Politecnico di Milano
School of Industrial and Information Engineering
Computer Science Master Degree
Advanced User Interfaces Course

Teo 2 (Emotional Teo)

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Academic Year 2016–2017

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Introduction

Robotic companions have been proved effective to promote social skills. It is though that this capability is enhanced when the robot exhibits come «emotional» behavior.
The goal is to re-engineer and extend the existing version of Teo 2 [6] with a cognitive module (enabling emotional sensing, expression features, adaptive human-robot spatial behavior and adaptive polite/intimate behavior).
The document is structured in this way:

- Chapter 1: target groups and needs
  the users, their needs, the goals of the system and the requirements analysis
- Chapter 2: state of the art
  what are the neurodevelopmental disorders and how can they be dealed through robotics
- Chapter 3: solution
  the user experience design and the software and hardware architecture of Teo2
- Chapter 4: empirical evaluation
  the evaluation plan of Teo2
- Chapter 5: value proposition
  a critical reflection about our work and what is the difference between our robot and the existing ones
- Chapter 6: future work
  what was left and future directions

Chapter 1

Chapter 1: target groups and needs

1.1 Users and needs

User:	Needs:
School children/NDD-affected children	- Learn to recognize emotions from others - Interact socially with others - Convey emotional rewards to the children throughout learning activities
Special Teachers/Therapists	- Improve emotional growth of the children introducing robotics in the traditional therapy

Table 1.1: Primary users and their needs

1.2 Goals of the system

- Develop empathetic behaviors
- Include socially correct spatial management
- Produce emotional reactions that make Teo 2 more emotionally natural than Teo 1 [8] and the first version of Teo 2 [6]

1.3 Requirements of the system

1.3.1 Functional requirements

- The user has to be able to talk with Teo
- The system has to be empathetic towards the users

1.3.2 Non-functional requirements

- Short response time
- Unharming materials
- Adequate battery autonomy

Chapter 2

Chapter 2: state of the art

2.1 NDD

Neurodevelopmental disorders (NDD) are impairments of the growth and development of the brain or central nervous system [2].
A narrower use of the term refers to a disorder of brain function that affects emotion, learning ability, selfcontrol and memory and that unfolds as the individual grows.
NDD has an incurable nature, but early interventions and appropriate therapeutic approaches can help patients to improve their intellectual and behavioral skills.

2.2 Robotics

The use of robots has been proved successful in many cases of subjects with different neurodevelopmental disorders, e.g., intellectual disability, attention-decit, hyperactivity disorder (ADHD), or Autistic Spectrum Disorder (ASD) [1] [5].
The use of social robots to provide alternative, "virtual" forms of Pet Therapy has been explored in research since late nineties.
Pet Therapy (PT) is a treatment that works well especially with NDD children, leading to improvements in various spheres.
According to current research [3], PT helps NDD subjects to release their often persistent state of anxiety and improves relaxation, as human-animal bond acts on "stress hormones" production, inducing a reduction of arterial pressure, cardiac and respiratory rates.
Some studies have found that 5- and 6-year-olds who were more attached to their pets expressed more empathy toward peers and that 7- to 10- year-olds who had more "intimate talks" with their pets also had more empathy toward their peers.
The pioneer in this field is PARO, a stuffed robot shaped like a baby harp seal and equipped with five kinds of sensors - tactile, light, audition, temperature, and posture sensors - with which it can perceive people and its environment. [7]

Figure 2.1: Seal Paro

Similarly, SAM is a stuffed dolphin that engages NDD children in a variety of play tasks. Sam's affordances and behavior has been designed for this specific target group in cooperation with a team of therapists from SAM Foundation and L'Abilità, two non-profit institution in Netherlands and Italy respectively. [4]

Figure 2.2: Dolphin Sam

Another approach is based in using humanoid robots that put themselves in the shoes of children companions.
One of the most famous is ASK NAO, a 58cm height robot which is adapted to the context of special children education, covering a broad range of varied skills: interpersonal communication, knowledge of everyday activities, vocabulary lessons, the

recognition of emotions, etc. [9]

Figure 2.3: ASK NAO

Still, given the wide range of NDD conditions and the specfic characteristics of each single subject, there is space for new exploratory experiences involving robotic interaction to enlarge the set of success stories and identify new forms of therapeutic and educational interventions for this target group.

Chapter 3

Chapter 3: solution

3.1 UX design

3.1.1 General approach

In many existing researches, the experiences with the robot are shaped as games, especially for children, and the robot is static and cannot be personalized by the users, limiting the range of opportunities that robotic interaction can potentially offer to NND subjects.
Recently, a project called KROG (Kinect-Robot for Gaming) [8] has begun to overcome these limitations, exploring the potentials of the integration of mobile robots and virtual worlds in order to support, through the game, various educational-therapeutic activities.
The robot used in the KROG project is called Teo.

Figure 3.1: KROG project - Teo 1

It has been designed to be used as a play tool for children of different ages and with different NDDs, enables a wide range of game-based experiences, and supports a number of play dimensions that are largely unexplored with this target group, such as movements in space, physical manipulation, and robot personalization.
Teo is emotional, huggable, mobile, and customizable.
Teo is also holonomic, free of moving on the floor in any direction at a speed similar to that of humans in indoor environments.
Its "natural" mobility has the potential of making the robot more easily accepted by NDD subjects and enables them to explore spatial relationships during robotic interaction.
Teo can exploit several interaction modalities in ways that are completely customizable to the needs and preferences of each specific subject.
Its soft body includes a set of sensors that detect various forms of body manipulation, such as hugs, caresses, slaps, and punches, that trigger Teo's emotional reactions, expressed by means of sound, light effects, or body movements.
Coloured LEDs and sound speakers are embedded in the body, supporting communication.
Teo also wears a set of large buttons on its hat that enable intentional touch interactions.
The set of stimuli offered by Teo contribute to create fun, to build an emotional bond with the robotic companion and to develop the awareness of cause-effect phenomena.
Stimuli can be either controlled by the therapist or triggered automatically by effect of interactions, which enlarges the gamut of activities that can be played with the

robot (it also relieves the caregiver from an attentionally intensive control of the child).

Our project aims to design new interactive experience using the existing version of Teo 2 [6].

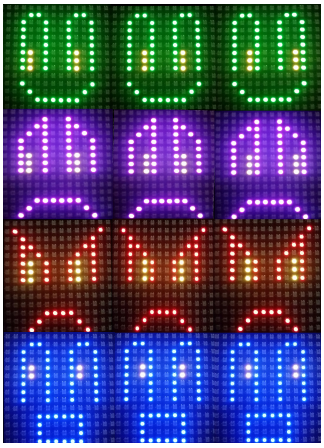
(a) Basic version of Teo 2 (Tolomeo)

(b) Emotional version of Teo 2 (Campo-Sardella-Sanchez)

Table 3.1: Differnces between the basic Teo 2 and the emotional one

The main features are the followings:

- dynamic face and body expressions (led matrix and led strips)



(a) Led matrix of the emotional Teo 2

(b) Led strips of the emotional Teo 2

Table 3.2: Dynamic face and body expressions of the emotional Teo 2 and the emotional one

- more natural voice (IVONA text to speech)

click here

- proximity zone detection

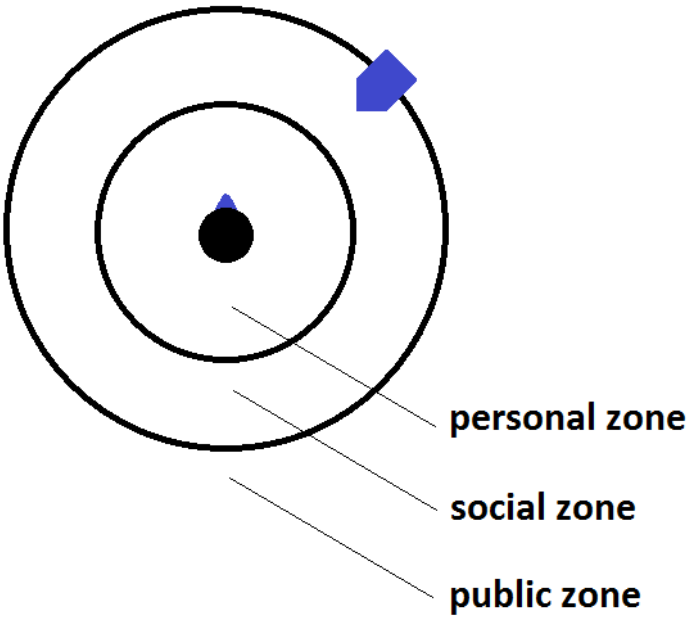


Figure 3.2: Proximity zones

- sound localization (with 3 microphones)

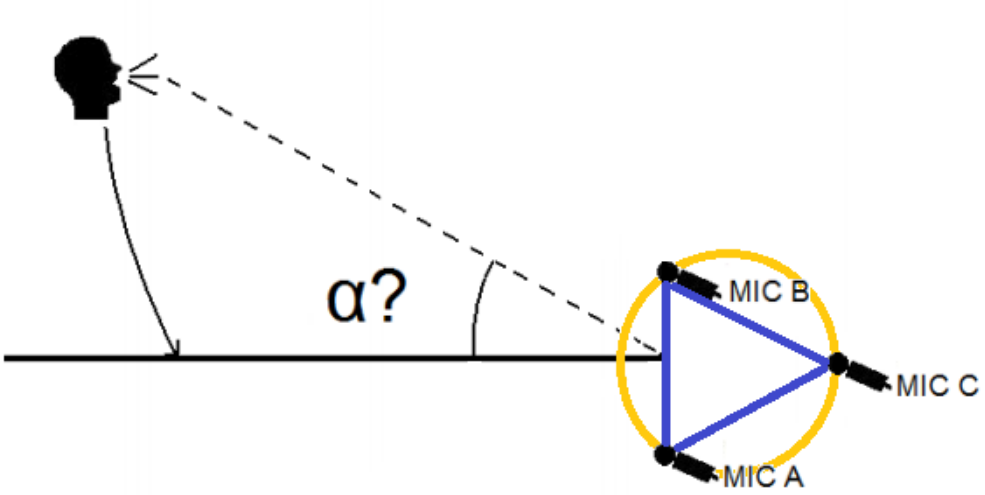


Figure 3.3: Sound localization

3.1.2 Scenarios

3.1.2.1 Talk2Teo

Input The therapist selects *Teo2Control* app and chooses *Talk2Teo*.

[optional]

The therapist can configure a joypad (which controls Teo) with the «Teo2 Settings» app.

In order to make things easy to use, there are the following presets of such configurations, so the therapist can choose what she prefers.

Default:	
Button:	Action:
X	Sad
Y	Happy
B	Scared
A	Angry
UP	“Hello”
DOWN	"Do you want to play?"
LEFT	«Great!»
RIGHT	“Well done”
ANALOG STICK 1	Move
ANALOG STICK 2	Rotate
LT	“Yes”, Nod
LB	Laugh
RT	“No”
RB	Cry
START	Reset to idle
SELECT	Unassigned

Table 3.3: Manual joypad actions - More Emotion preset

Greetings:	
Button:	Action:
X	Sad
Y	Happy
B	Scared
A	Angry
UP	“Hello I’m Teo!”
DOWN	"What’s your name?"
LEFT	“Nice to meet you!”
RIGHT	"Do you want to play?"
ANALOG STICK 1	Move
ANALOG STICK 2	Rotate
LT	“Yes”, Nod
LB	Laugh
RT	“No”
RB	Cry
START	Reset to idle
SELECT	Unassigned

Table 3.4: Manual joypad actions - More Emotion preset

More Emotions:	
Button:	Configuration:
X	Sad
Y	Happy
B	Scared
A	Angry
UP	Surprised
DOWN	Bored
LEFT	*Sigh*
RIGHT	*Gasp*
ANALOG STICK 1	Move
ANALOG STICK 2	Rotate
LT	“Yes”, Nod
LB	Laugh
RT	“No”
RB	Cry
START	Reset to idle
SELECT	Unassigned

Table 3.5: Manual joypad actions - More Emotion preset

If the therapist skips this configuration phase, then the default preset will be associated to the joypad.

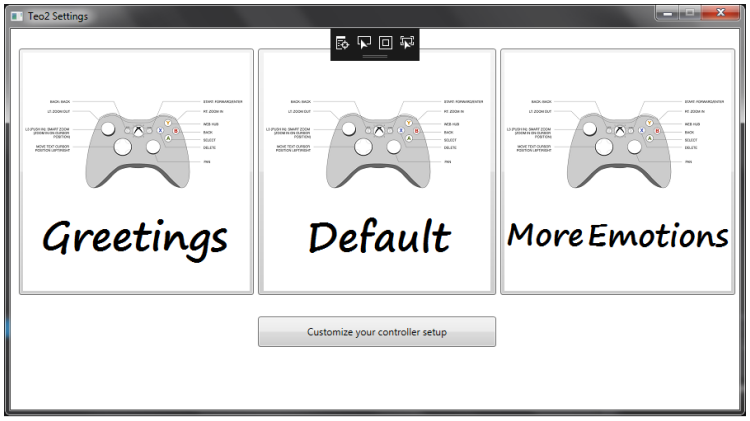


Figure 3.4: Joypad presets

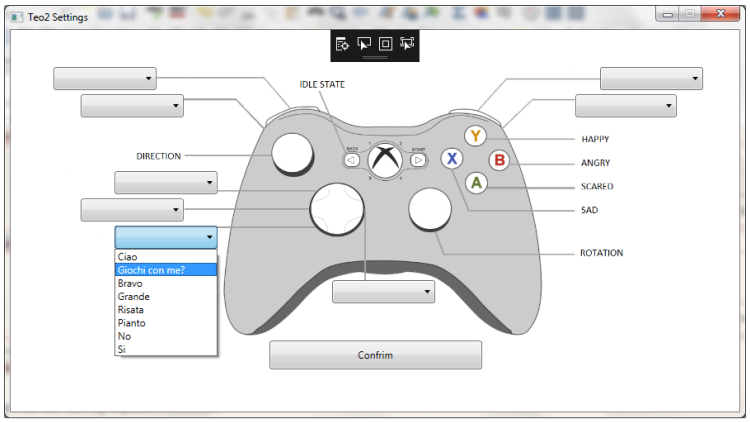


Figure 3.5: Joypad customization

Goal Talking to the user showing empathetic behaviours.

Activities The therapist controls Teo using a joypad, allowing a *free2play* approach.
The behaviours can be divided in manual and automatic ones.

Manual behaviours

1. Move/Rotate
2. Speak
3. Select mood (happy, sad, angry, scared)
4. Non-linguistic utterances

(a) high profile: laugh, cry

(b) low profile: nod, gasp, sigh

Observation#1: everytime the a mood is selected, an animation follows.

- *Happy: Teo rotates 30° clockwise, 60° counter-clockwise and 30° clockwise*
- *Sad: Teo rotates 180° clockwise*
- *Scared: Teo goes back 40cm and vibrates for 3 sec*
- *Angry: Teo moves forward 20cm, vibrates for 0,5 sec and goes back 20cm*

Observation#2: the voice pitch depends on the mood

Automatic behaviours

1. Face animation

   Every 3 sec a face animation occurs

2. Breathing

   A fading effect on the led strips simulates the breathing (whose frequence depends on the mood)

3. Wake up

   In the idle state Teo is sleeping, and it is snorling. Teo has to be awakened by the child which has to touch it or talk to it. Once woke up, Teo says «Hello!»

4. Hit

   Everytime the child hits Teo, it becomes sad and cries.

5. Where are you?

   Everytime the children go away from Teo (from the social zone to the public one) Teo becomes scared saying «Where are you?». When the children comes back, Teo becomes happy saying «Welcome back!»

6. Scheduled low profile non-utterances

   Every 5 sec of inactivy, Teo makes a low profile non-linguistic utterance (randomly chosen)

Feasibility The automatic behaviours are more complex with respect to the manual ones, so they will be implemented in case there will be enough time

3.1.2.2 MarcoPolo

Version 1

Input The therapist selects *Teo2Control* app and chooses *Marco-Polo game - version 1.*

Goal The goal of the game is to help the child to recognize spatial relations with Teo.

Rules The child and Teo share sufficiently large space to move around.
The game starts with a 'blindfolded' Teo, which explains the child the dynamic of the game.
Teo prompts the kid to move away from him.
Anytime Teo needs help would ask «Where are you, <name of the child>?» and the child must answer back «Teo, here!».

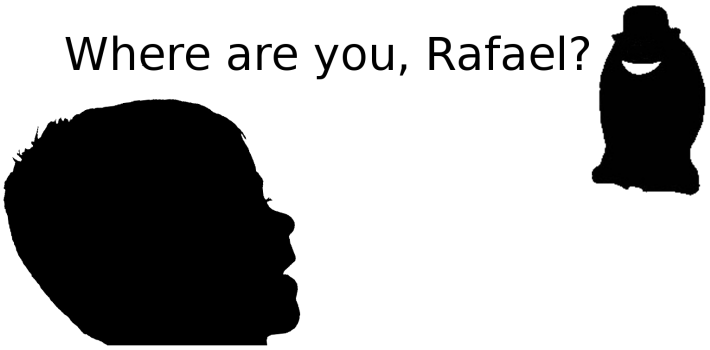


Figure 3.6: 1st step of Marco-Polo1 game

Teo will, then try to move towards the child.

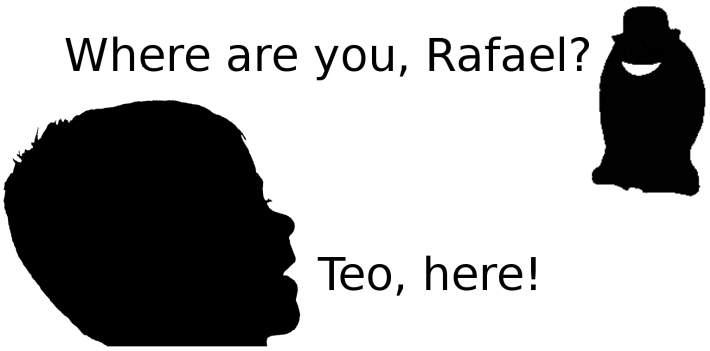


Figure 3.7: 2nd step of Marco-Polo1 game

If Teo is able to reach to the 'intimate region' with the kid for a moment, Teo wins and shows happiness congratulating the kid for helping him.

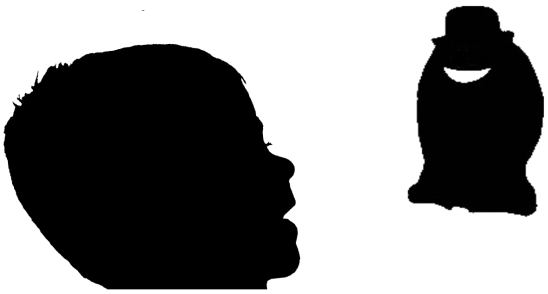


Figure 3.8: 3rd step of Marco-Polo1 game

Else, Teo keeps asking the kid for help and continues looking.

Conclusion of the game The game ends when the child hugs Teo.

Feasibility

- the accuracy of the microphones must be sufficient in order to locate the voice (0-90°, 91°-179°, 180°-269°, 270°-359° with respect to Teo)
- Teo processing power must be enough in order to process the sound localization
- constraining the child to stay in a fixed spot until Teo finds him would allow to complete the game, even though is not mandatory for the implementation

Version 2

Input The therapist selects *Teo2Control* app and chooses *Marco-Polo game - version 2.*

Goal The goal of the game is to help the child to associate the sequence presented to a spatial relation with the physical checkpoints.

Rules The child and Teo share sufficiently large space to move around.
The game starts with a 'blindfolded' Teo, which explains the child the dynamic of the game.
A projector will show on the floor a sequence of images (checkpoints).
The child must move to the checkpoint and call «Teo, here!» so Teo could start moving in his direction.

Figure 3.9: 1st step of Marco-Polo2 game

Figure 3.10: 2nd step of Marco-Polo2 game

Whenever Teo arrives to a correct checkpoint, congratulates the child happily and prompts him to keep doing a great job.
The game ends when Teo reaches the final checkpoint.

Feasibility

- this is an extension of the 1st version of Marco-Polo game, so its implementation depends on the completion of the latter one
- it is necessary to install a RFID reader on Teo in order to recognize the checkpoints
- it is necessary to have a projector in the room

3.2 Implementation

3.2.1 HW architecture

The architecture is the same of the basic version of Teo2 [6].

Figure 3.11: Architecture of Teo2 project

The main innovations are:

1. the bluetooth network is centralized on the PC
2. Teo2 can be controlled through a Xbox joypad
3. the motors are connected to the Arduino pins 9, 10 and 11

3.2.2 SW architecture

3.2.2.1 Talk2Teo

The software of *Talk2Teo* is distributed in the following way: the manual behaviours are managed mainly by the PC, the automatic ones only by Teo2 (Arduino).

PC The pc program is called Teo2Control, which provides support to Teo2 internal logic and let the therapist control Teo2 through the Xbox 360 controller. The application communicates with Teo2 through Bluetooth serial port, it is also connected to a Bluetooth speaker.

Functionality description

1. Control Teo2: the therapist uses the Xbox controller to directly control Teo2. Xbox input is caught and parsed by Teo2 control which will forward the requested command to Teo2 via Bluetooth.
2. Support Teo2: Teo2 is unable to communicate with Bluetooth speaker, thus to do so it has to send a request to the pc. Upon receiving messages from Teo2, Teo2 Control will parse them and perform actions accordingly. This

can include send messages back to Teo2 or send audio files to the Bluetooth speaker.

Architecture description Teo2 Control uses an event based architecture, its different components communicates through events (like input received from Xbox 360 controller or Bluetooth). This architecture permit the application to be fully scalable as each function or method is independent from the others.

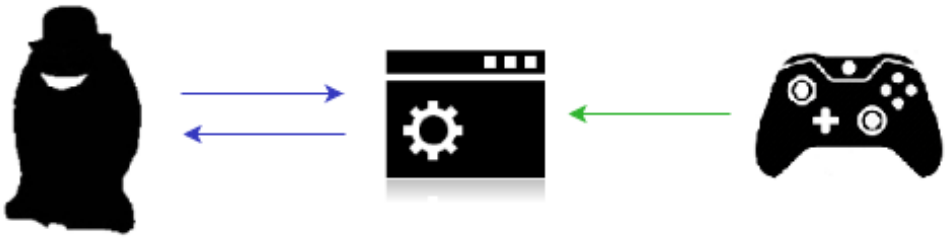


Figure 3.12: High level architecture of *Talk2Teo*

UML models

1. BTManager. This component is responsible of receiving and sending Bluetooth messages. Anytime a message is received from the Bluetooth serial port connected to Teo2 it will raise an event and alert the Parser. BTManager also manages the outgoing messages decided by the Parser.

2. XBManager. This component is responsible of receiving Xbox 360 controller input. Anytime an input is received from the Xbox 360 controller it will raise an event and alert the Parser.

3. Parser. The Parser is the logic of Teo2 Control. It decides which action to take depending on the input received, when the decision is made it will raise an event alerting the BTManager. Using Teo2 Setting is possible to switch between 3 premade sets of commands for the controller and to set a custom set; Teo2 control will follow the indications in the selected XML file, which maps every key to a command.

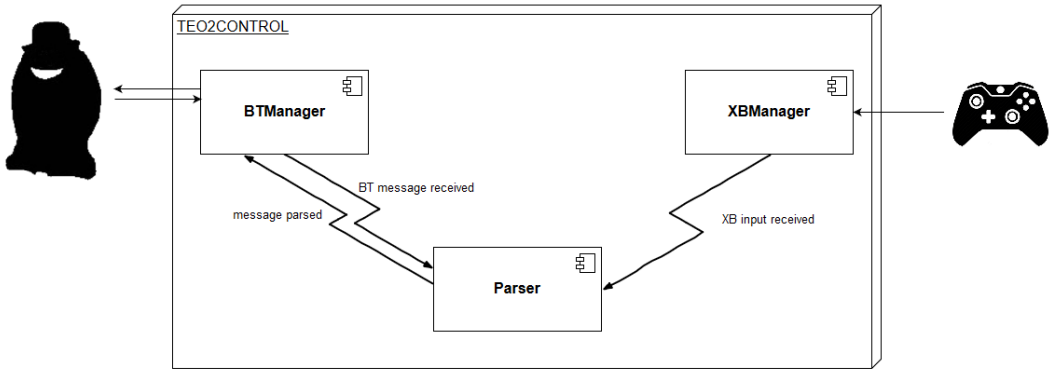


Figure 3.13: UML components diagram of Teo2Control

Incoming and outgoing messages and input from both Xbox and Bluetooth are stored in shared buffers to which each component access when a certain event is raised. For example if a message is received from the Bluetooth port connected to Teo2 BTManager will push it in the BT input buffer and raise an event to alert the Parser which will pop the message from the same buffer.
The System uses 3 buffers:

- BT input buffer
- BT output buffer
- XB input buffer

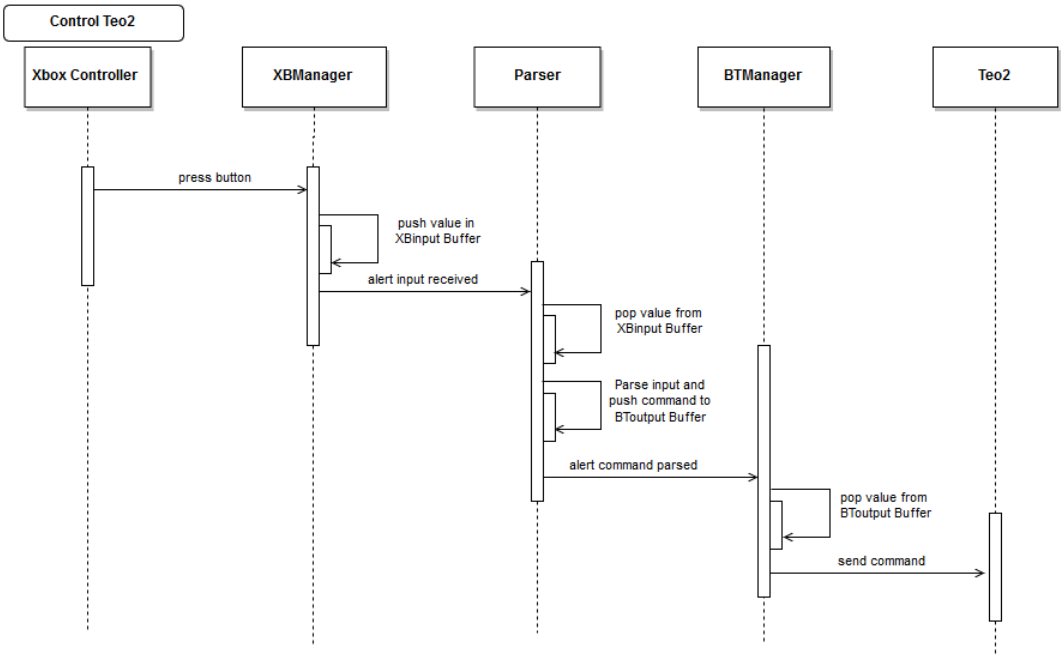


Figure 3.14: This diagram describes the workflow of the system in the case in which the user is using the Xbox controller to control Teo2.

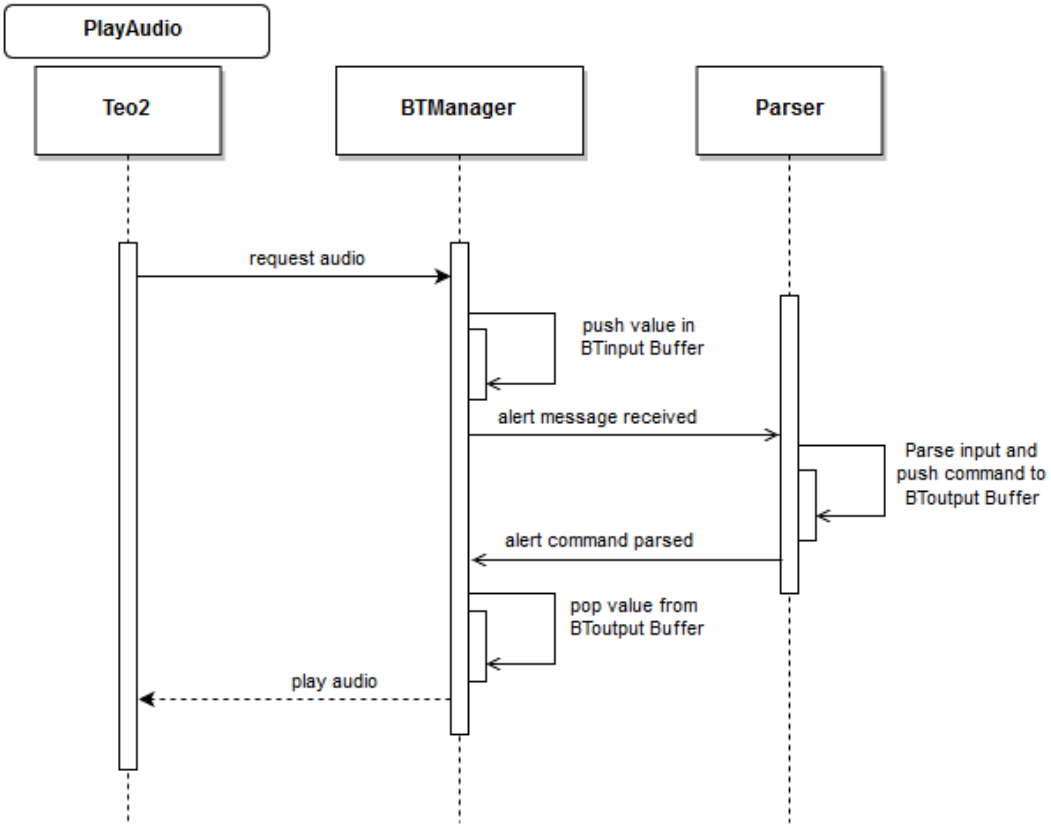


Figure 3.15: Since the Arduino board inside Teo2 is unable to communicate with the Bluetooth speaker it requires a computer to play the audio files for it. This diagrams describe the process with which Teo2 plays an audio file. 2.

Arduino The Arduino sketch follows this logic:

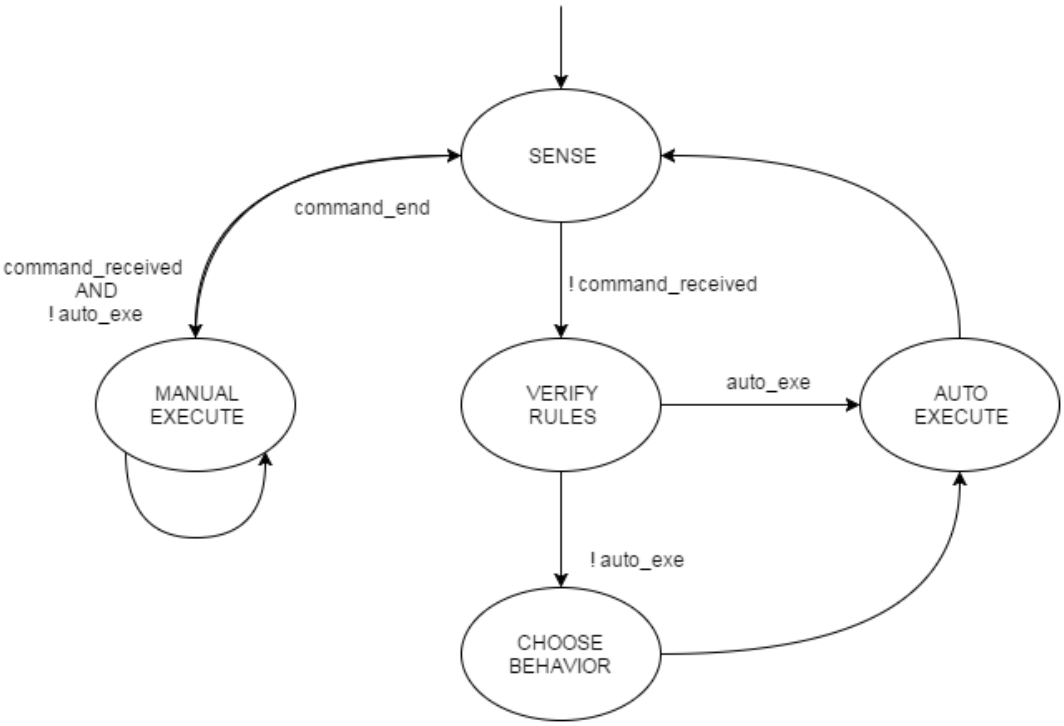


Figure 3.16: Final state machine of Talk2Teo logic

Communication protocol To communicate with Teo2 a set of fixed commands is used, this set defines a protocol of communication between Teo2 and the computer application.

Command	Meaning
move x y z	Move at forward speed x (in m/s), strafe y (in m/s) and angular z (in rad/s)
happy	Set Happy mood
sad	Set Sad mood
scared	Set Scared mood
angry	Set Angry mode
auto on/off	Toggle automatic behaviors
idle	Set idle state
end of sound	Communicate end of playing sounds

Table 3.6: The main commands from PC to Teo2

Command	Meaning
ready	Teo2 is on and ready to start communication
end motion	Teo2 has ended automatic movements
say x	Teo2 requests to say a certain word/phrase x

Table 3.7: The main commands from Teo2 to PC

When Teo2 is switched on and for all the duration of the session it will send "ready" via Bluetooth, this message is caught by Teo2 Control which will establish the connection. If no "ready" message is received the program will close. Notice that each of the PC to Teo2 commands can be set in the XML files corresponding to the preset but Teo2 sketch has to be changed too in order to recognise new commands.

3.2.2.2 MarcoPolo

MarcoPolo instead is totally on Teo2.

Chapter 4

Chapter 4: empirical evaluation

First of all, we would make a distinction between the Teo2 we have made, the prototype, and a hypothetical final product.

4.0.1 Prototype

It is the current state of Teo 2, which implements *Talk2Teo*.

4.0.1.1 Evaluating processes

As the system described consist of different parts is it necessary to plan different evaluating processes:

Aspect to evaluate:	computer application
Partecipants:	therapists
Evaluation context:	usability lab
Evaluation method:	task-driven
Tasks:	1. install the application 2. Run *Teo2Settings* ad selects a preset 3. Create a custom set of commands 4. Run *Teo2Control*
Questionnaire:	- How difficult did you find to accomplish the tasks? [Very easy: 1, 2, 3, 4, 5: Very hard] - Do you find useful for the therapy sessions the possibility to create a custom set of commands? [Not at all: 1, 2, 3, 4, 5: Very useful]

Table 4.1: Evaluation plan of computer application

Aspect to evaluate:	robot control system
Partecipants:	therapists
Evaluation context:	usability lab
Evaluation method:	task-driven
Tasks:	1. Move Teo2 around at both high and low speed 2. Change Teo's moods 3. Make Teo2 talk
Questionnaire:	- How difficult did you find to accomplish the tasks? [Very easy: 1, 2, 3, 4, 5: Very hard] - How long did you feel it took you to learn the function of the controller's buttons? [Very short time: 1, 2, 3, 4, 5: Too much - How would you set the 'happy' mood? [A, B, X, Y] - How would you make Teo2 rotate? [left stick, right stick, directional arrows] - How do you feel is the controller's behaviour? [Almost never works: 1, 2, 3, 4, 5: Always works] - How do you evaluate the mobility of Teo2? [Difficult to control: 1, 2, 3, 4, 5: Perfect, easily controllable]

Table 4.2: Evaluation plan of robot control system

Aspect to evaluate:	robot features
Partecipants:	therapists
Evaluation context:	informal setting
Evaluation method:	inspection
Evaluation technique:	interview
Features to evaluate:	- face expressions design - face expressions animations - face and strips brightness - face and strips colours - movement speed - movement degrees of freedom - emotional movements appropriateness - voice tone - automatic behaviours appropriateness

Table 4.3: Evaluation plan of robot features

4.0.2 Final product

For the therapists, we propose a Teo that is remotely controlled, just at the reach of their hands, so they can trigger emotional behaviors as rewards or a demonstration for cause-effect relationship, we want the therapist to make Teo speak so it can prompt the child to follow the activity, we want to be able of moving it around so it can be used as a guide for the kid around the room. We want Teo to be versatile for the therapist and the dynamic she sees fit to develop with the child. Finally, we want Teo to gather data about the child through its sensors, in order to give the therapist useful structured informations.
For the children, we propose a Teo that has set of behaviors that will make it a likable companion for a child. We want it to react to hug, hits and caresses, to show interest and autonomously motivate the continuation of story-telling activities, to have a set of games to play with the children, to call out for the child when Teo can't find him near. We want to create a Teo that can be a friend to the child.

4.0.2.1 Evaluating processes

For the final product, the computer application and the robot control system will be evaluated applying the procedure described above for the prototype.
The robot features, instead, will be evaluated in the following task-driven procedure. There will be 10 therapy sessions, one per week, for a period of 2.5 months. After each session the following aspect will be evaluated:

Aspect to evaluate:	robot's impact on the children
Partecipants:	therapists, NDD children
Evaluation context:	usability lab
Evaluation method:	task-driven
Tasks:	design activities that include Teo as part of the therapy allot time for the kid to interact with Teo indipendently
Questionnaire:	- Has the child understood Teo while speaking? [no, a bit, enough, almost, totally] - Did the child feel comfortable around Teo? [no, a bit, enough, almost, totally] - Did the child show interest in Teo? [no, a bit, enough, almost, totally] - Did the child, overall, liked Teo's behaviours? [no, a bit, enough, almost, totally] - Do you think that the child would like to have Teo in another session? [Yes, No] - What was the level of social interaction and relationship before the therapy? [1, 2, 3, 4, 5] - What is the level of social interaction and relationship after the therapy? [1, 2, 3, 4, 5] - What was the level of verbal and non-verbal communication before the therapy? [1, 2, 3, 4, 5] - What is the level of verbal and non-verbal communication after the therapy? [1, 2, 3, 4, 5] - What was the level of interest of the child in playing before the therapy? [None: 1, 2, 3, 4, 5: Really interested] - What was the level of interest of the child in playing after the therapy? [None: 1, 2, 3, 4, 5: Really interested] - What game di the child like the most? [Talk2Teo, MarcoPolo]

Table 4.4: Evaluation plan of robot impact on the children

Notice that these are a set of sample questions that has to be refined and possibly enlarged following the opinion of an expert or a therapist who should inspect the robot and its automatic behaviours in order to state the appropriateness of Teo2 within the therapy.

Aspect tot evaluate:	robot's usefulness within therapy
Partecipants:	therapists, NDD children
Evaluation context:	usability lab
Evaluation method:	task-driven
Tasks:	design activities that include Teo as part of the therapy
Questionnaire:	- How did you find to design activities for therapy session involving Teo? [Very easy: 1, 2, 3, 4, 5:Very hard] - How did you find to use and control Teo during the realization of the therapy? [Very easy: 1, 2, 3, 4, 5: Very hard]

Table 4.5: Evaluation plan of robot usefulness

Notice that these are a set of sample questions that has to be refined and possibly enlarged following the opinion of an expert or a therapist who should apply the proper metrics to the therapy realized with Teo.

After 2.5 months, the above two aspects will be evaluated, and the therapists will be interviewed in order to collect their opinions and feedback about Teo.

Interview topics:	- What do you think are the PROS of Teo? - What do you think are the CONS of Teo? - What feature would you like to add to Teo? - Does using Teo make a significant difference in the therapy with respect to the classical therapy? - Is it an improvement?

Table 4.6: Final therapists interview

Chapter 5

Chapter 5: value proposition

The main critical aspect of our work is related to the time: the design, the software development and the documents creation have taken ~100 hours from each of us. Besides this, it has been one the most challenging project ever made in our students career, because of its multidisciplinarity. It is required to manage a mixture of design, creativity, psychology, computer science and electronics.
Furthermore, Teo has an amazing advantage with respect to the other robots in the market because it is cheap.

Chapter 6

Chapter 6: future work

6.1 What was left

For the lack of time, unfortunaately we hadn't implemented a logger of data (about distance and touch) collected by the Teo sensors.
A big issue has occured during the development of the sound localization code. Arduino can sample at 50kHz, that means 50kB/s, that force us to sample for 100ms because of the saturation of the memory. Moreover, sampling from 3 microphones simultaneously means to divide the frequency (50kHz/3=16kHz), which could produce aliasing for the Nyquist theorem (if the nput signal has a frequency of more than 8kHz).
Furthemore, sampling only 100ms don't let to understand which of the 3 signal come first (Interaural Time Difference algorithm).
This was the main reason for which we could not complete *MarcoPolo* game (the therapist could simulate it using *Talk2Teo*).

6.2 Future directions

Our solution is still far from its potential.
Arduino could be replaced with a Raspberry Pi 3 or an Intel Edison, which would allow Teo to easely compute digital signal processing, in order to deal with **voice recognition** and **face detection**.
Finally, Teo could have enough resources in order to have an artificial intelligence, which would allow Teo to be a companion in the children life, not «only» a tool used by a therapist.
The synthesized voice could be replaced with a real one in order to get better engagement of the children (even if a synthesized voice allow to modify the sentences more easly).

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