Models For Facial Expressions With Low-Cost Table-Top Robots

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"This thesis is dedicated to my parents!"

Abstract

Social robotics is a very interesting field of robotics, which is growing at a very rapid pace so it is necessary for social robots to become more communicative and engaging through non-verbal communication, It is very important for them to understand human expressions and emotions.

This thesis work focuses on studying various models for facial expressions of Emotions like the circumplex model of emotion and we are also creating a Facial mimicking model which can imitate human emotions on a humanoid tabletop robot(Professor Einstein Robot) and designing various emotions like happiness, sadness, anger, disgust, fear etc., Implementation of these models on professor Einstein robot and finally performing qualitative and quantitative analysis of the results of both models.

For testing these emotional models we make use of the humanoid companion tabletop robot "Professor Einstein" by Hanson robotics. The robot is connected via open-face software for the detection of facial features and expressions.

Keywords: Social Robots, Non-verbal Communication, Expressions, Emotions, Tabletop robot, Professor Einstein Robot.

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Chapter 1

Introduction

Social robotics is a fascinating field in which humans and robots can communicate with each other just like the interaction between humans. The research in the field of social robotics and human-robot interaction is being moved at a rapid pace. Now the technology of robotics is such that anyone can have a robot at home and is very much accessible.

Consider a small social companion robot at home waking you up early in the morning as a friend, interacting with you when you are bored, telling your day today schedule which you ask them, and understanding your facial expressions and emotion when you are at your office and cheering you up when you are at a bad mood. Doesn't all these sound exciting? All these examples given are no more fantasy and are actually happening in the real world with rapid growth in the field of social robotics.

So now let us discover the scenarios presented above, a robot waking you up with its voice, making gestures to show something you ask for and understanding your emotional state through expressions and reciprocating through emotions.

So the interaction between humans and robots can take place in two ways:

Verbal Communication and Non-verbal communication

Verbal communication: In this way of communication, humans and robot can interact with each other with the help of words, sentences, language and most importantly voice as the main medium of communication. Example: A small social robot guiding a person with the required address while travelling.

Non-verbal communication: In this way of communication, Humans and robot can interact with each other with the help of body language, tone, and pauses in speech, facial expressions, as a medium of communication. Example: In the present world, there are many robots which look similar to humans like Ameca by Engineered Arts, Sophia by Hanson Robotics, and a humanoid robot which resembles professor Einstein by Hanson robotics etc.

In this thesis, we mainly concentrate on the interaction between Robots and Humans through Non-verbal communication, i.e., mainly with the means of facial expressions and emotions. We conduct research on the various facial expressions and evaluate the numerous emotions generated through the professor Einstein robot by Hanson robotics[1].

Professor Einstein robot is a tabletop humanoid companion robot. Table-top robots are very small in size, and compact and they are comparably cheap robots. They have very limited sensorimotor capabilities. They are capable of human-robot interaction like interacting via voice commands and facial expressions. This robot's face is built with a material called Frubber, a proprietary nanotech skin that resembles human skin.

The main aim of this research is to experiment with professor Einstein robot's facial features and its sensorimotor capabilities, to check how the robot's expressions can generate various emotions through a very famous psychological emotional model which describes a wheel of emotion in a two-dimensional circular space which has arousal and valence dimensions called the "Circumplex Model of Emotion". We first create a software program which can take arousal and valence as inputs and then test, how the robot's face can generate emotions at various dimensions of valence and arousal. Then verifying the correctness of detected emotions.

In the next part, we define and create another software architecture which can Mimick or Imitate human facial expressions through the computer's web camera. Implement this model on the Einstein robot. At the end verify the correctness of detected facial expressions and generated emotions. For this purpose, we use various tools like Openface, Computer vision, and Py-feat for the detection of facial features, mapping, and detection of expressions and emotions.

In the end, we compare the results of both models through quantitative and qualitative analysis with the help of various graphical interpretations and preparing a questionnaire and conducting a survey from various people. We collect all these responses and perform a statical analysis of the survey. In the last part, we present the conclusion of the thesis with the prospective future work.

1.1 Overview of the Thesis

The thesis is divided into five chapters.

The dissertation's opening chapter acts as an introduction to the remaining work.

Chapter 2, deals with all the background information and terminologies required to understand the thesis.

Chapter 3, explains how the Circumplex Model of Emotion and Facial Mimicking Model were designed and implemented on professor Einstein Robot.

Chapter 4, gives the results of the thesis, and different cases for experimenting

Chapter 5, provides the conclusion of the thesis with future prospects.

Chapter 2

Background

This chapter deals with all the background information and terminologies required to understand this thesis report

2.1 Facial Expressions and Emotions

As we discussed in the previous section Facial Expressions and Emotions are a form of Non-verbal communication. Let's see what are facial expressions.

One or more motions or positions of the muscles beneath the skin of the face compose a facial expression. These movements express the emotional state of an individual person to the observer. The most general and common facial expressions observed are anger, surprise, sadness, neutrality, happiness, fear and disgust.

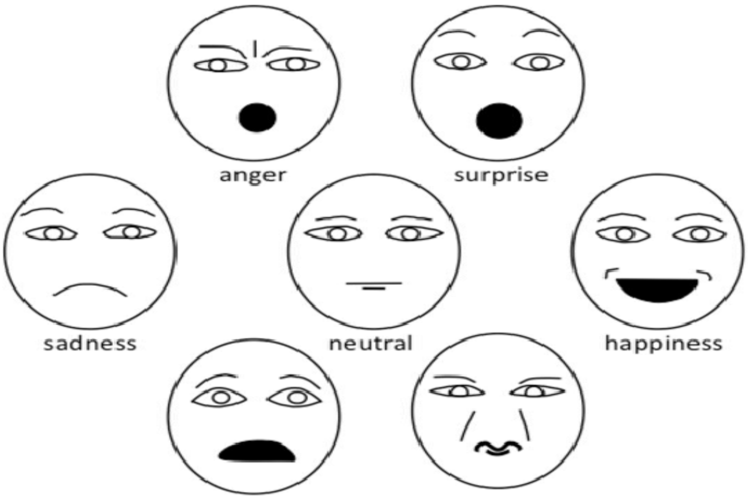


Figure 2.1: Different emotions

2.1.1 Emotions

Emotions are the spontaneous reactions that people experience when they come across certain situations. For example,a student who passed his examination with a good grade experiences happiness, and A student who failed his examination experiences sadness. As you can see from the example the event of the examination is the same, but the if the result is positive then there is a positive emotion and if the result is negative there is a negative emotion.

Our day to day decisions is also based on our emotional state like happiness, sad, anger, disgust etc. They have a strong influence on our life. For example:If We are working in the office and we are happy, then we are very productive at work. If we are sad or angry our productivity automatically decreases.

2.1.1.1 Emotion expression in human interaction

Before studying the emotional interaction through robots. We have to study deeply human interactions and emotions, how emotions are expressed in humans and what situation generates what kind of human emotion.

Darwin was one of the scientists who started researching the topic of facial expressions and emotions through humans and animals. In his research, he discovered that emotions can be expressed in many different ways including speech, facial expressions, body movements and psychological factors.

We know from the introduction chapter that emotions can be expressed in mainly two ways verbal communication and non-verbal communication. In this thesis, we concentrate mainly on the non-verbal communication part of expressing emotions. Mainly through facial expressions, interactions and emotions. So let's discuss in detail how emotions are divided and the different theories and models of emotions.

2.1.2 Classification of emotions

Classification of emotions is done by two approaches:

- emotions are discrete and fundamentally different constructs.
- emotions can be characterized on a dimensional basis in groupings.

2.1.2.1 Emotions as discrete categories

In the discrete theory of emotion, there are basic emotions common among all humans irrespective of their culture, place, and language. These fundamental emotions are referred to as "discrete" because they are thought to be distinguishable through an individual's facial expression and biological processes[1].

Paul Ekman is a well know discrete theorist who conducted studies and research in this field to determine which are the most common emotions. He described the six basic discrete emotions and they are anger, disgust, fear, Happiness, sadness and surprise. According to Ekman each emotion is considered a discrete category and is not an emotional individual state[2].

2.1.2.2 Dimensional models of emotion

According to the dimensional models of emotion, Researchers have defined emotions into one or more dimensions. These models try to conceptualize emotions by defining where they lie in two or three dimensions.

In 1897, Wilhelm Max Wundt, the father of modern psychology proposed that emotions can be described in three dimensions they are[3]:

- pleasurable versus unpleasurable
- arousing or subduing
- strain or relaxation

In 1954, Harold Schlosberg, proposed three dimensions[4]:

- Pleasantness versus unpleasantness
- attention versus rejection
- level of activation

Most of these dimensional models of emotion use valence, arousal or intensity dimensions. The most prominent two-dimensional models of emotions are the Vector model, the Circumplex model of emotion, and the Positive Activation – Negative Activation (PANA) model.

2.1.3 Circumplex Model of Emotion

In our research, one of the main models of emotion we test is the Circumplex model of emotion.

The circumplex model of emotion was proposed by James Russell in 1980[5]. According to this model, emotions are distributed in a two-dimensional circular space. They have two dimensions, they are:

- Arousal dimension
- Valence dimension

The arousal dimension represents the vertical axis and the valence dimension represents the horizontal axis, while the centre of the circle represents a neutral valence and a medium level of arousal[6]. This model can be seen in fig 2.2.

- If both valence and arousal are negative, we experience emotions like Depression, Boredom and tiredness.

- If the valence is positive and arousal is negative, we experience emotions like relaxed, calm, and content.

- If the valence is positive and arousal is positive we experience positive emotions like Happy, excitement and delight.

- If the valence is negative and arousal is positive we experience positive emotions like anger, frustration and tiredness.

This model is generally used to test the responses of emotional words, emotional facial expressions, and affective states[5].

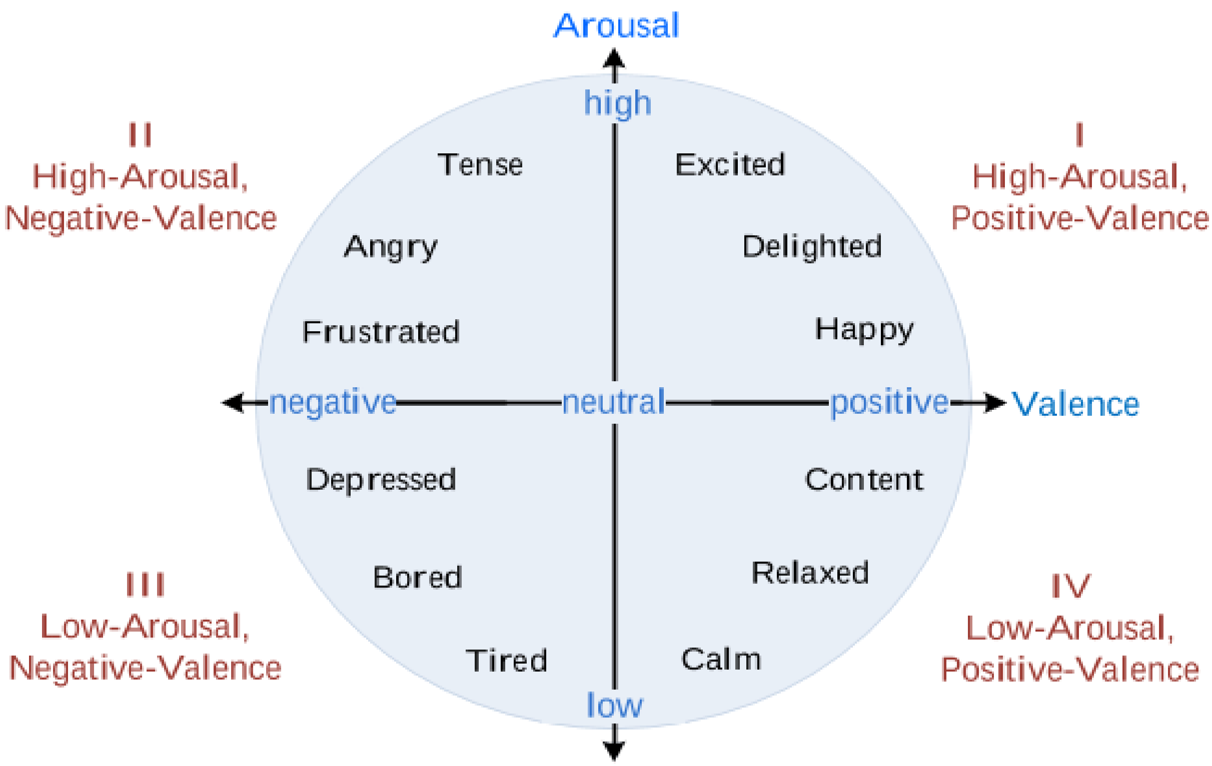


Figure 2.2: Circumplex model of emotion

2.2 Social Robots

A social robot is an autonomous robot that is able to interact and communicate with other robots, with humans, and with the respective environment, it should also, satisfy the cultural behaviour and analysis of the society.

There are numerous systems which are designed and developed to interact with people, web agents, synthetic characters and robots for physical labour. These systems can be either embodied or disembodied.

Embodied: These are the systems in which humans can interact with a robot, an animated avatar or an on-screen synthetic social characters

Disembodied: These are the systems in which humans can interact via speech or text entered into a robot.

In this thesis, we study embodied systems. These can send non-verbal communication to humans in the form of facial expressions, body posture, gestures, and gaze direction.

These days, we see that social robots are used in various fields and health care is a very prominent field which is making wide use of social robots like elderly care, child care and culturally aware social interaction etc. A few popular examples of social robots are Pepper and Nao robots by Softbank robotics, Kismet, Sofia and Professor Einstein robot by Hanson Robotics, Ameca by Engineered Arts etc.

2.2.1 Nonverbal Cues in Human-robot Interaction

Many people think that robots and humans can coexist as social agents, but not necessarily as social equivalents to humans[7]. Whether the robots become embodied agents and whether this state is static or cumbersome and unstable is still a question to consider for the research.[8].

According to some Japanese robotics researchers: to become a social agent, robots should engage the world with sensitivity, sensibility, feeling, aesthetics, emotion, affection, and intuition [9] a Kokoro function. Kokoro in Japanese has a very complex meaning that says any of heart, spirit, and mind, integrating emotion, thinking, and intention, and describing the inner world or essence of a person, to be particular robots in this case. So the roboticist and robot creators in japan refer to robots as a "third existence", which means a robot is neither a living creature nor a non-living creature [10].

Additionally, people frequently convey their feelings and interior moods through outwardly observable bodily changes. This context plays a big role in how physiological signs are interpreted. Embarrassment, tension, happiness, excitement, rage, and other emotions can all be indicated by facial flushing. Heavy breathing is a common indicator of exhaustion after vigorous exercise or it may indicate anxiety or even a panic attack. These indicators can enhance a robot's perceived "aliveness" and influence perceptions of its Kokoro function.

A social robot is said to be very lively and human-like if it can understand emotions and psychological cues within the context of human-robot interaction. Yoshida and Yonezawa [11] created a stuffed bear-style robot that can breathe, have a heartbeat, have varying temperatures, and have other involuntary bodily movements related to physiological and psychological states. Lütkebohle et al. [12] mimicked blushing in the robot Flobi with an array of red LEDs in its cheeks.

2.2.2 Empathy in social robotics

Empathy is defined as "the act of perceiving, understanding, experiencing, and responding to the emotional states and thoughts of another person" [13].

In human-human interaction, empathy plays a very vital role in maintaining the relationships between people[14]. Just like humans even in social robots, the concept of an empathetic connection between humans and robots can take the field of social robotics to a much higher level. Empathy is a sub-division of behavioural adaptation and it's becoming a very important concept to explore in the field of social robotics[15]. This paper shows[16], how various models of emotions were designed to build empathetic and emotional robots.

2.2.3 Socially Assistive Robots

Socially assistive robots are used in various industries these days like elderly care, healthcare services, rehabilitation, education etc [17]. Considering healthcare and elderly care, these robots should be able to recognise the voice, facial features and emotions to monitor human safety and health, social mediation, interaction and companionship. Even during the COVID-19 pandemic [18], more robots were deployed in hospitals which resulted in reducing the spread of the virus. As the social dexterity of robots increases like listening, conversations and reading emotional cues, socially assistive robots become more effective.

2.2.4 Kismet

Kismet, a social robot is a pioneering work in the field of social robotics which studies facial emotion recognition on a robot's face. The main objective of this work was to study and research how emotions expressed on a robot's face could have an impact while interacting with people[19].

- The robot has 21 Degrees of Freedom and is roughly 1.5 times the size of an adult human head.

- It has three DoF which can direct the robot's gaze.

- It has three DoF which can direct the orientation of its head;

- It has Fifteen DoF to move its facial features (eyelids, eyebrows, lips, ears).

- Kismet is outfitted with four CCD cameras and two small microphones.

- Kismet is inspired by infant social development, psychology, ethology, and evolution in order to engage in natural and intuitive social interaction with humans and ultimately learn from them.

2.3 Table Top Robots

Table-top robots are usually small in size compared to big humanoid robots and are comparatively very cheap. They have limited sensorimotor functions and are capable of human-robot interaction, they usually depend on cloud services for any intense operations and computations. For example, they connect to the cloud for speech-to-text or text-to-speech conversations. In this thesis, as we mentioned earlier in chapter 1, we use a table robot called "Professor Einstein" by Hanson Robotics[20].

2.3.1 Professor Einstein Robot

"Professor Einstein" robot is a tabletop companion robot designed by Hanson Robotics, a Hongkong based company. It was mainly designed for the purpose of teaching mathematics and science to kids[21].

The appearance of the robot resembles the great genius scientist Professor Einstein. The robot's attire can be seen wearing black pants, a white sweater with a shirt collar and a black tie. The white hair of the robot is very tame and it has a white bushy moustache.

In this thesis, we use the Einstein robot's face as a testbed to verify the correctness of both the Circumplex model of emotion and the Facial Imitation models of emotion.

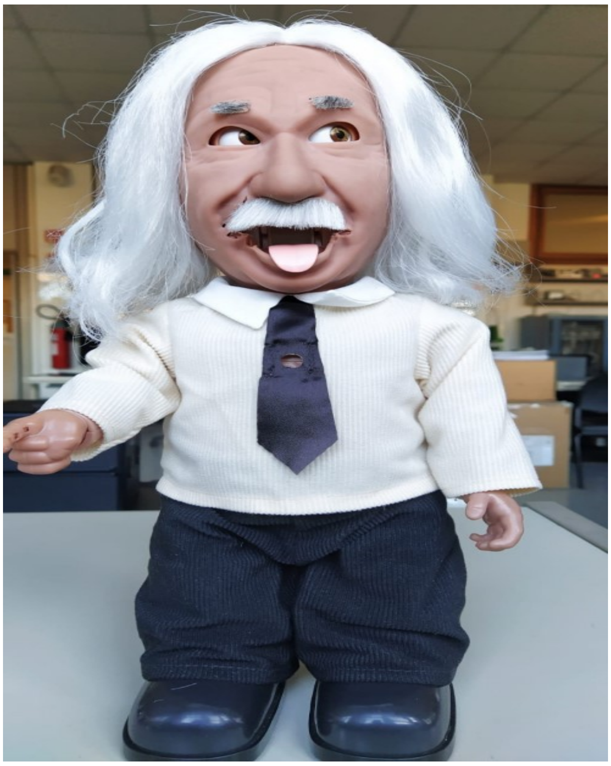


Figure 2.3: Professor Einstein Robot

2.3.1.1 The hardware of the Professor Einstein Robot

Now let's see, how the Professor Einstein robot is built and what components its hardware is made up of

- The main computer board is powered by an ARM7 processor.

- Two NiMH rechargeable batteries are hidden inside the robot's feet, allowing it to run for three hours.

- The main audio input is provided by a microphone on its chest; two additional microphones on the sides of the head aid in sound direction location.

- A camera on its chest is also used to track faces and assist the robot in maintaining eye contact.

- Infrared sensors on the bottom of the shoes keep the robot from slipping off a table.

- The robot keeps moving using 9 coreless DC motors with custom gearboxes.

- It also can walk thanks to the motors on its legs and feet.

- There are five motors in the face alone that are used to create the various expressions.

2.3.1.2 How to set up the Einstein Robot

Firstly, turn on the robot with the power button which is at the back side below the robot's shirt. We can see ON and OFF written on the back on the sides of the power button.

As soon as the robot turns on and starts it should say the following:

"Ok here we go, just one, I don't see any WiFi networks I recognize, go to the connection channel in your Stein-O-Matic to solve your problem".

To control and program the robot, we want the WiFi, SSID and the password. To find out this information, press the binding button as shown in the fig below. The robot is ready to operate.

Figure 2.4: Power button at the backside of the robot

2.3.1.3 Motors controlling the Head and Facial Expressions of the Robot

The Facial expressions of the robot can be controlled by four motors:

- Eyebrows
- Eyelids
- Mouth
- Lip-corners

With the help of the following motors, the facial motors can be moved and various facial expressions can be generated

The head Movement of the robot can be controlled by two motors

- Head turn
- Head pitch

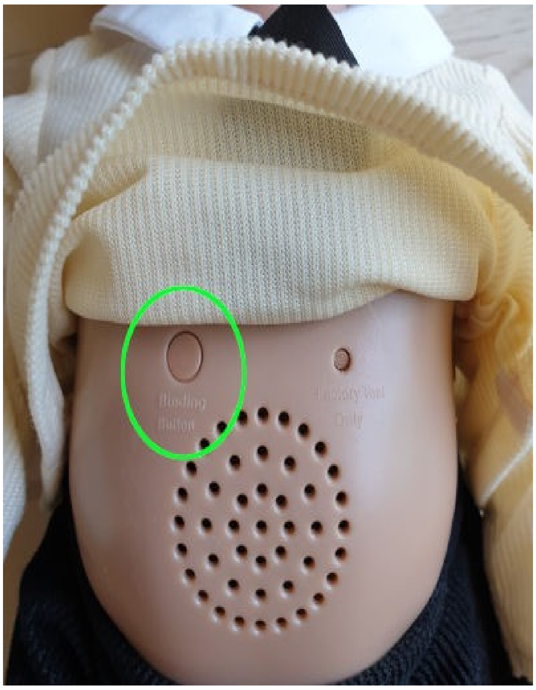


Figure 2.5: Binding button on the backside of the robot

Position of Motors: The position of the robot motors can be moved at various points between 0.0 and 1.0 positions.

Delay of the Motors: This is the time in seconds that the motor can take to move to the desired position, between 0.0 and 1.0 seconds.

2.3.1.4 The various Facial Movements of the Einstein Robot

Eyebrows: This command is used to control the eyebrows of the robot.

Raise_eyebrows: with this command, the robot can raise its eyebrows.

Frown_eyebrows: with this command, the robot can frown its eyebrows.

cheeky_eyebrows: with this command, the robot can make a cheeky eyebrows expression.

Neutral_eyebrows: with this command, the robot can get its eyebrows to the neutral position.

Eyelids: This command is used to control the eyelids of the robot

Eye_lid_open: To open the eyelids.

Eye_lid_close: To close the eyelids.

Mouth: This command is used to control the mouth part of the robot

Close_mouth: To close the mouth.

Open_mouth: To open the mouth.

Lip_corners: The corners of the lips can be controlled by this motor.

Poke_tongue: The robot can poke its tongue in a funny way with the help of this command.

2.3.1.5 The Head Movements of the Einstein Robot

The robot's head can be moved both linearly and vertically. The various movements of the robot can be seen below.

Horizontal head Movements of the robot:

Head_turn

Head_turn_left: with this command, the robot can move its head left.

Head_turn_middle: with this command, the robot can move its head in the middle.

Head_turn_right: with this command, the robot can move its head right.

Vertical head Movements of the robot:

Head_pitch

Head_down: with this command, the robot can move its head down or bend its head.

Head_middle: with this command, the robot can move its head into the middle.

Head_up: with this command, the robot can lift its head above and look up.

2.3.1.6 HR Little API

This is the basic tool provided by the developers of Professor Einstein robot to control motors and basic actions of the robot.

How To install the HR Little API:

Use the link and make use of the Github repository

https://github.com/hansonrobotics/hr-little-api

Or

We can also install this API with the help of PyPI in the command line using pip

pip install hr-little-api

Important Classes and Functions to control the robot:

Robot class: This has a number of methods to control the actions of the robot.

robot = Robot(): This is used to Instantiate a Robot object:

robot.do(): we can create actions by calling functions that represent the action we want the robot to make, and then pass the action through this function.

motor(self, motor_id: MotorId, position: float, seconds: float): This is a very important function to move the robot to a particular position within a certain time.

motor_id: This is the ID of the motor present in the robot.

position: The position of the motor can be varied between 0.0 and 1.0

seconds: This is the time in seconds that the motor should take to move to the desired position, between 0.0 and 1.0

2.3.1.7 Py-Feat: Python Facial Expression Analysis Toolbox

This is a free open-source tool which we use in this research for the purpose of emotional detection and analysis. It provides numerous tools and models to detect various facial expressions(action units, emotions, and facial landmarks) from videos and images. This can be used to preprocess, analyse data and visualize them[22].

Py-Feat was mainly created for Human behaviour researchers, to extract facial expressions from images, and videos with basic codes and to analyze the data using the detectors built in the py-feat and for computer vision researchers to develop and share their latest models to reach many researchers and others interested in the field of analysing facial expressions. Installation The easiest way to install py-feat is through PyPI

pip install py-feat

Chapter 3

Implementation

This chapter explains how the Circumplex Model of Emotion and Facial Mimicking Model were designed and Mapped on Professor Einstein Robot.

3.1 Circumplex Model of Emotion

A detailed explanation about the Circumplex model of emotion can be found in chapter2.1.3.

In this section, we will see how the Circumplex model of emotion was made into a software model and connected with professor Einstein robot. The wheel of emotion was tested using Professor Einstein robot's face as a test bed.

3.1.1 Robot settings and Software Development

The following steps were followed for making a software program for the circumplex model of emotion.

The first step is to get to know about the robot's environment and the tools used to control the motors and actuators of the robot.

The tool used to Control the Professor Einstein robot is called HR-Little-API

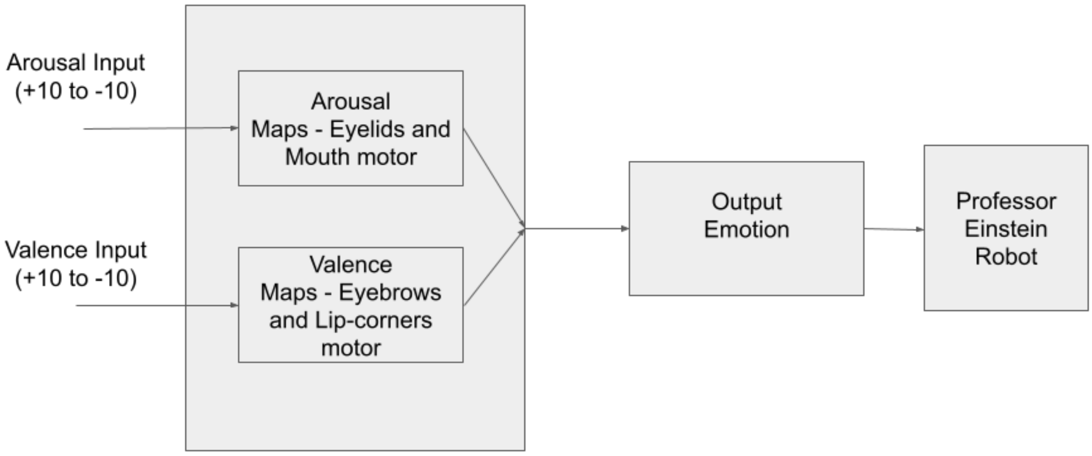


Figure 3.1: Basic software block diagram of the circumplex model of emotion

from Hanson Robotics. This tool lets you control all the motors of the robot and allows you to experience the various activities of the robot like walking, speech control and, Making funny expressions. A detailed explanation of the HR-Little API and its various important functions are discussed in chapter 2.3.1.6.

Once we get familiar with the HR-Little API tool and the robot's environment, we should try to test the functioning of all individual motors and check the various expressions and try to generate as many facial expressions by changing the combination of the motors on the face as of the Einstein robot with the help of the robot API.

Now, after testing many combinations of expressions. Make a software program through which different parts of the robot can be controlled using the motors.

After creating the above software, I experienced that the robot has many unnecessary actions which performs manually during the use of the robot like walking and it generates a default voice which disturbs the course of the experiment.

To come across this problem, I used the concept of real-time scheduling and Multi-threading through which the signals of the unnecessary default actions can be blocked and our main program can be carried out.

After all these steps, Now we're ready to create the software program for the Circumplex model of emotion.

We know that in the Circumplex model of emotion, the emotions are distributed in a two-dimensional circular space.

The two dimensions are Arousal and Valence.

Arousal represents the vertical axis valence represents the horizontal axis The circle centre depicts a neutral range of valence and a medium range of arousal.

From the above information we create a software program which can take valence and arousal as inputs3.1, for this purpose Arousal and valence are mapped with the robot as shown below:

Arousal - The Eyelids and Mouth motors are mapped with arousal

Valence - The Eyebrows and Lipcorners motors are mapped along with valence.

The positive and negative maximum values were given to be +10 and -10 as the range for the model so that it can be mapped accordingly to the robot's motors and position value which has the range between 0.0 to 1.0 and we are scaling the value to 10 for the convenience of performing the experiments.

3.1.2 Output Images of valence and arousal

The photo 3.2 shows the robot's surprised expression generated from the values of arousal 10 valence 10.

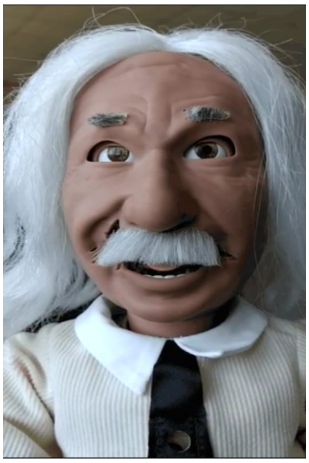


Figure 3.2: Surprise: Arousal 10, Valence 10

The photo 3.3 shows the robot's Neutral expression generated from the values of arousal 1 and valence 1.

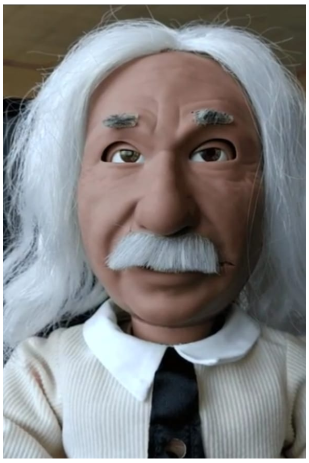


Figure 3.3: Neutral: Arousal 1, Valence 1

The photo 3.4 shows the robot's Happy expression generated from the values of arousal 5 and valence 10.

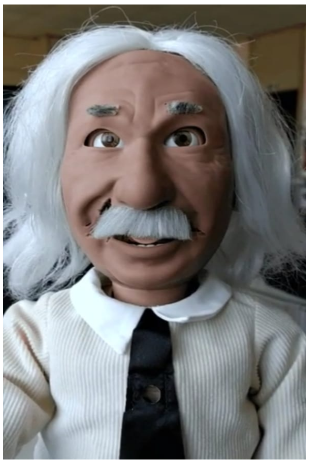


Figure 3.4: Happy: Arousal 5, Valence 10

The photo 3.5 shows the robot's Sad expression generated from the values of arousal -10 and valence 10.

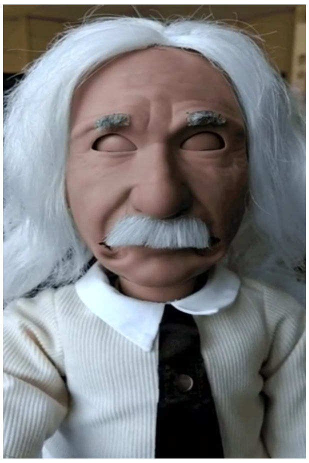


Figure 3.5: Sad: Arousal -10, Valence -10

The photo 3.6 shows the robot's Fear expression generated from the values of arousal 5 and valence -7.

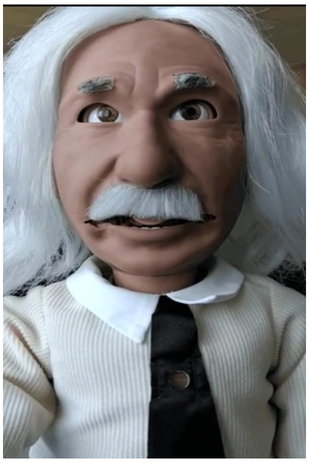


Figure 3.6: Fear: Arousal 5, Valence -7

3.2 Mimicking or Imitating the Human Facial Expressions on Prof. Einstein Robot

The main aim of this section is to discuss the software Architecture to mimic the facial expressions of a human on a Humanoid companion Robot (Prof. Einstein Robot)

3.2.1 Software Architecture of facial mimicking system

This is the block diagram 3.7 of how this system functions to take the human face or expressions as the input and replicate it on the Prof. Einstein robot.

The basic functioning blocks of this system are

Input: Here we can give facial expressions of a human in various forms such as Images, Videos, and through a live web camera.

Openface API: This is a state-of-the-art tool intended for facial landmark detection, facial action unit recognition(FAUs). A detailed explanation of this tool is discussed in section 3.2.2.

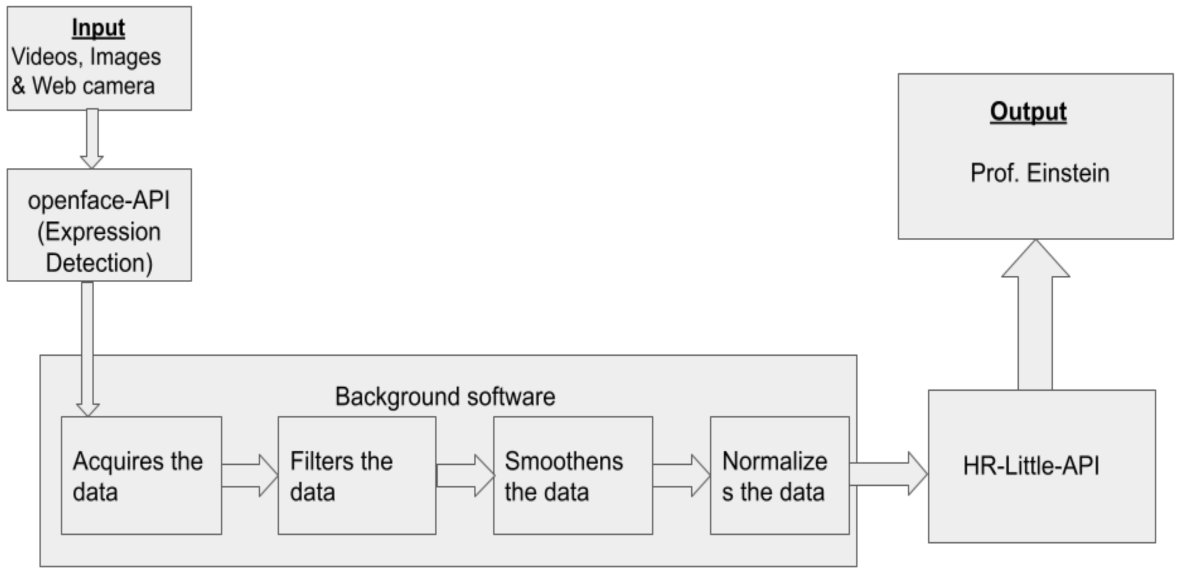


Figure 3.7: Software Architecture of Facial imitating system

Background Software: This block is designed for data acquisition, filtering, processing, and visualisation.

HR-Little-API: This is a tool used to control the movements of Professor Einstein Robot. Refer to chapter 2 for a detailed explanation of this tool.

Professor Einstein Robot: This is the hardware, where we can see the replica of our facial expression. More details can be found in chapter 2.

The image 3.10 shows the comparison of other tools and openface[23].

3.2.2 OpenFace

OpenFace is an open-source free tool that can perform various analysis on facial behaviour like detecting the action units, head pose, facial landmark detection etc.

3.2.2.1 How to detect Faces and the position of each individual facial movement

Facial Action Coding system (FACS) To detect the individual facial movements on the human face. There is a taxonomized system called the Facial Action Coding system (FACS). This system was developed by a Swedish anatomist called Carl-Herman Hjortsjö [24]

Each and every individual facial muscle and its movements are encoded by the FACS system with a slight instant change in facial appearance. Any anatomically possible facial expression can be coded with the help of FACS. These are further classified into particular Action Units (AU), through which expressions are produced. These are the common standards to describe any possible facial expression.

The below image shows the Action Units with respect to their paired facial anatomies[25].

3.2.2.2 Available tools for Facial Action Units(FAU) Recognition and why choose open-face

In this section, let's see what are the tools currently available for Action Unit recognition and why I choose the open-face tool for the thesis.

There are very less tools which can detect action units and are free of cost. There are a number of commercial systems that can perform Action Unit Recognition like:

- iMotions
- Affectiva
- Noldus FaceReacer

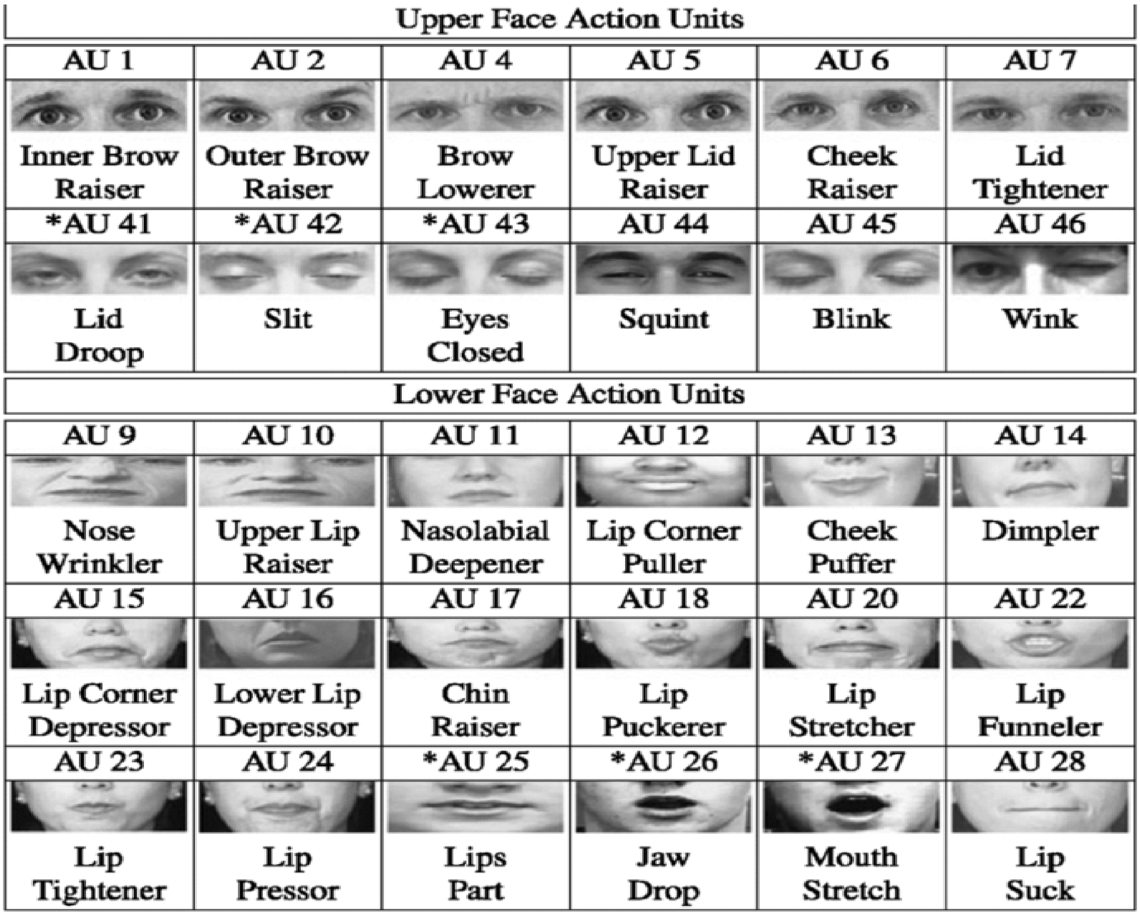


Figure 3.8: Action Units

Drawbacks

- The cost of these tools are really high.

- The algorithms and the training data used by them are normally not known.

- Some tools are restricted to single-machine use.

- The commercial product may be discontinued leading it impossible to reproduce the results due to a lack of product transparency.

open face tool is free to use and most importantly it covers most of the discussed drawbacks of the above-mentioned alternative commercial products.

In this research, we use the OpenFace tool for AU recognition and we map

Tool	Approach	Landmark	Head pose	AU	Gaze	Train	Fit	Binary	Real-time
COFW[13]	RCPR[13]	✓				✓	✓		✓
FaceTracker	CLM[50]	✓	✓				✓	✓	✓
dlib [34]	[32]	✓				✓	✓		✓
DRMF[4]	DRMF[4]	✓	✓					✓	✓
Chehra	[5]	✓	✓					✓	✓
GNDPM	GNDPM[58]	✓						✓	
PO-CR[57]	PO-CR [57]	✓						✓	
Menpo [3]	AAM, CLM, SDM[1]	✓				✓	✓		[2]
CFAN [67]	[67]	✓						✓	✓
[65]	Reg. For [65]	✓	✓			✓	✓	✓	✓
TCDCN	CNN [70]	✓	✓					✓	✓
EyeTab	[63]				✓	N/A	✓	✓	✓
Intraface	SDM [64]	✓	✓					?[3]	✓
OKAO	?	✓	✓	✓	✓			✓	
FACET	?	✓	✓	✓				✓	✓
Affdex	?	✓	✓	✓				✓	✓
Tree DPM [71]	[71]	✓				✓	✓		
LEAR	LEAR [40]	✓						✓	✓
TAUD	TAUD [31]			✓				✓	
OpenFace	[7, 6]	✓	✓	✓	✓	✓	✓	✓	✓

Figure 3.9: Comparision of Action Unit tools

all the AU's available on openface with professor Einstein Robot's face so that a facial imitating system can be formed.

OpenFace can recognize a subset of AUs, specifically: 1, 2, 4, 5, 6, 7, 9, 10, 12, 14, 15, 17, 20, 23, 25, 26, 28, and 45.

Intensity and presence of AUs

In the open-face API AUs can be represented in two ways:

Presence - It detects if the AU is present in the face (for example AU07_c)

Intensity - This show how intense is the detected AU (minimal to maximal) on a 5-point scale.

Extraction from images and extraction from videos

OpenFace can extract Action Units from images, image sequences and videos.

This software can run both in static mode as well as live in dynamic mode. Images and videos can be uploaded into open-face, and then we get the output file in the form of a CSV file. The live video of a person can interact through a web camera. The open-face software gives the action units reading live and also stores it simultaneously. The working of open-face can be seen in the below figure.

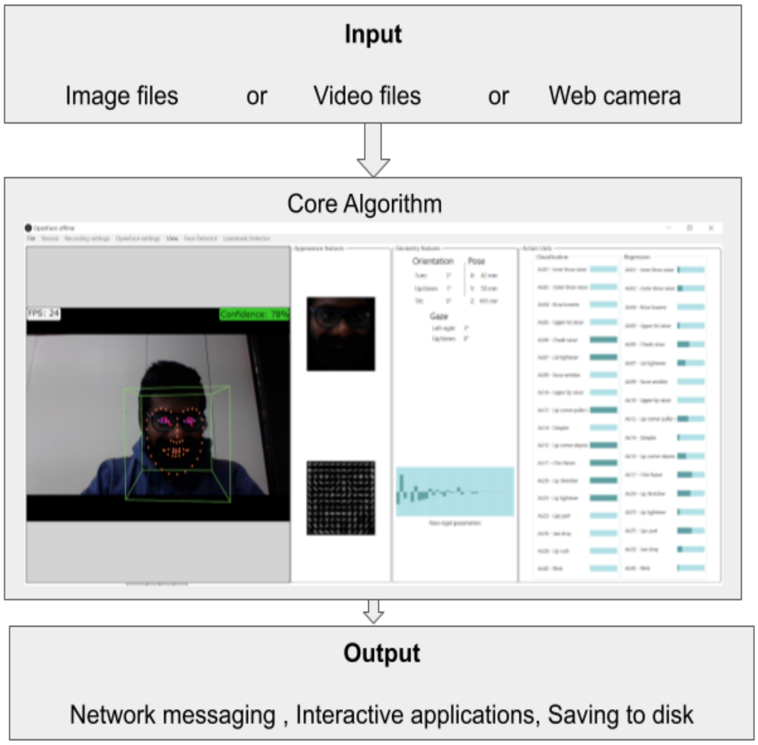


Figure 3.10: Working of OpenFace

3.2.2.3 Mapping Between Human's and Robot's Features

In this section, let's match the AU's between the open-face tool and the Professor Einstein robot. The matched AU's are paired with the respective facial motors of the Einstein robot. All the matched AU's and their respective functions can be seen in fig 3.2.2.3

AU	Description	Example image
1	Inner Brow Raiser	
2	Outer Brow Raiser	
4	Brow Lower	
12	Lip corner puller	
15	Lip corner depressor	
5	Upper Lid raiser	
7	Lid Tightener	
25	Lips part	

The corresponding AU's of the open-face are mapped to the professor Einstein robot as shown above and the software is ready for experimentation.

3.2.3 Performing the Experiment by connecting the Robot and camera (Background Software)

3.2.3.1 Data Collection

The face has four motors Eyebrows(AU01, AU04), Eyelids(AU05, AU07), Lip-corners(AU12, AU15) and Mouth(AU25). Collect the data using the open face from multiple users. For example Set the timer to 30 sec, start with the eyebrows, raise the eyebrows to the maximum value and hold on to them for 5 seconds after 5 seconds frown the eyebrow to the least possible minimum value repeat these for 30 seconds and do the same exercise for each of the eyelids, lip corners and mouth. Save all these data and perform the analysis.

3.2.3.2 Data Analysis

Data analysis is a very crucial step for the system. The data is obtained in the form of a CSV file.

- From the obtained data extract only the required set of AU information and filter the remaining data.

- The obtained data will have a lot of noise and disturbances.

- To overcome the noise we have to smoothen the data, for this task we can take the moving average of the data, so the curve is smoothened. Normalize the moving average - to match the robot motor inputs for the range (0.0 to 1.0)

3.2.3.3 Final Step - Mimicking

- Activate the camera and connect the Einstein robot

- The user faces the camera connected to the robot.

- The software detects the Facial action units and automatically creates a CSV file live with constantly updating the Action unit values.

- Import the data from the CSV file into the software script.

- Since the min and max values were already recorded and given in the script.

- The final output of the facial expressions is replicated on the robot

- The output graphs after performing data analysis can be seen if chapter 4.

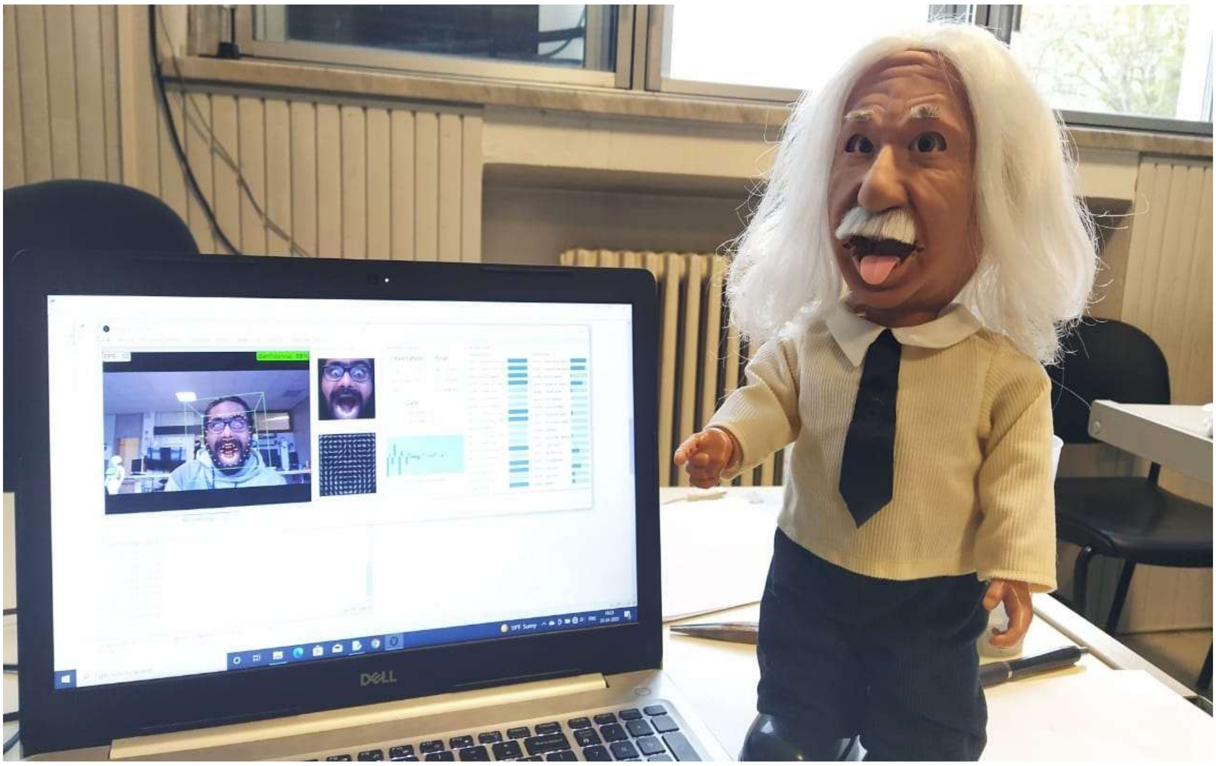


Figure 3.11: Testing by connecting to the camera

3.3 Emotion Validation

In this section, we will perform experiments to validate the results of the correctness of the Circumplex model of emotion and the Facial mimicking model of

Figure 3.12: Facial Imitation

emotion. we perform two kinds of experiments:

- Expression detection(Using Py-feat)
- A questionnaire submitted online to recruited participants

3.3.1 Expression Detection

For the purpose of emotion detection, we make use of a tool called py-feat. A detailed explanation of the py-feat tool can be found in chapter 2.3.1.7. The block diagram of py-feat can be seen in figure 3.13

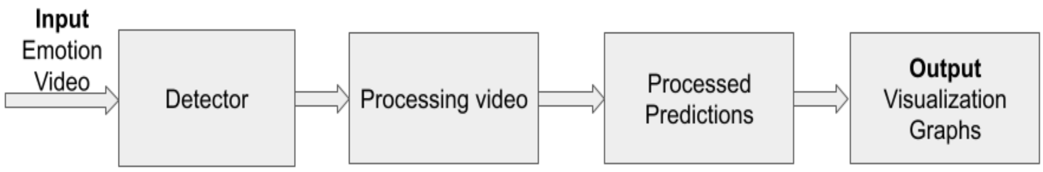


Figure 3.13: Block diagram of Py-feat

Recording input videos for circumplex model of emotion

In chapter 3.1.1, we have created the software model of the circumplex model of emotion and tested it with various combinations of valence and arousal.

Record a video of the Einstein robot performing basic emotions generated from the circumplex model of emotion with different combinations of valence and arousal for 30 seconds. Create an anger expression through the valence-arousal model, For the first 5 seconds let there be maximum anger expression and for the next 5 seconds neutralize the expression. Repeat these steps for the next 30 seconds and use these videos as input to the py-feat for finding the emotion.

Recording input videos for the facial mimicking model of emotion
In chapter 3.2.1, we have created the facial mimicking system to replicate human

emotions on Professor Einstein robot. Record a video of the human performing various Facial emotions and the robot imitating the basic emotions for 30 seconds neutralizing the emotion for every 5 seconds. Example: Generate an anger expression in front of the camera, record yourself and record the expression generated by the robot. it repeats the expression of anger for 30 seconds continuously.

Detector: The detector in pyfeat contains many trained models which can detect action units, emotions, face pose, and facial landmark detection. Depending on the requirement, we can choose the specific model or choose the default model.

Processing Video: After setting up the detector, we can use .detect_video(). This method detects the facial expressions in the given input video.

Processed predictions: Here we extract all the required information from the facial emotion video like action units, emotions etc.

Output graphs: From the data of processed predictions, we can plot the graphs of all the emotions detected in the video.

3.3.2 Creating a Questionnaire to compare the two models with the videos and perform a survey

A survey is created to evaluate the facial expressions generated by the Circumplex model of emotion and the facial mimicking model.

The emotions generated by the circumplex model of emotion and the facial mimicking model of emotions are recorded in a series of short videos.

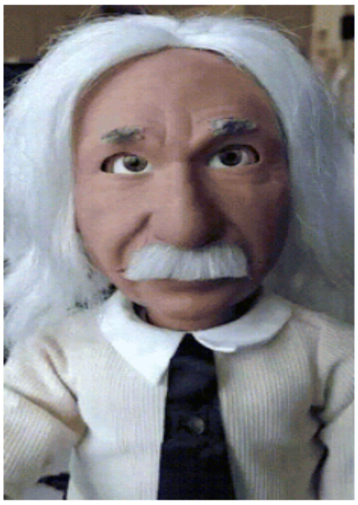
These videos are shuffled and given to the users participating in the survey.

In this survey, the participant will see a series of short videos in which Professor Einstein's Robot shows various facial expressions. The main task is to identify and rate the emotion on a scale of 1 to 5 (where 1=strongly disagree and

5=strongly agree), based on the emotion recognized from the video.

The survey results are then used for the quantitative analysis. The average of each emotion is calculated on those data and we draw a conclusion of which model was able to detect emotions more accurately.

The complete survey can be found in the link below:



Mark only one oval per row.

	1	2	3	4	5
Happy					
Sad					
Surprise					
Anger					
Neutral					
Fear					

Figure 3.14: A questionnaire to evaluate both models of emotion

`https://forms.gle/1bigHqPfYBKDFJQP6`

Chapter 4

Results

In this chapter, we will discuss all the results obtained from experimenting with different models of emotions on Professor Einstein Robot

4.1 Results of Circumplex Model of Emotion

In this section, we see the output graphs for emotions generated through the circumplex model of emotion.

4.1.1 Anger

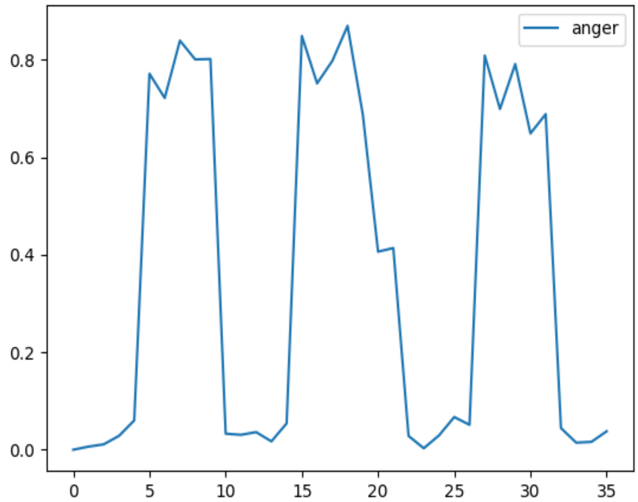


Figure 4.1: Anger

The graph 4.1 shows the plot of emotion for anger where 0.0 is the minimum emotion and 1.0 is the maximum emotion. This graph clearly shows that the anger emotion is raising every 5 seconds, so the graph is going to the peak for every recurring 5 seconds and coming back to its neutral position after 5 seconds.

4.1.2 Happiness

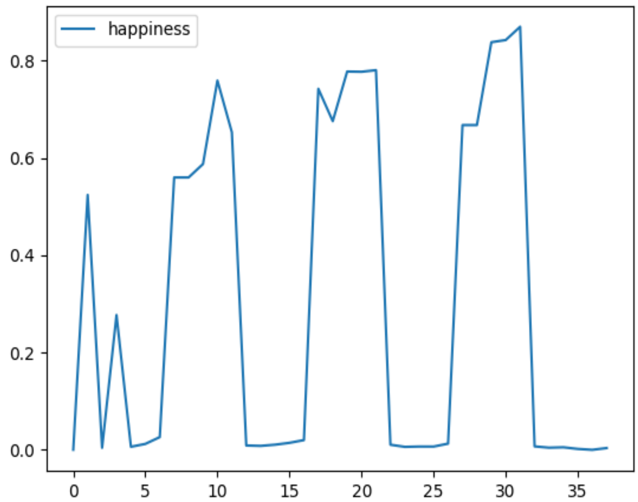


Figure 4.2: Happiness

The graph 4.2 shows the plot of emotion for happiness where 0.0 is the minimum emotion and 1.0 is the maximum emotion. This graph clearly shows that the happiness emotion is raising every 5 seconds, so the graph is going to the peak for every recurring 5 seconds and coming back to its neutral position after 5 seconds.

4.1.3 Fear

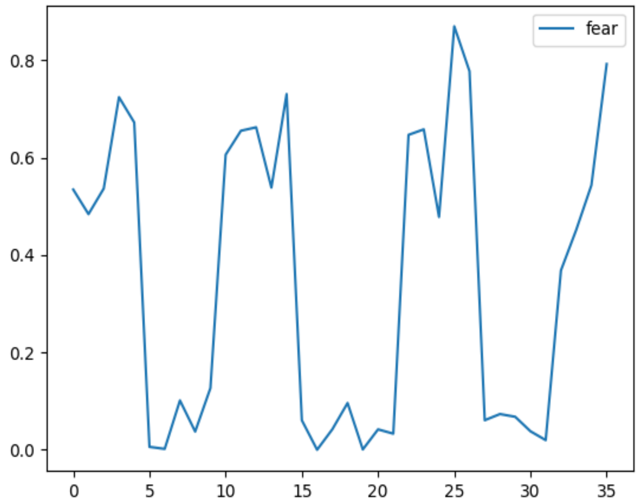


Figure 4.3: Fear

The graph 4.3 shows the plot of emotion for fear where 0.0 is the minimum emotion and 1.0 is the maximum emotion. This graph clearly shows that the fear emotion is raising every 5 seconds, so the graph is going to the peak for every recurring 5 seconds and coming back to its neutral position after 5 seconds.

4.1.4 Neutral

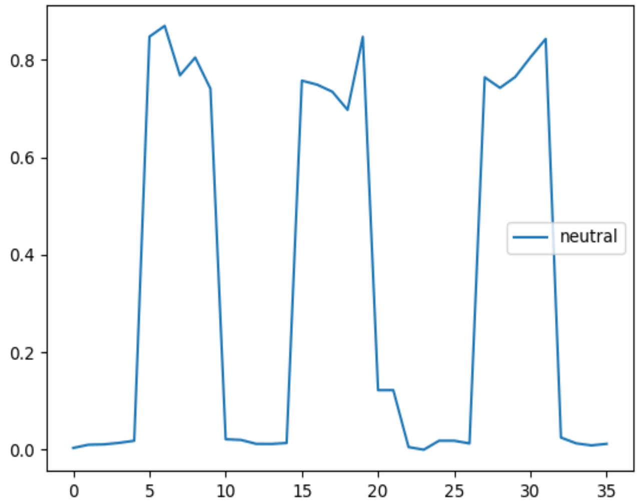


Figure 4.4: Neutral

The graph 4.4 shows the plot of emotion for neutral where 0.0 is the minimum emotion and 1.0 is the maximum emotion. This graph clearly shows that the neutral emotion is raising every 5 seconds, so the graph is going to the peak for every recurring 5 seconds and coming back to its neutral position after 5 seconds.

4.1.5 Sadness

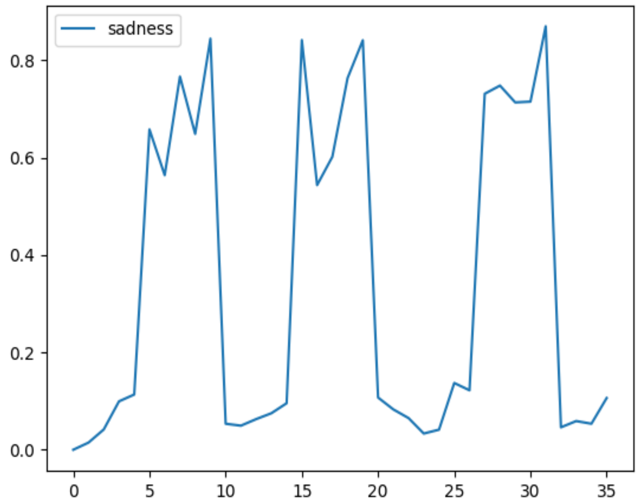


Figure 4.5: sadness

The graph 4.5 shows the plot of emotion for sadness where 0.0 is the minimum emotion and 1.0 is the maximum emotion. This graph clearly shows that the sadness emotion is raising every 5 seconds, so the graph is going to the peak for every recurring 5 seconds and coming back to its neutral position after 5 seconds.

4.2 Results of Facial mimicking Model of Emotion

In this section, we see the following outputs:

- We check individually if all the AUs are correctly mapped to the robot's motor.

- Graphs plotted after emotion validation of both human and robot.

4.2.1 Graphs to check if the AU's are correctly mapped with the robot's facial motors

In this section, you will find the results of the experiments done in 3.2.3. The resultant graphs are shown for four mapped motors of Einstein robot with the AU's of open-face software. Here, we present the test results of a participant verifying the correctness of mapping by performing the experiment. The mapped four motors are:

- Eyebrows
- Eyelids
- Lip corners
- Mouth

Eyebrows

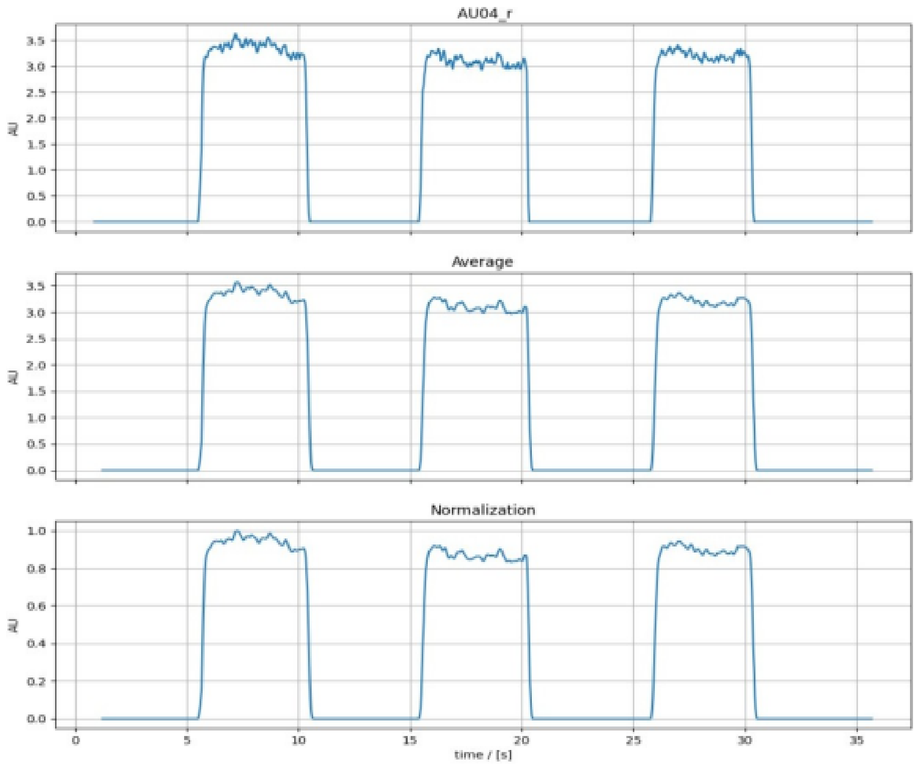


Figure 4.6: Eyebrows

This graph is the output generated after mapping the eyebrow motor of the robot to action unit AU_04 generated from open-face software. The first top graph shows the collected data from open-face software after performing the experiment. In the centre graph, the moving average of the data is performed to smoothen the curve so that the eyebrow movement will be smooth without external noise and fluctuation. The final graph shows the normalised output of the data between 0.0 and 1.0 because the robot's motors can only take the input in that range. The change in shift of the graph for every 5 seconds shows that the AU and the eyebrow are correctly mapped.

Eyelids

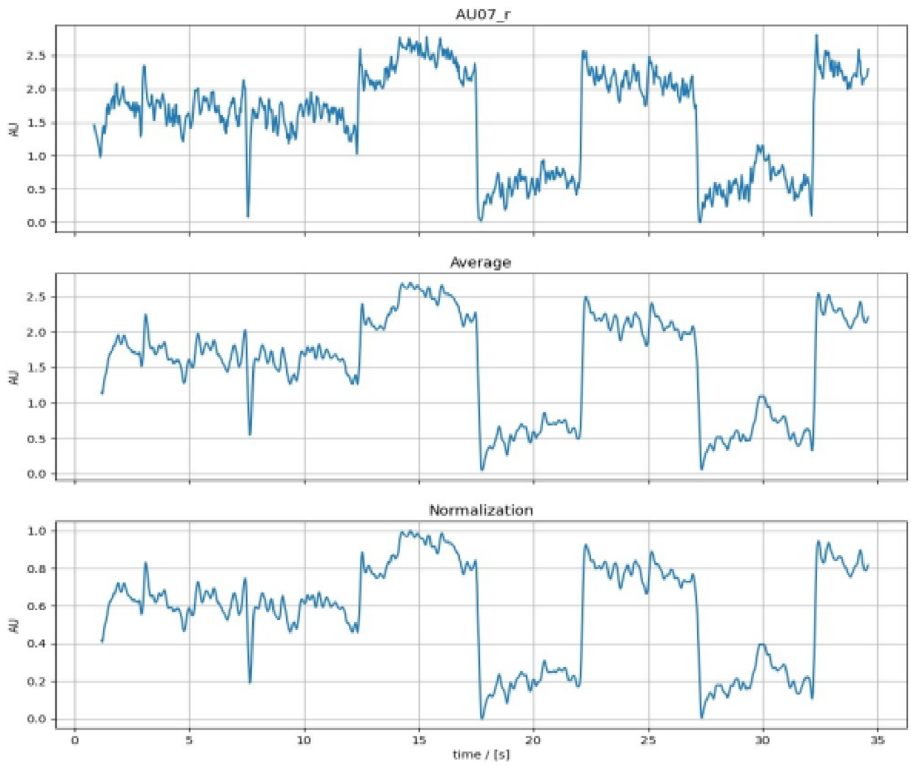


Figure 4.7: Eyelids

This graph is the output generated after mapping the eyelids motor of the robot to action unit AU_07 generated from open-face software. The first top graph shows the collected data from open-face software after performing the experiment. In the centre graph, the moving average of the data is performed to smoothen the curve so that the eyelid movement will be smooth without external noise and fluctuation. The final graph shows the normalised output of the data between 0.0 and 1.0 because the robot's motors can only take the input in that range. The change in shift of the graph for every 5 seconds shows that the AU and the eyelids are correctly mapped.

Lip Corners

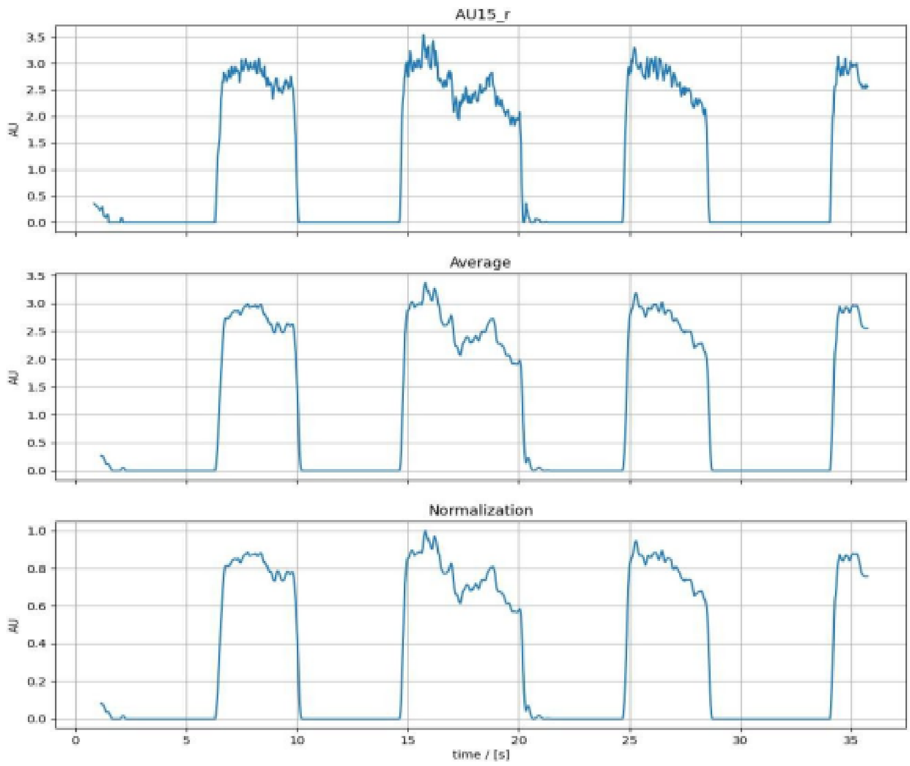


Figure 4.8: Lipcorners

This graph is the output generated after mapping the Lip Corners motor of the robot to action unit AU_15 generated from open-face software. The first top graph shows the collected data from open-face software after performing the experiment. In the centre graph, the moving average of the data is performed to smoothen the curve so that the Lip Corners movement will be smooth without external noise and fluctuation. The final graph shows the normalised output of the data between 0.0 and 1.0 because the robot's motors can only take the input in that range. The change in shift of the graph for every 5 seconds shows that the AU and the Lip Corners are correctly mapped.

Mouth

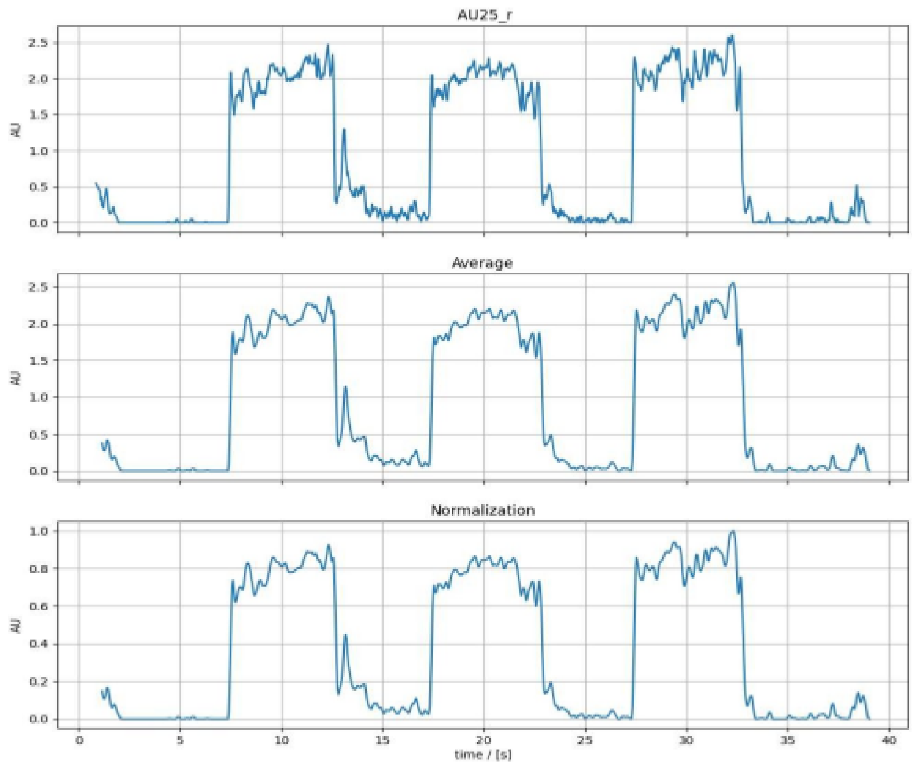


Figure 4.9: mouth

This graph is the output generated after mapping the mouth motor of the robot to action unit AU_25 generated from open-face software. The first top graph shows the collected data from open-face software after performing the experiment. In the centre graph, the moving average of the data is performed to smoothen the curve so that the mouth movement will be smooth without external noise and fluctuation. The final graph shows the normalised output of the data between 0.0 and 1.0 because the robot's motors can only take the input in that range. The change in shift of the graph for every 5 seconds shows that the AU and the mouth are correctly mapped.

4.2.2 Comparision graphs between Human and Robot

In this section, we see the output graphs for the emotion detection experiment between human and robot's facial emotions, we compare both emotions and plot graphs to find the difference between them which can be seen in this section. If the difference plot is low it infers that the system is working correctly.

4.2.2.1 Happiness

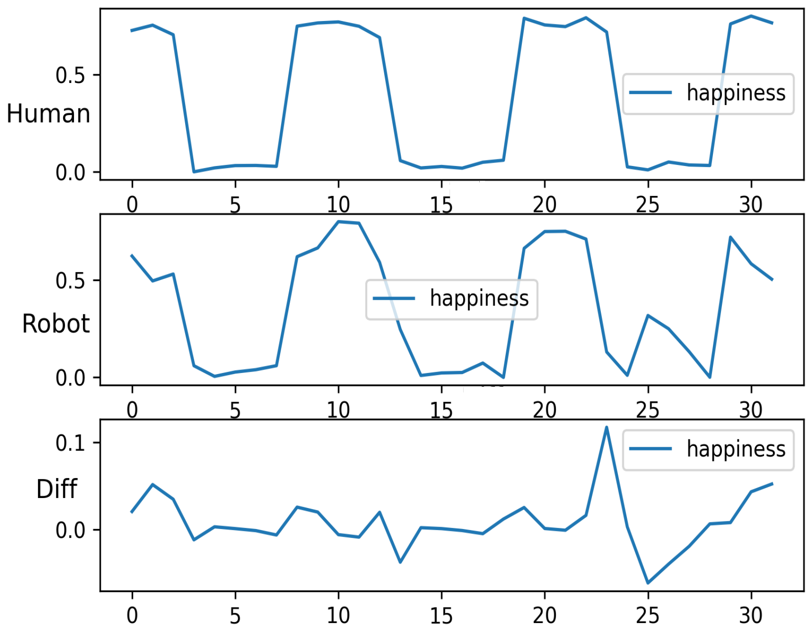


Figure 4.10: Human: Happiness facial emotion generated by human's face, Robot: Happiness facial emotion generated by robot's face, Difference: The difference in happiness emotion between human and the robot's facial emotion

This graph is plotted to analyse the happiness emotion between human's and Robot's faces. In the first graph, the Human's emotion of happiness is detected and the graph for experimental data is plotted, the scale is set between 0.0 and 1.0, we can see from the graph that the happiness emotion is recognised at its peak in the alternative 5 seconds. In the Second graph, The robot's emotion of happiness is detected and the graph for experimental data is plotted, we can see from the graph that the happiness emotion is recognised at its peak every alternative 5 seconds. In the last graph, the difference between Human emotion and Robot emotion is calculated and the difference graph is plotted. The difference in emotion is found to be very low. We conclude Facial mimicking model is working correctly

4.2.2.2 Fear

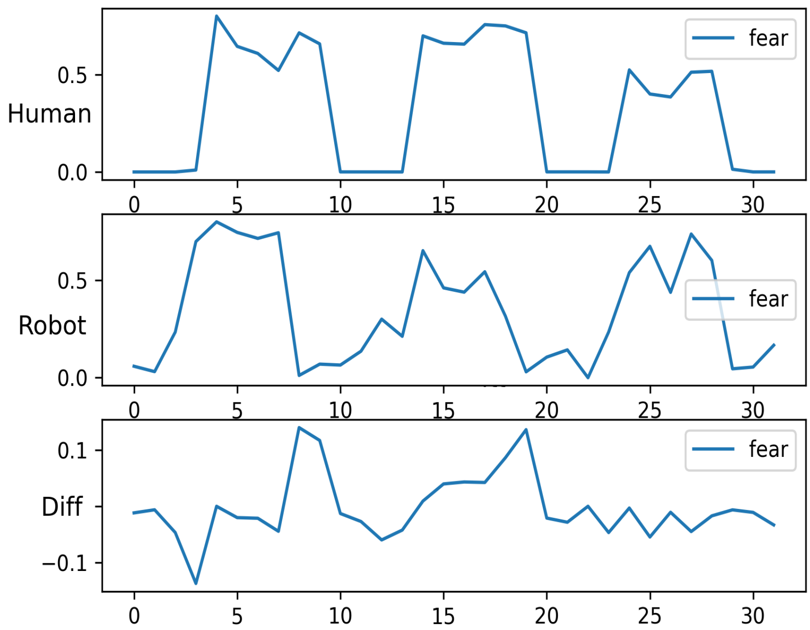


Figure 4.11: Human: Fear facial emotion generated by human's face, Robot: Fear facial emotion generated by robot's face, Difference: The difference in fear emotion between human and the robot's facial emotion

This graph is plotted to analyse the fear emotion between human's and Robot's faces. In the first graph, the Human's emotion of fear is detected and the graph for experimental data is plotted, the scale is set between 0.0 and 1.0, we can see from the graph that the fear emotion is recognised at its peak in the alternative 5 seconds. In the Second graph, the robot's emotion of happiness is detected and the graph for experimental data is plotted, we can see from the graph that the fear emotion is recognised at its peak in a few cycles. In the last graph, the difference between Human emotion and Robot emotion is calculated and the difference graph is plotted. The difference in emotion is found to be very low.

We conclude Facial mimicking model is working correctly

4.2.2.3 Neutral

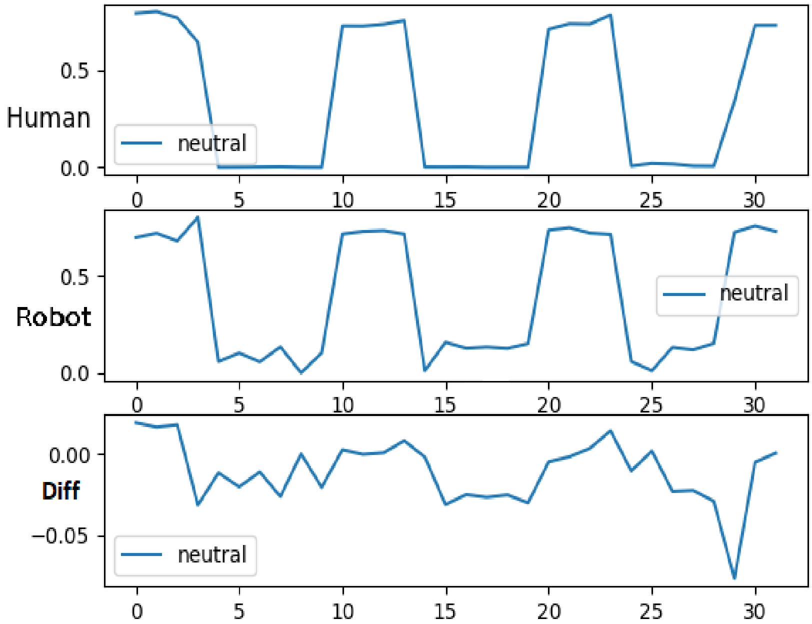


Figure 4.12: Human: Neutral facial emotion generated by human's face, Robot: Neutral facial emotion generated by robot's face, Difference: The difference in neutral emotion between human and the robot's facial emotion

This graph is plotted to analyse the neutral emotion between Human's and Robot's faces. In the first graph, the Human's emotion of neutral is detected and the graph for experimental data is plotted, the scale is set between 0.0 and 1.0, we can see from the graph that the happiness emotion is recognised at its peak in the alternative 5 seconds. In the Second graph, the robot's emotion of neutral is detected and the graph for experimental data is plotted, we can see from the graph that the neutral emotion is recognised at its peak every alternative 5 seconds. In the last graph, the difference between Human emotion and Robot emotion is calculated and the difference graph is plotted. The difference in emotion is found to be very low. So we can conclude that the facial mimicking model of emotion works correctly.

4.2.2.4 Sadness

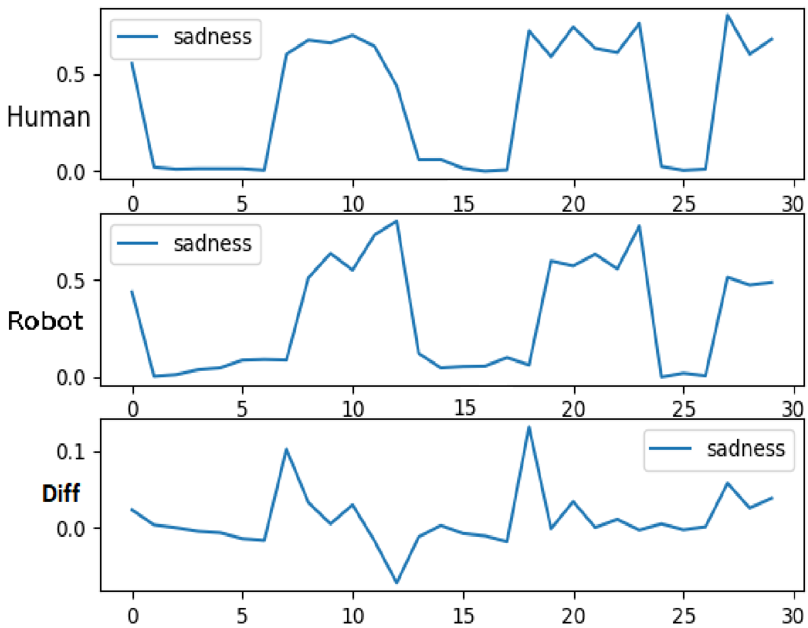


Figure 4.13: Human: Sadness facial emotion generated by human's face, Robot: Sadness facial emotion generated by robot's face, Difference: The difference in sadness emotion between human and the robot's facial emotion

This graph is plotted to analyse the sadness emotion between Human's and Robot's faces. In the first graph, the Human's emotion of sadness is detected and the graph for experimental data is plotted, the scale is set between 0.0 and 1.0, we can see from the graph that the sadness emotion is recognised at its peak in the alternative 5 seconds. In the Second graph, the robot's emotion of sadness is detected and the graph for experimental data is plotted, we can see from the graph that the sadness emotion is recognised at its peak every alternative 5 seconds. In the last graph, the difference between Human emotion and Robot emotion is calculated and the difference graph is plotted. The difference in emotion is found to be very low. So we can conclude that the facial mimicking model of emotion works correctly.

4.2.2.5 Surprise

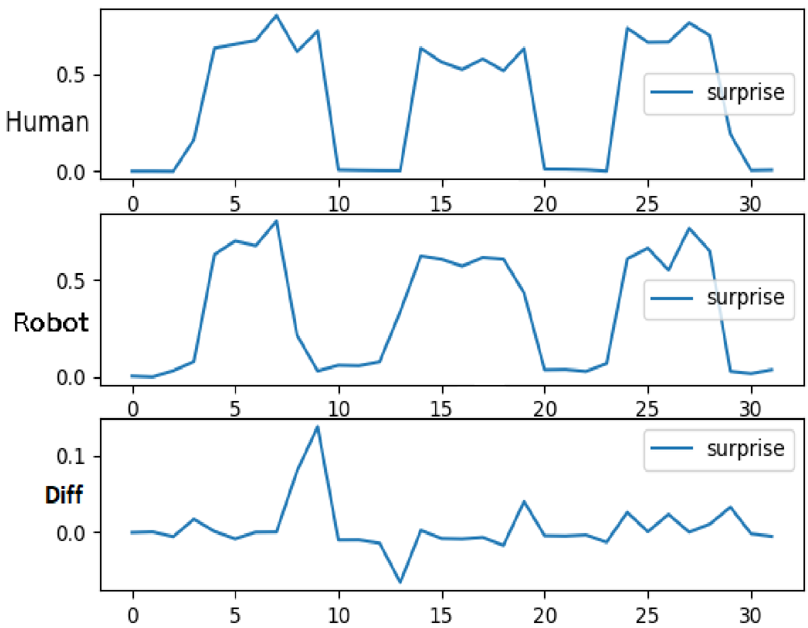


Figure 4.14: Human: Surprise facial emotion generated by human's face, Robot: Surprise facial emotion generated by robot's the face, Difference: The difference in surprise emotion between human and the robot's facial emotion

This graph is plotted to analyse the surprise emotion between Human's and Robot's faces. In the first graph, the Human's emotion of surprise is detected and the graph for experimental data is plotted, the scale is set between 0.0 and 1.0, we can see from the graph that the surprise emotion is recognised at its peak in the alternative 5 seconds. In the Second graph, the robot's emotion of surprise is detected and the graph for experimental data is plotted, we can see from the graph that the surprise emotion is recognised at its peak every alternative 5 seconds. In the last graph, the difference between Human emotion and Robot emotion is calculated and the difference graph is plotted. The difference in emotion is found to be very low. So we can conclude that the facial mimicking model of emotion works correctly.

4.3 Quantitative analysis based on the questionnaire's responses

In this section, we will compare the results of the circumplex model of emotion and the facial-mimicking model of emotion, based on the results of the questionnaire. A detailed explanation of the questionnaire can be found in chapter 3.3.2.

Now, let's compare all the emotions one by one based on the participant's responses. Then find the averages of all the emotions and compare which model works better based on their respective averages. The questionnaire is designed on the Likert scale, with the intensity of emotions ranging between 1 and 5. A maximum average of 5 for an emotion detected means a wide group of people have ease in detecting that emotion and a maximum average of 0 means a wide group of people find it difficult in detecting the emotion. The emotion detection survey is filled by 65 people

4.3.1 Comparision of emotions based on averages calculated

4.3.1.1 Anger

Circumplex model of emotion	
Anger	
[Happy]	1.981142241
[Sad]	2.052262931
[Surprise]	2.71794181
[Anger]	3.299299569
[Neutral]	2.543372845
[Fear]	1.964170259

Facial Mimicking Model	
Anger	
[Happy]	1.890904018
[Sad]	2.399274554
[Surprise]	2.272321429
[Anger]	3.272600446
[Neutral]	2.147321429
[Fear]	2.000279018

Figure 4.15: Comparision of anger emotion

The above tables show the averages calculated for anger emotion with the responses recorded by various participants.

In the Circumplex model of emotion, 3.299 is the average emotion calculated out of 5.

In the Facial mimicking model of emotion, 3.272 is the average emotion calculated out of 5.

The average values of both the models seem to be almost similar but the Circumplex model's average is slightly more compared to the Facial mimicking model. So we can conclude that the circumplex model is better in this case.

4.3.1.2 Happy

Circumplex model of emotion	
Happy	
[Happy]	3.645572917
[Sad]	1.9140625
[Surprise]	2.780208333
[Anger]	1.711197917
[Neutral]	1.846614583
[Fear]	1.947916667

Facial Mimicking Model	
Happy	
[Happy]	3.28984375
[Sad]	1.915104167
[Surprise]	2.3046875
[Anger]	2.184895833
[Neutral]	2.203125
[Fear]	1.88046875

Figure 4.16: Comparision of happy emotion

The above tables show the averages calculated for Happy emotion with the responses recorded by various participants.

In the Circumplex model of emotion, 3.645 is the average emotion calculated out of 5.

In the Facial mimicking model of emotion, 3.289 is the average emotion calculated out of 5.

The average values of both the models seem to be almost similar but the Circumplex model's average is slightly more compared to the Facial mimicking model. So we can conclude that the circumplex model is better in this case.

4.3.1.3 Sad

Circumplex model of emotion	
Sad	
[Happy]	1.765881148
[Sad]	3.699026639
[Surprise]	1.532786885
[Anger]	1.899077869
[Neutral]	2
[Fear]	1.882428279

Facial Mimicking Model	
Sad	
[Happy]	1.699282787
[Sad]	3.666495902
[Surprise]	1.96567623
[Anger]	2.06557377
[Neutral]	1.882428279
[Fear]	2.331967213

Figure 4.17: Comparision of sad emotion

The above tables show the averages calculated for sad emotion with the responses recorded by various participants.

In the Circumplex model of emotion, 3.699 is the average emotion calculated out of 5.

In the Facial mimicking model of emotion, 3.66 is the average emotion calculated out of 5.

The average values of both the models seem to be almost similar but the Circumplex model's average is slightly more compared to the Facial mimicking model. So we can conclude that the circumplex model is better in this case.

4.3.1.4 Surprise

Circumplex model of emotion	
Surprise	
[Happy]	3.534579918
[Sad]	1.832479508
[Surprise]	3.233862705
[Anger]	1.882428279
[Neutral]	1.816342213
[Fear]	2.04892418

Facial Mimicking Model	
Surprise	
[Happy]	2.099385246
[Sad]	1.932889344
[Surprise]	3.165983607
[Anger]	2.033555328
[Neutral]	2.433145492
[Fear]	2.315829918

Figure 4.18: Comparision of surprise emotion

The above tables show the averages calculated for surprise emotion with the responses recorded by various participants.

In the Circumplex model of emotion, 3.233 is the average emotion calculated out of 5.

In the Facial mimicking model of emotion, 3.1659 is the average emotion calculated out of 5.

Here, more participants have chosen the happy emotion and its average is 3.534 rather than the original emotion of surprise. so we can conclude that the Facial mimicking model is better in this case.

4.3.1.5 Neutral

Circumplex model of emotion	
Neutral	
[Happy]	1.899846311
[Sad]	2.683657787
[Surprise]	1.916239754
[Anger]	1.999231557
[Neutral]	3.399846311
[Fear]	1.899590164

Facial Mimicking Model	
Neutral	
[Happy]	1.816854508
[Sad]	2.03227459
[Surprise]	2.01664959
[Anger]	1.99897541
[Neutral]	4.016905738
[Fear]	1.915727459

Figure 4.19: Comparision of neutral emotion

The above tables show the averages calculated for neutral emotion with the responses recorded by various participants.

In the Circumplex model of emotion, 3.399 is the average emotion calculated out of 5.

In the Facial mimicking model of emotion, 4.016 is the average emotion calculated out of 5.

The average values of the Facial mimicking model are much higher than the circumplex model, so we can conclude that facial mimicking model is better in this case.

4.3.1.6 Fear

Circumplex model of emotion	
Fear	
[Happy]	2.101822917
[Sad]	2.252864583
[Surprise]	2.354947917
[Anger]	2.117708333
[Neutral]	2.000520833
[Fear]	3.271875

Facial Mimicking Model	
Fear	
[Happy]	2.117447917
[Sad]	2.373697917
[Surprise]	2.490104167
[Anger]	2.439322917
[Neutral]	1.99921875
[Fear]	2.948177083

Figure 4.20: Comparision of fear emotion

The above tables show the averages calculated for anger emotion with the responses recorded by various participants.

In the Circumplex model of emotion, 3.271 is the average emotion calculated out of 5.

In the Facial mimicking model of emotion, 2.948 is the average emotion calculated out of 5.

The average values of the circumplex model are quite higher than the facial mimicking models So we can conclude that the circumplex model is better in this case.

So finally, after the quantitative analysis of the questionnaire responses data, we can say that in most of the cases for testing emotions, the circumplex model of emotion is seen to be comparatively much better for emotion detection than the facial mimicking model of emotion.

Chapter 5

Conclusion

In this thesis, our main aim was to compare and evaluate the various emotional models for facial expressions using cheap table-top robots. The two models of emotions we compared were the Circumplex model of emotion and the Facial mimicking or imitation model of emotion using Professor Einstein robot. By comparing these two models and performing various quantitative and qualitative analysis, we have to decide which emotional model was well suited and worked better on the Professor Einstein robot's face.

For this purpose, we developed software for both models of emotion. The circumplex model of emotion software was developed in such a way that it can take valence and arousal as inputs and mapped accordingly with professor Einstein robot's facial motors. Then the experiments were conducted with this model connecting to Professor Einstein robot by varying different combinations of valence and arousal values. The wheel of emotion was tested for different emotions. The results of this test were successful, and the robot could generate different emotions. The results can be found in chapter 3.1.2.

After verifying the basic valence-arousal model. The same model was used for a different experiment in which the robot was made to perform various facial expressions like anger, happiness, fear, and neutral for a time of 30 seconds. Using this set of videos the emotions were detected from the robot's face and a graphical analysis was performed to check how well the emotions were detected. The resultant graphs can be found in chapter 4.1

Now, the facial mimicking model's software was developed in such a way that it can imitate our facial expressions on a live computer's web camera using tools like open-face. The same set of experiments was conducted by making emotional sets of videos of 30 seconds each of both human and the imitated expression of the robot and they were recorded. The emotions of all the test cases were detected and the output graphs were plotted by comparing the emotions and their respective difference. The results can be seen in chapter 4.2.2.

Finally, we prepared a questionnaire, a survey comparing output videos of both the circumplex model of emotion and the facial mimicking model of emotion. A total of 65 participants had taken part in the survey and the data was analysed and compared using the average of emotions. The results can be seen in chapter 4.3.1

From all those experiments performed and the analysis done, we can conclude that the Circumplex model of emotion has performed better than the Facial mimicking model of emotion on a tabletop Professor Einstein robot's face.

For future work, more emotional models can be developed and tested on Professor Einstein robot. In this thesis only the robot's facial motors were explored for facial movements and expressions, so even other motors for head movements, walking and other sensorimotor of the robot can be explored for different nonverbal communications. In this thesis, only basic emotions were designed, compared and explored there is a possibility of creating and comparing more emotions which are not common in day-to-day life.

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