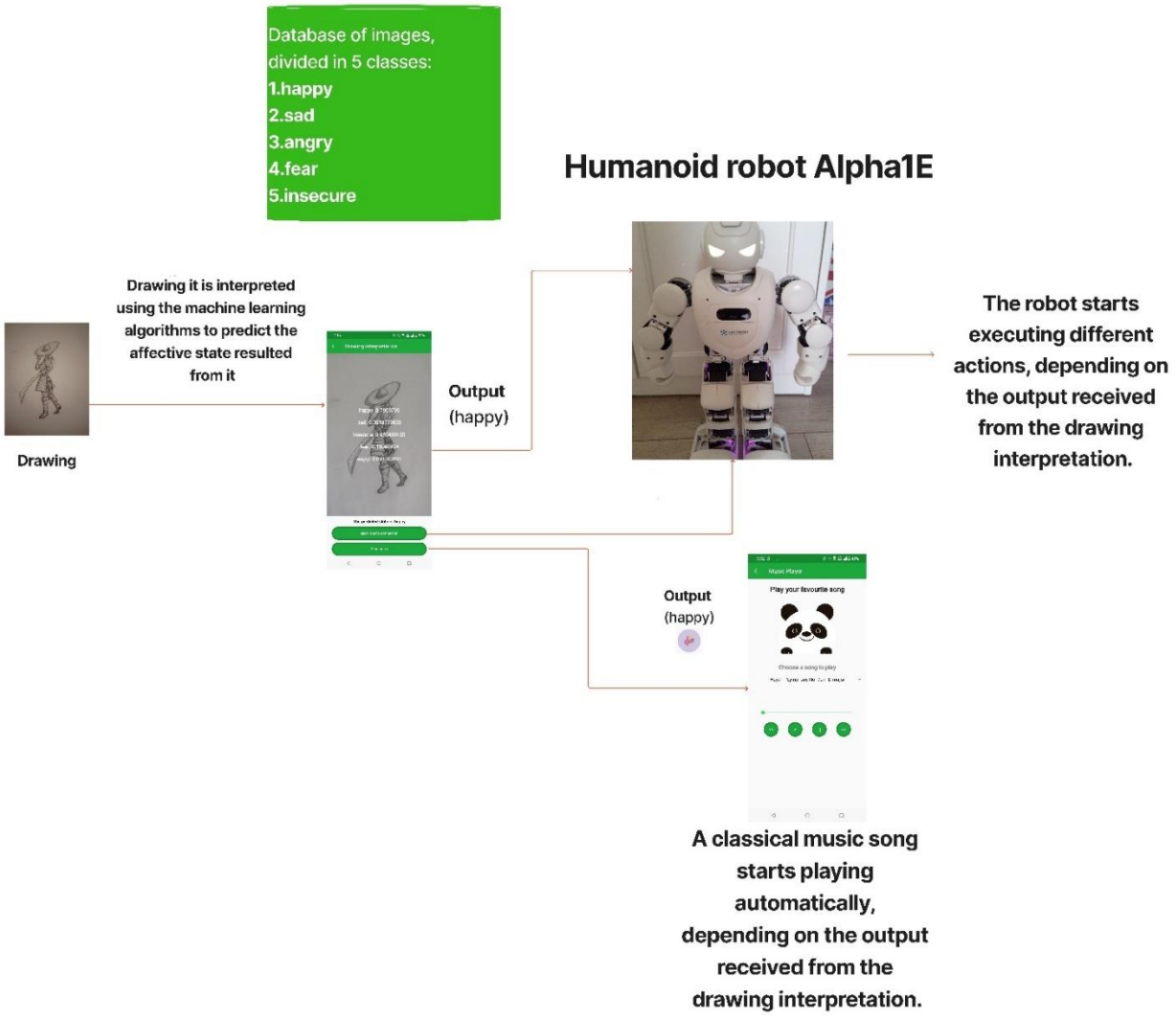

Fig.15. Alpha 1E/Alpha 1P flow

The connection was realized in 3.24 seconds. For Alpha 1P, the connection time was 3.23, as described in Chapter 4.

5.5. Conclusions

Music therapy is an important factor for helping children diagnosed with ASD. Numerous articles have demonstrated its utility. In this section we tried to reflect why we have chosen to integrate a Music module into PandaSays application. The user can choose to connect to a robot and listen to a classical music song or choose to go directly to the music module, based on the affective state resulted from the machine learning algorithm.

CHAPTER 6. Conclusions

6.1. Final remarks

Autism is a neurodevelopmental disorder that can never be entirely cured. Diagnosing autism from an early age can help children integrate better in society and develop social skills.

As presented in this thesis, numerous related papers have demonstrated that the child interacts better with a device, whether it is a phone, tablet, or robot. In this context, PandaSays application was developed. The application functions on android devices as phones and tablets and the robot connection for Marty it is available only within the Android application, whereas the connection with the humanoid robots Alpha 1E and Alpha 1P can be deployed separately on other operating systems as iOS or Web. To create an integrated system, we have chosen to present the flow on an android device.

In the second chapter we presented the related existing devices and tools to predict the affective state of the child that was diagnosed with ASD or to improve his communication with his parents or tutors.

Screening tools are helpful in diagnosing autism, detecting behaviors or social skills, but they can misdiagnose autism as the screening tests are sensitive to data gathered from people that have other psychiatric diseases.

Wearable devices are characterized by a high cost of acquisition, low access to them and time consuming, as the data must be gathered after the child was monitored and further sent for a more rigorous analysis. Moreover, some of the devices are not suitable for children or by trying to make the child wear them, might make him anxious or nervous.

Eye-tracking devices, as the wearables, have a high cost of acquisition and are available only in medical facilities or special clinics. Those devices detect autism spectrum disorder after the age of eight, and the main goal is to detect autism as early as possible.

Game based solutions for diagnosing autism spectrum disorder have the advantages of being interactive and developing the children's social skills.

Robot-based solutions demonstrated that with the use of humanoid robots, can help the child learn new foreign languages, arithmetic, sign language, and vocabulary.

Considering all the solutions described in this thesis, after the investigation, we found out that our proposed solution does not exist yet, so it was the main motive to develop it.

In the third chapter, we started to make experiments related to the best model to incorporate in the application. We concluded that MobileNet represented the best one, as it has fewer parameters than VGG16 and ResNet and it is smaller than the others mentioned. Moreover, the accuracy obtained by training the model created with MobileNet was 58 %, greater than the one built with VGG16 – 35%. To mention that the dataset was constantly increased.

In the fourth chapter, we continued to update the machine learning model, as the dataset reached 1453 drawings. The new accuracy obtained for MobileNet was 84.583 %, and for VGG16 – 56.25%. After having a stable machine learning model, we started to make the connection with the robot via Bluetooth communication protocols for Alpha 1E and Alpha 1P and via IP address for Marty robot. The application was used by one of the child diagnosed with autism, as described in the fifth chapter, and the results were: the child's drawings reflected the child is happy, and he enjoyed playing with the robot.

The fifth chapter proposed to make an introduction about music therapy and present the advantages of using it for children diagnosed with autism. In this context, we have integrated a Music Module, containing 5 classical music songs that were known to help children with autism spectrum disorder.

6.2. Contributions of the thesis

As experiments have shown, the contributions provided by this thesis can be considered relevant for the eHealth solutions dedicated to automatic affective state evaluation and support for children diagnosed with autism. They are listed below as follows:

- A critical analysis of the technologies used for the development of the applications created for individuals diagnosed with ASD has been realized. In this purpose the most relevant technologies for communication and affective state evaluation of the child diagnosed with autism were presented.
- A machine learning solution for the mobile application has been developed, that can be easily used for everyone that needs it. The algorithm uses MobileNet neural networks to evaluate the affective state of the child based on his/her drawings, without the need to go to a certified psychologist, as the dataset is already validated by one.
- It was developed a complete and comprehensive solution that consists of seven modules: Drawing module, Drawing Interpretation Module, Music therapy module, Augmented Reality module, Text-To-Speech module, Sign Language module, Robot module.
- A comparison between neural networks as MobileNet, VGG16, ResNet and Feedfoward Neural network has been made in order to find the most suitable model for the PandaSays android application. We analyzed the F1-score, recall, precision, and accuracy.
- The integration of a humanoid robot in the application, via Bluetooth communication protocols has been done, in order to make the application more interactive and more engaging for the child.
- It was realized the evaluation of the importance of accessibility for children diagnosed with autism or with visual, speech or hearing impairments and integrating this in the application, respecting the accessibility guides.
- A robust analysis of the music therapy studies has been done; in this context, the best classical music compositions have been selected to be integrated into the PandaSays application.
- A comprehensive framework for persons with autistic spectrum disorder has been developed based on aspects that can improve behavior and can determine a better evaluation of the emotional state and providing also with good therapeutic benefits.

6.3. Future Work

PandaSays application development has just opened a very promising research path. As future work, the following actions are considered:

- Improve the machine learning model.
- Increase the dataset of drawings and validate them.
- Apply the solution in more Autism Centers in order to improve it based on the analysis of the results in different cases.
- Test the application with the robots in schools or numerous events where children are present.
- Develop the application on other operating systems such as iOS and Web.
- More tests will be done in the case of robot usage, creating a stronger link to the Music Module.
- Continue the Augmented Reality module, by building a game.
- Render a specific space in virtual reality, depending on the machine learning output from drawing's interpretation.
- Translate the application in German language since it has been requested from the community from Germany involved in therapies development for autism.

List of Publications

Papers Published in International Conferences:

1. L. Popescu and N. Popescu, "Machine Learning based Solution for Predicting the Affective State of Children with Autism," 2020 International Conference on e-Health and Bioengineering (EHB), Iasi, Romania, 2020, pp. 1-4, doi: 10.1109/EHB50910.2020.9280194, WOS:000646194100068.
2. A. L. Popescu and N. Popescu, "A critical analysis of the technologies used for development of applications dedicated to persons with autism spectrum disorder," 2020 19th RoEduNet Conference: Networking in Education and Research (RoEduNet), Bucharest, Romania, 2020, pp. 1-5, doi: 10.1109/RoEduNet51892.2020.9324880. WOS:000654265900029
3. A. -L. Popescu and N. Popescu, "Neural networks - based solutions for predicting the affective state of children with autism," 2021 23rd International Conference on Control Systems and Computer Science (CSCS), Bucharest, Romania, 2021, pp. 93-97, doi: 10.1109/CSCS52396.2021.00023.

Papers Published in Journals:

1. Popescu, A.-L.; Popescu, N.; Dobre, C.; Apostol, E.-S.; Popescu, D. IoT and AI-Based Application for Automatic Interpretation of the Affective State of Children Diagnosed with Autism. *Sensors* 2022, *22*, 2528. https://doi.org/10.3390/s22072528. WOS:000781611200001 (ranked Q2, IF = 3.847)
2. Popescu, A.-L.; Popescu, N. Drawing Interpretation Using Neural Networks and Accessibility Implementation in Mobile Application. *Computation* Journal 2022, 10, 202. https://doi.org/10.3390/computation10110202. WOS:000894595500001(ranked Q2)

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