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Lopako, Human-Robot Interaction for Early Alzheimer's Therapeutic Device

Adrián González Ortega

Resum– L'expansió global de la malaltia d'Alzheimer, juntament amb l'absència d'eines estandarditzades i accessibles per a l'acompanyament terapèutic, planteja una crisis urgent en l'atenció a les persones diagnosticades en fases inicials. Lopako respon amb un robot social que integra musicoteràpia, reminiscència i terapia sinestèsica de manera personalitzada i empàtica. La motivació principal d'aquest Treball de Fi de Grau és perfeccionar la interacció humà-robot (HRI) per fer-la més intuïtiva, inclusiva i emocionalment significativa. Amb aquest objectiu, es desenvolupen i prototipen diverses millores d'HRI, entre les quals destaca un braçalet wearable com a interfície física i sensorial, que permeten ampliar els canals de comunicació, enriquir el feedback multisensorial i adaptar l'experiència terapèutica a cada usuari.

Paraules clau– Interacció Humano-Robot, cura de l'Alzheimer, robòtica social, tecnologia wearable, salut digital, teràpia no farmacològica, tecnologia assistencial, estimulació cognitiva, disseny centrat en l'usuari.

Abstract– The global spread of Alzheimer's disease, together with the lack of standardized and accessible tools for therapeutic support, poses an urgent crisis in the care of people diagnosed in early stages. Lopako responds with a social robot that integrates music therapy, reminiscence and synesthetic therapy in a personalized and empathic way. The main motivation of this thesis is to improve human-robot interaction (HRI) to make it more intuitive, inclusive and emotionally meaningful. To this end, several HRI improvements are developed and prototyped, among them a wearable armband as a physical and sensory interface, that allow to expand the communication channels, enhance the multisensory feedback and adapt the therapeutic experience to each user.

Index Terms– Human-Robot Interaction, Alzheimer's care, Social robotics, wearable technology, Digital Health, non-pharmacological therapy, Assistive Technology, Cognitive Stimulation, user-centered design

1 Introduction

ALzheimer's disease (AD) affects more than 800k people in Spain and 55 million worldwide, expected to nearly triple by 2050 [4, 19]. Non pharmacological therapies (NPTs) such as music therapy, reminiscence, and cognitive stimulation have consistently shown moderate evidence of slowing cognitive decline and improving quality of life [6]. However, these interventions remain irregular, labour intensive, and difficult to access outside specialised centres. Consequently, people diagnosed in the early stages (and their largely informal caregivers) face a long therapeutic gap during which deterioration progresses unchecked and caregiver burden increases.

Some digital solutions and socially assistive robots (SARs) attempt to fill this gap but suffer from several

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persistent limitations. Most systems rely on spoken dialogue or touchscreen menus that demand linguistic precision, sustained attention, or fine-motor coordination, capabilities that deteriorate early in AD [17]. Some SARs such as PARO or Pepper can deliver scripted activities but rarely adapt content in real time to the user's emotional state or therapy progress. Without meaningful personalization, engagement wanes in a matter of days [1].

This work is motivated by the need to explore more intuitive, empathetic modes of interaction with people living with Alzheimer's disease. Lopako was developed as a socially assistive robot supporting non-pharmacological therapies. Its name combines the Hawaiian word for robot "lopako" with the familiar Spanish name "Paco", reinforcing approachability and ease of recall. [11]

Initial pilots showed high acceptance but also revealed key interaction bottlenecks: voice recognition errors, privacy concerns related to the camera, and usability challenges for users with speech deficits or difficulties navigating touchscreen interfaces.

To address these issues, the project proposes a comprehensive enhancement of Lopako's human–robot interaction (HRI), combining targeted hardware and software upgrades with cloud-based personalization. A central innovation is the integration of a wearable interface that acts as a low-friction HRI layer between the robot and the user. This wearable ensures that personalization algorithms are translated into actions that are perceivable, intuitive, and emotionally engaging.

The work aligns with Sustainable Development Goals (SDGs), including:

- SDG 3 – Good Health and Well-being: By supporting therapies that improve emotional and cognitive health.
- SDG 10 – Reduced Inequalities: Through the design of accessible, inclusive technologies adapted to older adults and people with cognitive impairments.
- SDG 9 – Industry, Innovation and Infrastructure: By applying innovative digital health solutions to social challenges in healthcare.

2 Objectives

The main objective of this Final Degree Project is to improve human–robot interaction (HRI) in Lopako, addressing the cognitive, sensory, and emotional limitations observed in previous pilots of the system. It adopts a systemic perspective to rethink how interaction is designed, delivered, and adapted throughout a therapy session.

To achieve this, the project focuses on the following five key goals:

- Redesigning the HRI layer of the Lopako system based on prior testing and user feedback. This involves identifying key barriers and proposing interaction alternatives more suitable for ADPs.
- Develop multimodal interaction including integrating haptic, visual and motion-based feedback across devices while replacing unreliable modalities.
- Create a real-time personalization pipeline implementing a modular architecture using Docker and N8N that dynamically adapt session content (music, images, prompts) to the patient's history and preferences.
- Prototype and integrate a complementary wearable that enriches the robot's communication through tactile signals and motion-based interaction.
- Validate usability, emotional impact and interaction quality conducting tests to assess the effectiveness of the proposed HRI improvements.

3 Methodology

This project will be managed using Scrum with time blocking to efficiently address both technical development and validation phases within the given timeline (March 9 - July 1, 2025, 300 hours).

- Sprint Duration: 2 weeks each.
- Number of Sprints: 8 Sprints (March - July).
- Jira will be used to organize, prioritize, and track tasks within each sprint, monitor progress effectively, and identify potential bottlenecks.
- Confluence will centralize documentation, maintain meeting notes and manage project-related knowledge.

4 Planification

The complete Gantt chart of the project is available in Appendix B. Despite careful initial planning, several deviations occurred:

- Sprint 2–3: The initial scope proved too ambitious for a 300-hour project. Activities involving collaboration with therapists or psychologists were deprioritized. Consequently, the project focus shifted solely to Human-Robot Interaction (HRI).
- Sprint 6: Hardware integration was delayed due to shipping issues with essential components. As a result, wearable construction and hardware HRI improvements was postponed to Sprint 7.

A strategic shift was introduced to broaden the scope of HRI improvements. Instead of focusing solely on the wearable, the project now includes global features to boost user engagement, such as content personalisation, expressive feedback, and simplified interfaces, based on findings from the state of the art. While the wearable remains a key component, time constraints limit full integration with therapies and real-world testing. The current priorities include establishing robust bidirectional communication with the robot, enabling intuitive and engaging interactions, and demonstrating a working connection to the personalization pipeline as a functional proof of concept.

5 State of the Art

Lopako began in December 2023 as a mobile app for cognitive stimulation in Alzheimer's patients. However, limited smartphone use among this population revealed major accessibility issues. In response, the project pivoted in June 2024 toward a physical socially assistive robot (SAR), supported by evidence favoring embodied, activity-based therapies over screen-based ones [18].

The first prototype, built on Raspberry Pi with a touchscreen and multimodal inputs, encountered barriers related mainly to unclear interaction flows but also low-quality speech recognition and privacy concerns caused by the built-in camera. Despite this, Lopako potential has been recognized winning the Social Innovation Prize of Viladecans and joining programs like GAccelerator, Visionaris UAB and Generación Propósito.

This chapter reviews assistive technologies and HRI strategies in Alzheimer's care, justifying the development of an accessible wearable to enhance engagement, personalization, and emotional resonance.

5.1 Survey-Based Justification of User Needs

A survey was conducted among 67 individuals, including caregivers, healthcare professionals, and general public to understand expectations and needs related to Alzheimer's care. Results confirmed strong demand for NPTs with cognitive stimulation rated as very important by 76.1% of respondents, followed by reminiscence (61.2%) and music therapy (50.7%).

In terms of functionalities, 66% emphasized the importance of content personalization and 52.8% simplicity of interaction, underscoring the importance of intuitive interfaces. One thing to note is the low value placed on verbal and tactile interaction. These findings validate the objectives: creating intuitive, engaging, and adaptive interactions accessible for ADPs.

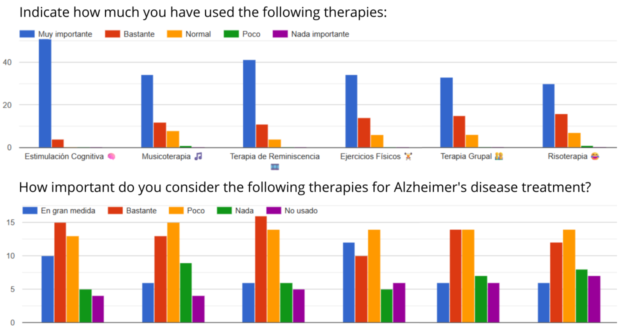

Fig. 1: Reported frequency of use of various non-pharmacological therapies among surveyed participants (N=67).

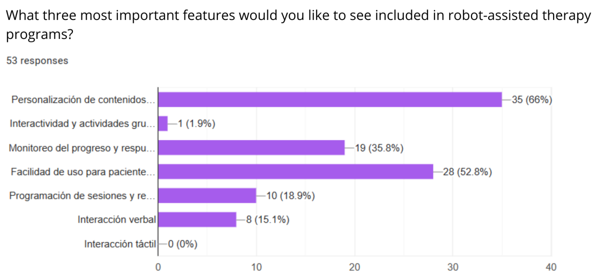

Fig. 2: Preferred features for SAR therapy programs (N=53).

Despite cognitive stimulation being the top-rated therapy, reminiscence and music therapy will be prioritized in this project due to their strong emotional resonance, suitability for multisensory interaction, natural fit for personalization and alignment with users preference for simple experiences over complex verbal or tactile commands.

5.2 Analysis of existing assistive technologies

Robinson and Nejat perform a meta-analysis of studies with SARs in the elderly, focusing on three dimensions [18]:

1. **Physical appearance of the robot:** Character type robots are better accepted than realistic humanoid robots. A familiar enough design, with expressive eyes and medium size optimizes acceptance by avoiding the uncanny valley. Soft material also improves affective perception.

2. **Multimodal interaction:** The combination of voice + visual or tactile feedback is more effective. Physical interaction generates engagement even without advanced functionalities. Cultural gestures (like greetings) are valued. ElliQ, with proactive

conversation, visual reminders and preference learning capabilities, results in 56% of users reporting greater social connection and reducing loneliness by 95% [5].

3. **Adaptive behaviors:** The future of HRI involves adaptive behaviors, like the robot detecting the user's emotional and activity state and modifying its behavior accordingly. The Guanghua-1 robot exemplifies this by detecting emotional and activity states to adapt its behavior according to the user's needs.

Also, a recent systematic review of intelligent robot interventions for ADPs (2025) showed that they can significantly reduce levels of agitation and anxiety in patients with dementia. It suggests that interventions are more effective the longer their duration [17]. Maintaining ADPs interest is a challenge that is yet to be achieved.

Rather than highly anthropomorphic designs like Pepper or costly high-end robots, Lopako adopts a character-like aesthetic with basic expressive elements to ensure user comfort and reduce development complexity. Auditory, visual, and tactile cues, supported through the wearable, address the need for multimodal feedback while respecting users' cognitive limitations. Also, Lopako's integration of personalization workflows and real-time feedback mechanisms represents a step forward in tailoring therapeutic interaction.

5.3 Non-pharmacological therapies

Given the limited efficacy and side effects associated with pharmacological treatments for Alzheimer's disease, non-pharmacological therapies (NPTs) have gained attention as complementary or alternative interventions. Research indicates that NPTs effectively improve cognitive function, activities of daily living, and emotional well-being, particularly in early and moderate stages. Nevertheless, variability in study protocols, target populations, and outcomes complicates direct comparison and reproducibility. This underscores the need for standardized, multimodal, home-based therapies for sustained and broader impact. [15]

5.3.1 Reminiscence Therapy (RT)

Reminiscence therapy involves stimulating personal memories through sensory cues such as photographs, music, objects, or stories to enhance cognitive functioning, reinforce identity, and boost emotional well-being in ADPs. [12] Effective RT sessions encourage to recall and discuss meaningful past experiences using multisensory prompts in individual or small-group settings. Evidence suggests RT improves communication skills, reduces anxiety and depressive symptoms, and strengthens social bonds.

TABLE 1: Key insights for designing reminiscence therapies.

Personal Relevance: Biographical information (life milestones, interests, preferred music) to select personally meaningful prompts.
Multisensory Stimulation: At least two sensory stimuli to deepen memory recall and emotional engagement.
Positive Structured Flow: Start with uplifting memories, follow clear themes and summarize briefly at the end to reinforce orientation.
Facilitator as Guide: Pose open-ended questions ("What do you remember about...?") allow natural pauses and validate responses to boost self-esteem.
Adaptive Complexity and Duration: 20–30 minutes for mild/moderate dementia, and under 10 minutes with simpler cues for severe stages.

5.3.2 Music Therapy (MT)

Music therapy leverages music to stimulate memories and positively influence emotional states in ADPs. It enhances social, mental, and emotional well-being. Research demonstrates that MT effectively improves cognitive functions, daily activities, and emotional health, with notable benefits in boosting mood, memory, and social interaction. [14] It also significantly reduces behavioral and psychological symptoms such as agitation and anxiety, exploiting the relatively preserved musical memory in Alzheimer's patients. [13] Successful MT sessions prioritize music as the main stimulus, focusing on familiar songs that evoke strong emotional and memory responses. They can incorporate activities like singing, participatory exercises, and discussions about popular music.

TABLE 2: Key insights for designing music therapies. [9]

Goal Oriented: Focus on stimulating memories, influencing emotions, enhancing mood, improving social interaction, and reducing agitation and anxiety.
Music as stimulus: Familiar songs, particularly those from the patient's youth, potentially paired with visual or other sensory stimuli.
Structured activities: Singing, participatory music-making, and interactive discussions related to music. Synchronized music and movement activities is very beneficial.
Flexible format and duration: Typically lasting between 30 to 45 minutes. Maintain regular frequency to optimize therapeutic outcomes.
Adaptive complexity: Tailor sessions to the severity of dementia, employing simpler auditory-focused activities for advanced stages, supported by therapists or caregivers and assistive technologies.

5.3.3 Chromatic Synesthetic Therapy (CST)

Chromatic Synesthetic Therapy (CST) uses the synesthesia present in <5% of the population in which multiple senses are interconnected. In the case of chromatic synesthesia, colors trigger sound perceptions. This is the foundation of AcercArte, a pioneering therapeutic initiative led by Eva Cayetana Somolinos Olmo, composer and synesthete, which combines iconic artworks with custom composed music soundtracks. [10]

Sessions are structured based on multisensory reminiscence: ADPs observe a painting, hear its music, and are guided through a series of emotional, verbal, and creative responses. This includes contextual storytelling, echo singing, musical improvisation, and personal reflection, aiming to stimulate autobiographical memory, verbal fluency, emotional expression, and creativity.

In 2024, AcercArte was accepted into a research program at Harvard's Marcus Institute for Aging Research [8], under the mentorship of Dr. Álvaro Pascual Leone, to explore its impact on cognitive decline, anxiety reduction, and emotional well-being in Alzheimer's patients. Early results highlight potential to delay neurodegeneration and improve quality of life using CST-based immersive experiences.

TABLE 3: Key insights for designing chromatic synesthetic therapies.

Multisensory Reminiscence: Combine visual art and music to evoke memories and emotions.
Contextual Storytelling: Guide participants through the story behind the artwork and music.
Echo Singing and Improvisation: Encourage creative vocal and musical responses.
Personal Reflection: Facilitate discussion and self-expression about feelings and memories evoked.
Adaptive Complexity: Adjust activities to cognitive and emotional abilities of each participant.

5.4 Serious games and decline detection

Serious games are digital apps designed with therapeutic or educational purposes. In Alzheimer's care, they offer interactive cognitive stimulation through engaging activities. They are becoming relevant for early-stage Alzheimer's. Projects such as Serious Games Lab (GameBCN, Generalitat) and startups like Punto Health demonstrate how AI can personalize therapies and detect early cognitive decline. Notably, The Mind Guardian, a game developed with the University of Vigo, reached 97.1% accuracy in early impairment detection. [3] Hospital del Mar's research validated that serious games enable monthly cognitive monitoring, outperforming traditional tests. [7] Some challenges include clinical validation, inclusive design for older users, and long-term sustainability. Their screen-based nature often limits accessibility for people with Alzheimer's, who may face difficulties with abstract interfaces or lack digital skills.

5.5 Alzheimer's wearable technologies

Wearable technologies have advanced significantly in Alzheimer's care. Milbotix's SmartSocks proactively detect agitation through physiological signs, enhancing patient safety. Cognito Therapeutics developed a non-invasive device using multimodal stimulation (visual, auditory, tactile) to promote cognitive health, aligning with Lopako's approach. Portable neurostimulation methods like tDCS also show promising cognitive improvements for mild to moderate Alzheimer's patients. [2]

One key inspiration for the wearable was WiiTerapia, an NPT using the Nintendo Wii console. It combines detected movement with vibration, cognitive challenges and physical exercise, fostering motivation through multisensory stimulation.

5.6 Insights for improving HRI

A recent study conducted by MIT Media Lab involved 28 older adults over a year-long co-design process to identify acceptable human-robot interactions in daily life. [1]

TABLE 4: HRI functionalities acceptance by Older Adults [1].

Focus Area	Preferred Features / Concerns
Medical adherence	Reminders, coaching, medication tracking
Memory support	Daily prompts, info storage, interactive recall
Exercise and physical therapy	Motivational support, guided routines
Emotional wellness	Mood tracking, empathetic interaction / Privacy, naturalness
Social connection	Conversation prompts, video calls / Autonomy, need human contact
Body signal monitoring	Heart rate or motion sensing / Surveillance, data trust
Financial management	– / Privacy + control loss

High acceptance · **Needs careful design** · **Strongly rejected**

Participants prioritized the following design features: [1]

- **Assistant-like behavior:** reminders, calendar help, storing contacts.
- **Modular interaction:** physical cues (LED, vibration), personalized commands.
- **Privacy-first design:** user control over data sharing and autonomy.
- **Naturalness:** slow, respectful robot speech, and non-intrusive engagement.
- **Integration:** support for existing tools (smart lighting, video calls. . .).

6 DEVELOPMENT

This chapter presents the implementation process of Lopako's improved HRI system, focusing on both hardware and software innovations that enable personalized and emotionally engaging NPTs for early-stage ADPs in a therapeutic demo that includes simplified applications of RT, MT and CST integrated into a coherent demonstration flow.

6.1 System Architecture

Lopako's system architecture is designed to enable seamless, adaptive, and multimodal therapeutic sessions for early-stage ADPs. As shown in Figure 3, the system is structured into two main operational phases: preprocessing and runtime. A full version of the architecture can be consulted in Appendix D.

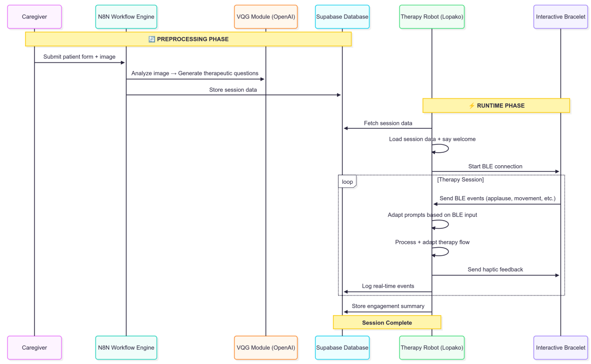

Fig. 3: Lopako's Simplified System Architecture

During preprocessing phase, a caregiver submits a patient form and a personal image through a web interface. This data is processed by the N8N workflow, which triggers the Visual Question Generation (VQG) module powered with OpenAI analyzes the image and generates reminiscence prompts tailored to patient's context. Session data (prompts, music preferences and visuals) is securely stored in Supabase.

In runtime phase, the robot retrieves the personalized session data and initiates the session with a welcome message. Then it starts a BLE connection with the wearable bracelet. During the session loop, the wearable provides haptic and visual feedback and sends user inputs (gestures, button press) which are used to adapt prompts. Engagement events are logged and stored.

6.2 Wearable Device

The wearable device designed acts as a tangible and expressive interface between Lopako and the user. It enables multimodal, low-latency interaction via physical input (button), motion-based gestures, and acoustic cues, while also delivering immediate visual feedback.

The firmware, written in Arduino C++, follows a modular event-driven structure:

- `procesarBoton()`: Detects button presses via interrupt (`isrBoton()`), triggering BLE event `BOTON_PRESIONADO` and LED animation (`COLOR_BOTON`).
- `procesarMovimiento()`: Exponential filters ($\alpha = 0.3$) to IMU data for gesture detection:
  - Swing: acceleration magnitude
  - Lift: high a_y + low $gyroY$
  - Rotation: $|gyroY| > 120°$/s

TABLE 5: Functionalities of the Wearable

Functionality	Description
Visual feedback (LED ring)	Displays colored light animations to indicate detected events (button press, applause, gestures) and to show dominant color during CST.
Physical interaction	A button press triggers a BLE message `BOTON_PRESIONADO` and visual feedback, used to initiate or confirm therapeutic actions.
Motion/Gesture detection	Detection of motion events (swing, lift, rotation) using filtered IMU data with thresholds.
Acoustic event detection	Applause or sharp sounds are captured and processed using amplitude variation of the PDM microphone.
Wireless communication	BLE UART protocol transmits encoded events and receives commands (`C:R,G,B,ms`) to trigger LED animations.
Energy safety + UX	Cooldown logic for BLE events, timeout for LED animations, and smooth signal filtering to reduce false positives.

TABLE 6: Wearable components selected

Component	Justification
Seeed XIAO nRF52840 Sense	BLE 5.0, 6-axis IMU, microphone, NFC. Compact, low-power, ideal for wearables.
LiPo Battery 3.7V 300mAh + TP4056	Safe rechargeable power with thermal/overcharge protection. Supports full-day use.
DRV2605L Linear Actuator Haptic Breakout	I2C-controlled actuator with <1ms latency and 170Hz resonance. Tactile expressivity.
NeoPixel Jewels	Soft colored light to guide, motivate or indicate activity status.
MakerFocus MAX30102	Heart rate and SpO2 sensing for potential stress or engagement tracking (connected for future integration).
Mechanical Push Button	Simple and reliable input method, easy to integrate and use.

- `procesarSonido()`: Calculates mean delta from PDM mic buffer to detect applause-like peaks, emitting `APLAUSO_DETECTADO`.
- `actualizarLEDs()`: Clears NeoPixel ring after 2 s inactivity to save power and reduce sensory load.
- `onBLEdataReceived()`: Parses commands (`C:R,G,B,ms`) to activate synchronized LED feedback via `mostrarColorBLE()`.

To estimate battery life, I used each component's average current based on real usage during therapy sessions, assuming 60 interaction events per day. All values refer to the regulated 3.3 V rail supplied by the onboard buck converter ($\eta \approx 90\%$).

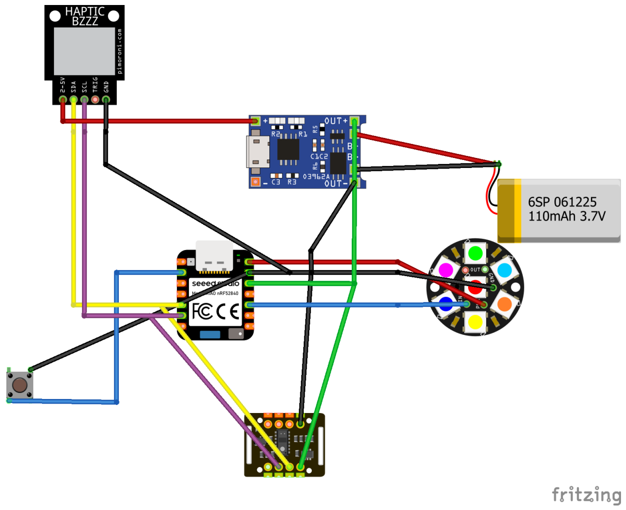

Fig. 4: Wearable connection fritzing

TABLE 7: Wearable component consumption

Sub-system	Avg. mA	Wh / 24 h	%	Justification
nRF52840 + BLE	0.35	0.029	4	75% idle scan, 25% short TX bursts (UART packets & ACKs). Cooldown $\geq$ 200 ms.
LSM6DS3 IMU	0.90	0.072	10	Always streaming 52 Hz for gesture filters (α = 0.3).
PDM Microphone	0.60	0.048	7	Applause detection runs continuously at 16 kHz.
NeoPixel LEDs (×7)	7.00	0.555	79	60 events × 2s on. Brightness 32/255. 1 mA idle per pixel when off.
DRV2605L Haptics	0.03	0.001	1	60 × 100 ms vibro-pulses (button + gesture ack).
Regulator + leakage	0.01	0.0007	1	
Total	**8.90**	**0.706**	**100**	

The bracelet averages 8.9 mA, resulting in 0.71 Wh per 24 h and 30 h of autonomy on a 300 mAh cell.

6.3 Lopako's Robot Device

The updated version of Lopako replaces components from earlier prototypes to enhance privacy, reliability, and personalization.

In the previous version, the robot relied on the PlayStation Camera's built-in microphone and an external Bluetooth speaker. However, the removal of the camera in this version due to privacy concerns requires an upgrade of the audio input/output system. The new configuration includes a USB desktop microphone with integrated noise filtering and a USB powered speaker with built-in audio decoding.

The robot lacked any form of personalization beyond a

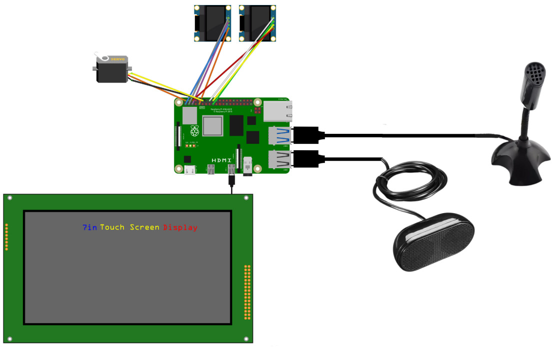

Fig. 5: Robot connection fritzing

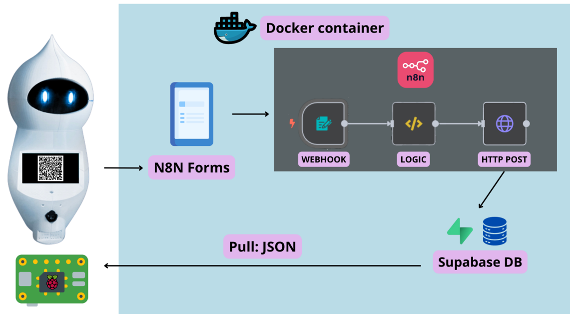

Fig. 6: Containerized workflow for therapy personalization using N8N inside a Docker container.

TABLE 8: Robot components selected

Component	Justification
Microphone M-306	Plug-and-play desktop microphone with integrated noise filtering (100–16kHz). Ensures reliable voice input at close range without requiring additional circuitry or drivers.
USB Speaker HK-5002	Compact 2×3W speaker with built-in audio decoding and USB 2.0 auto-recognition. Provides sufficient clarity and volume for voice prompts and music feedback during therapy.

discarded facial recognition module. The current version introduces a fully integrated personalization pipeline, significantly enhancing therapeutic relevance and emotional connection. Now it can address the user by name, adapts therapy content (using personal images, questions, preferred music, and familiar phrases) and displays personalized micro-content (jokes, greetings, reminders) during idle times to maintain engagement.

6.4 Global Data Pipeline Architecture

To enable personalization of therapeutic sessions, a modular backend pipeline based on containerized orchestration was developed and deployed inside a Docker container on a Hostinger VPS. The system leverages N8N, an open-source workflow automation tool, to dynamically generate customized therapy sessions based on patient context. This system collects contextual data through a form, processes media assets and generates a fully adapted session that the therapeutic robot can execute. The following figure illustrates the core structure:

As shown, the pipeline integrates the backend workflow via N8N, cloud data from Supabase, and customizable execution strategies within the local therapy engine.

6.5 Personalization and VQG workflow

This low-code automation pipeline integrates form input, AI-based visual analysis, and structured session generation with Supabase storage. The process consists of the following stages (see Figure 7):

Session Form Trigger via Webhook: The form collects essential personalization data: Patient's name, personal images related to meaningful memories, preferred music, frequently repeated phrases and things the person enjoys most. This form uses a custom-styled UI aligned with Lopako's brand. A full version of the form can be consulted in Appendix C.

Binary Extraction and Conversion: The uploaded image is extracted in Base64 format and then converted into a file object to enable compatibility with cloud storage and AI analysis.

Image Upload and Vision-Based Analysis: The converted image is uploaded to Google Drive, and its link is passed to the OpenAI GPT-4o Vision model, which performs the following steps:

- Detects and classifies visual elements (person, family, place...)
- Applies informed templates based on the category
- Generates three therapeutic reminiscence questions in JSON format following syntax rules
- Ensures open-ended, emotionally positive, and memory-accessible prompts

JSON parsing and merging: The raw AI output is parsed, cleaned, and merged with the original form data. This ensures a complete, structured dataset per session.

Structured payload assembly:

- patient_id
- image_url

- questions (AI-generated)
- music, phrase, and likes (from form input)

Database upload to Supabase: The final session object is sent via an authenticated POST request to the Supabase REST API. Headers include a static API key and bearer token for secure access. Data is stored in a PostgreSQL database and indexed by patient and session.

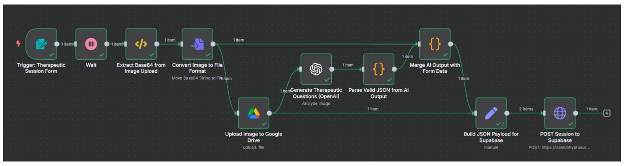

Fig. 7: N8N Detailed workflow

6.6 Music Therapy Dataset Generation

The music therapy (MT) dataset was built upon the Banda Sonora Vital project, developed by the Music Technology Group at Universitat Pompeu Fabra in col-laboration with Fundació Pasqual Maragall, Sanitas Mayores, and Alzheimer Catalunya [23]. This curated playlist includes songs strongly linked to the autobio-graphical memories of older adults in Spain, validated through scientific research in reminiscence and dementia care.

Technically, the database is implemented using SQLite and managed through SQLAlchemy (ORM). It includes metadata such as title, artist, duration, tempo (BPM), key, mode, energy level, and usage recommenda-tion in therapy (active stimulation, relaxation. . .).

6.7 Synesthetic Art-Music Dataset

The dataset used in CST sessions was created in collaboration with Eva and her project AcercArte. The dataset is based on her playlist titled "La Banda Sonora de los Cuadros" [21], which translates iconic artworks into original musical compositions, inviting users to become synesthetes for a moment and feel the art through sound. Five selected examples were adapted and integrated:

Each pairing includes a visual, a corresponding music track, a poetic description, and reflective sensory-based questions. During sessions, the therapy follows six phases:

1. Visual Introduction: Artwork and description are displayed to evoke emotional and sensory context.
2. Guided Listening: The original composition is played to link visual and auditory perception.
3. Echo Singing: Users vocally repeat short melodic fragments, reinforcing participation and rhythm.

TABLE 9: Selected Synesthetic Pairings

Painting	Artist	Main Theme
La Noche Estrellada	Vincent van Gogh	Celestial movement and calm imagination
El 3 de Mayo	Francisco de Goya	Historical tension and resilience
La Gioconda	Leonardo da Vinci	Intimacy and mysterious elegance
El Grito	Edvard Munch	Emotional intensity and expressive chaos
Mujer con sombrilla	Claude Monet	Lightness, nature, and nostalgic peace

4. Emotional Reflection: A second listening phase with questions that stimulate sensory memory and interpretation.
5. Creative Improvisation: Users interact with Lopako via the wearable, triggering musical piano notes through movement.
6. Closure: The user's favorite artwork and sound are replayed, reinforcing the multisensory connection.

6.8 Software and Design Patterns

The therapeutic application is built upon a modular MVC (Model View Controller) architecture, extended by the Strategy pattern to ensure flexibility, reusability, and compliance with SOLID principles.

```
lopakoterapia/
├── src/                          # Main source code
│   ├── core/                     # Core logic
│   │   └── models/               # Data models
│   ├── controllers/              # MVC controllers
│   ├── views/                    # MVC views
│   ├── strategies/               # Therapy strategies and others
│   └── main.py                   # Main entry point
├── assets/                       # Multimedia resources
│   ├── audio/                    # Audio files
│   └── images/                   # Images
├── data/                         # Data and configurations
│   ├── sessions/                 # Therapy sessions
│   ├── databases/                # Databases
│   └── config/                   # Configurations
├── docs/                         # Documentation
├── tests/                        # Tests and integration
├── sec_scripts/                  # Secondary unused scripts
├── vosk-model-small-es-0.42/     # Voice recognition model
├── logs/                         # Music therapy DB log files
├── venv/                         # Python virtual environment
├── requirements.txt              # Python dependencies
└── run.sh                        # Execution script
```

Fig. 8: Lopako Software Architecture

Models:

- `Sesion`, `SesionRepository`, `SupabaseRepository`, `BLEEventLogger` – manage sessions, sync with Supabase, and log BLE interactions.

Views:

- `VisorView` (Tkinter GUI) displays media, animations, user input, and visual/audio feedback, based on `VisorController` instructions.

Controllers:

- `VisorController` (session flow), `PatientController` (user data), `VoiceController` (offline voice via Vosk + PyAudio).

Strategies:

- `MusicoterapiaStrategy` (music flow), `FadeTransicionStrategy` (visual transitions), `TTSStrategy/GTTSStrategy` (text-to-speech), `VisorStrategy` (visual behavior), `SinestesiaStrategy` (art-music therapy).

Key libraries include: Tkinter (GUI), Vosk + PyAudio (offline voice), bleak (BLE), gTTS (TTS), pygame / playsound (audio), Pillow (images), supabase-py (API), sqlite3 / SQLAlchemy (DB), librosa / numpy (audio features), and Python stdlib for I/O and concurrency.

The codebase follows PEP 8, uses type hints, and includes robust error handling.

7 RESULTS

To evaluate the effectiveness of the proposed HRI improvements, a structured comparative user study was conducted. Two therapeutic sessions were executed: once using the previous version of Lopako without wearable integration [20], and once with the enhanced system featuring the wrist-worn device [22]. Both sessions were conducted under controlled conditions with one representative user: my grandmother.

Fig. 9: Final assembly of the improved Lopako system, including the wearable prototype.

A short Likert-scale questionnaire and direct observation were used to assess multiple dimensions of HRI quality:

The user reported a clear improvement in the emotional tone of the session. She described the robot as much kinder, appreciated hearing her own name, and expressed joy upon recognizing familiar music, photos and personalized greetings. The wearable contributed to creating a more

TABLE 10: Comparative HRI scores before and after wearable integration

	Before	After
Clarity of interaction	2/5	4/5
Intuitiveness (ease of understanding)	2/5	4/5
Observed emotional engagement	0/5	4/5
Observed physical participation	1/5	3/5
Perceived personalization	0/5	4/5
Accessibility and ease of use	2/5	4/5

expressive, tangible interaction: the LED ring and soft vibration feedback made the experience more immersive and responsive without relying on verbal commands or touchscreens.

Most notably, the user remained engaged throughout the session without requiring intervention. The system prompted spontaneous verbal interaction and emotional responses, indicating an increase in self-motivation and affective connection.

Fig. 10: User testing phase, showcasing interaction during the therapeutic session

8 CONCLUSIONS

This project successfully improved Lopako's human–robot interaction (HRI) through a wearable device and real-time personalization, enabling intuitive and emotionally engaging sessions for early-stage ADPs. User testing showed notable increases in clarity, personalization, and participation without requiring caregiver intervention.

Lopako's potential was publicly recognized during its final development week, when Lopako was selected to represent Viladecans at the Innpulso Emprende event in Gijón (June 2025) [16]. The robot was showcased live and received highly positive feedback from the jury and families, particularly regarding its personalized interactions and emotional tone.

The foundations laid in this work will support the upcoming research pilot scheduled for 2026, involving over 150 participants. In collaboration with Eva Cayetana Somolinos (AcercArte), the study will compare robot-led and therapist-led sessions using chromatic synesthetic reminiscence therapy to assess cognitive, emotional, and behavioral outcomes.

Today, Lopako stands as a functional and engaging therapeutic companion. Next steps include developing a smaller and more scalable prototype, enabling group-based interaction, and integrating large language models (LLMs) for richer, more natural dialogue. Ultimately, this project contributes to the ethical, inclusive, and sustainable development of AI-assisted therapies aligned with the future of person-centered healthcare.

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ANNEX

A GLOSSARY

TABLE 11: Acronyms and abbreviations used throughout the document

Acronym	Definition
ADP	Alzheimer's Disease Patient
HRI	Human-Robot Interaction
IMU	Inertial Measurement Unit
LRA	Linear Resonant Actuator
SAR	Socially Assistive Robot
NPT	Non-pharmacological therapies
BLE	Bluetooth Low Energy
RT	Reminiscence Therapy
MT	Music Therapy
CST	Chromatic Synesthetic Therapy
SDG	Sustainable Development Goals

B GANTT DIAGRAM

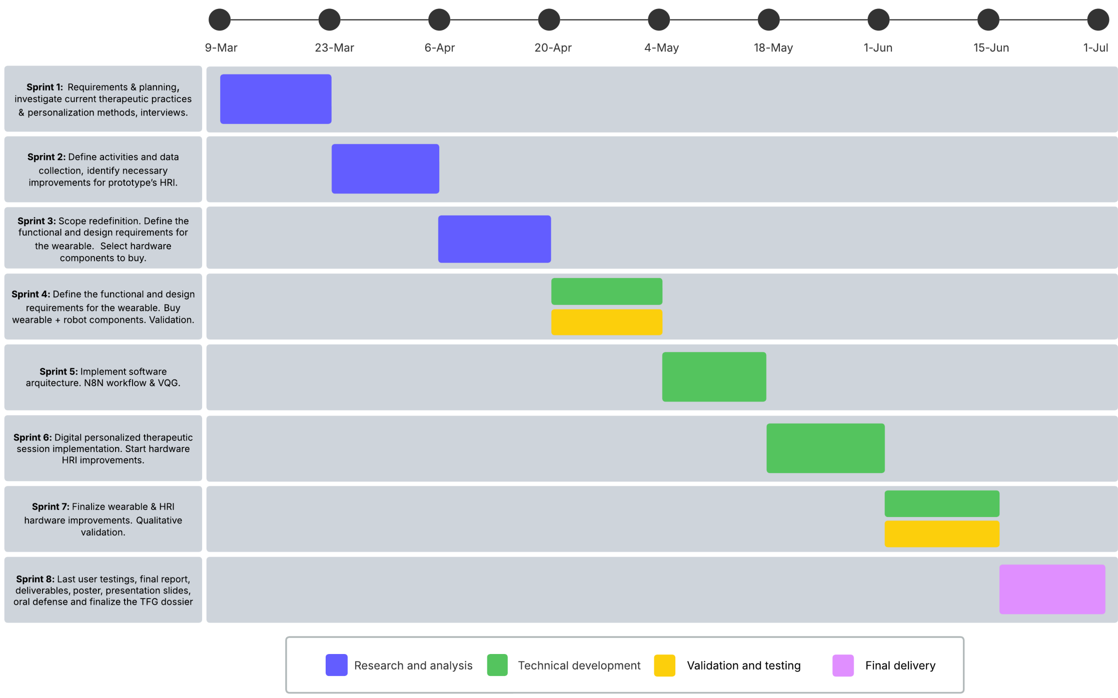

Fig. 11: Project Gantt diagram showing timeline and milestones

C FORMS

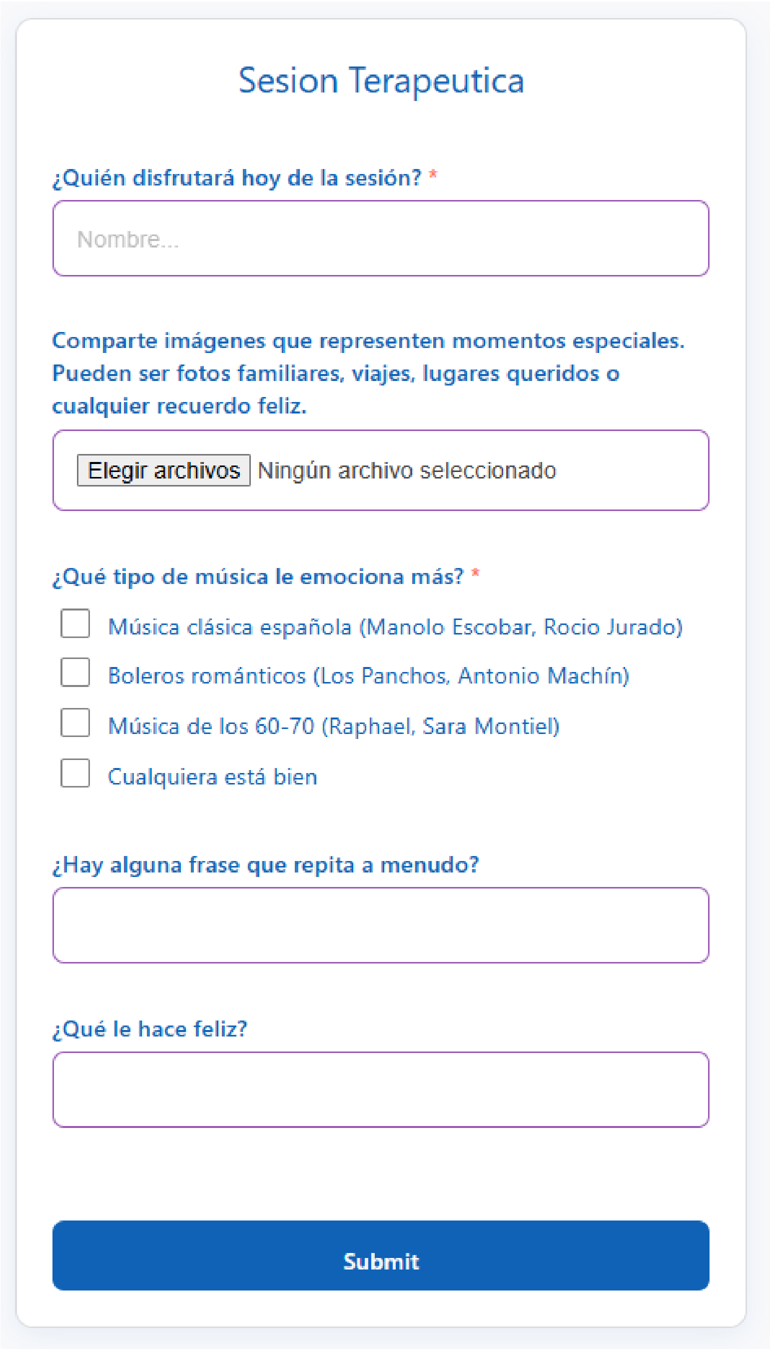

Fig. 12: Patient personalization form interface

D SYSTEM ARCHITECTURE

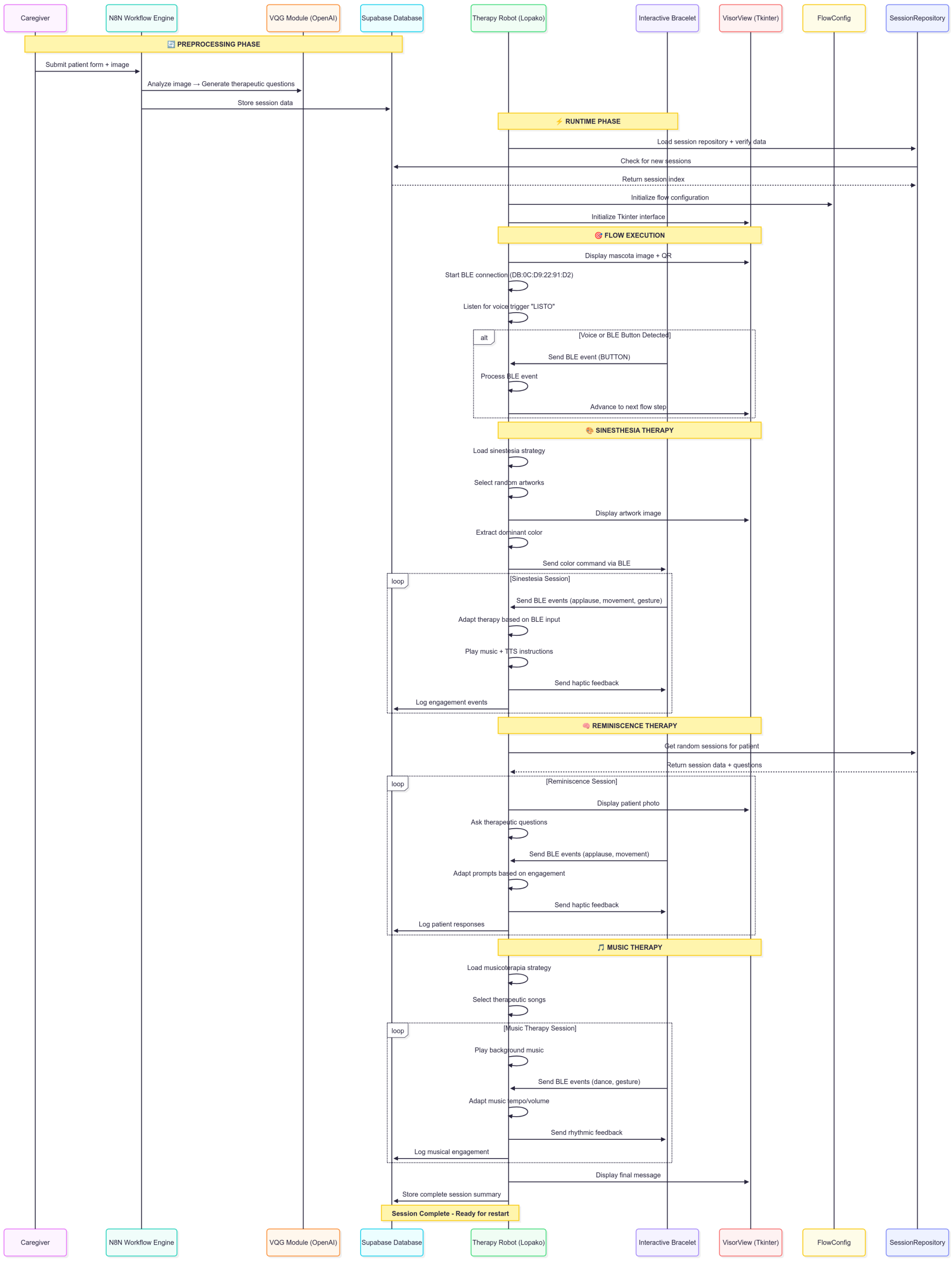

Fig. 13: Detailed system architecture showing all components and interactions