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KURAL: Knowledge-Driven Universal Responsive AAC for Learners with ASD

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Abstract*— Autism Spectrum Disorder (ASD) is a neurodevelopmental disorder affecting about 1% of the global child population, and approximately 1.47% in India. Individuals with ASD often struggle with verbal communication, leading to difficulties in expressing their needs and emotions. The inability to express oneself not only results in frustration but also hinders social integration and independence. This paper presents a novel, multimodal assistive system designed to enhance communication for Tamil-speaking children with ASD through visual, auditory, and interactive means. The system integrates a digital Picture Exchange Communication System (PECS) localized for Tamil, culturally adapted digital Tamil social stories, and wearable smart glasses. The PECS is an evidence-based augmentative alternative communication (AAC) tool widely used in special education to teach functional communication skills. The smart glasses reduce auditory overload by filtering background noise and delivering slow-paced speech, while the digital social stories provide visual narratives to improve socio-emotional understanding. By combining traditional methods with modern technology, the proposed system aims to establish two-way communication—enabling children to express themselves to others through PECS, while assisting them in understanding others' speech via smart glasses. This approach seeks to bridge the communication gap faced by children with ASD and provide them with a more inclusive environment.

Keywords* — Autism Spectrum Disorder (ASD), Augmentative and Alternative Communication (AAC), Picture Exchange Communication System (PECS).

I. INTRODUCTION

Autism Spectrum Disorder (ASD) is a neurodevelopmental disorder characterized by persistent challenges in social communication, sensory processing, and behavior regulation. Individuals with Level 2 ASD require substantial support to manage their daily living skills and social relationships. In India, particularly in the southern states, community surveys estimate ASD prevalence at approximately 23.3 per 10,000 children, highlighting a significant public health concern [1], [2]. Despite growing awareness, most contemporary assistive communication technologies are neither culturally nor linguistically adapted for non-English-speaking communities—such as Tamil-speaking populations— limiting their accessibility and relevance.

Modern Augmentative and Alternative Communication (AAC) systems, including Picture Exchange Communication Systems (PECS) and popular AAC mobile applications, exhibit several intrinsic limitations: inadequate Tamil language support, insufficient personalization of local cultural norms, poor accommodation of sensory sensitivities common in Level 2 ASD, and rapid technical obsolescence [3], [4]. Moreover, these tools often function in isolation from the multisensory environments of children with autism, reducing their utility in naturalistic, real-world settings.

Recent research has underscored the importance of sensory integration in ASD interventions [5]. Evidence further indicates that culturally situated content markedly enhances engagement and comprehension among neurodivergent learners. Nevertheless, there remains a conspicuous absence of integrated platforms combining culturally responsive AAC with sensory-adaptive technologies in wearable offline-enabled formats. Bridging this gap is essential for delivering equitable, inclusive assistance in low-resource environments.

This work introduces the "Multi Sensory Device for Autistic Children", a wearable learner-communicator system explicitly designed for Tamil-speaking children with Level 2 ASD. The device integrates five interconnected modules: a digital Tamil PECS system for sentence composition and image-to-speech, an adaptive audio module featuring local speech synthesis and noise reduction, a culturally modified social story viewer, and adjustable sensory smart glasses with Irlen filters and directional speakers.

The primary objective is to enhance communication and sensory modulation through a multisensory culturally responsive approach. The secondary goals included caregiver customizability and offline support for rural deployment. Initial testing was conducted in a controlled laboratory environment (Technology Readiness Level 5), with qualitative and quantitative feedback gathered from teachers and therapists to guide future refinement.

II. RELATED WORKS

In recent years, considerable progress has been made in the development of assistive technologies for individuals with Autism Spectrum Disorder (ASD) [6], particularly in the

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areas of communication, sensory modulation, and culturally responsive learning. However, many existing systems have been developed for Western populations and fail to address the linguistic, sensory, and infrastructural needs of children in regional contexts, such as Tamil Nadu.

A. AAC Systems and PECS-Based Communication

The Picture Exchange Communication System (PECS) remains one of the most widely used AAC techniques for children with autism. It helps nonverbal or minimally verbal children express their needs and feelings using pictorial cards. Several digital extensions of PECS that provide mobile-friendly AAC platforms have emerged in recent years. However, these systems are primarily designed for English-speaking users and often depend on paid subscriptions, making them inaccessible in many Indian settings. Moreover, they do not offer culturally relevant symbols or Tamil language support, which limits their effectiveness in regional settings.

B. Cultural Adaptation in Autism Tools

Studies have shown that culturally responsive tools significantly improve engagement and learning outcomes in neurodivergent children [7]. Localized imagery, native language support, and familiar social cues improve com prehension and retention [8]. Despite this, most available AAC tools present generic Western symbols—such as unfamiliar foods or clothing—which are not relatable to children in Tamil Nadu. Tools such as the Jellow Communicator attempt to address cultural needs but still lack full Tamil support, offline deployment, and integration with sensory aids.

C. Social Stories and Visual Narratives

Social stories are widely used to teach appropriate behavior to children with autism through structured visual narratives [7]. These tools help improve the understanding of daily routines, social rules, and expected behaviors [7], [9]. While several studies have shown their effective ness, most story banks use foreign contexts that may be confusing or irrelevant to Indian children. Our system localizes this concept by introducing comic-style social stories embedded in Tamil culture, such as stories about local festivals, school habits, and interactions with the elderly.

D. Sensory Modulation Technologies

Children with ASD often experience sensory processing difficulties, such as hypersensitivity to sound or light [10], [11]. Accordingly, various tools have been introduced, including noise-canceling headphones and Irlen lenses, for visual filtering [11], [12]. However, a significant limitation is that most of these are standalone solutions and are not integrated into AAC platforms [13]. Our system directly addresses this gap by introducing smart glasses equipped with Irlen filters and directional speakers that provide real-time audio modulation and visual comfort. This creates an all-in-one wearable support tool that combines sensory support with communication, a feature that is lacking in many existing technologies.

E. Offline Access and Rural Deployment

A major limitation of current AAC and assistive apps is the need for consistent Internet connectivity. Many rural regions in India still face bandwidth issues, making cloud based or login-dependent platforms impractical. Prior research has emphasized the importance of fully offline mobile-based tools for wider adoption [8]. Our system directly addresses this by ensuring that all modules—PECS, social stories, and audio playback—are pre-packaged and functional without Internet access, allowing deployment in rural and low-resource settings.

F. Summary of Gaps and Contribution

In summary, while existing technologies address isolated challenges in autism support, few provide integrated, culturally contextual, or offline-capable solutions. The proposed Multi-Sensory Device for Autism bridges these gaps by combining Tamil-based PECS, social narratives grounded in local culture, and sensory modulation via wearable smart glasses. This holistic approach promotes spontaneous communication, reduces sensory overload, and enhances the daily lives of Tamil-speaking children with ASD.

III. PROPOSED SYSTEM

A. PECS-Based Communication Module

This project introduces a culturally relevant, mobile based communication tool designed specifically for Tamil speaking children with Autism Spectrum Disorder (ASD). Inspired by the principles of picture-based communication systems, the proposed solution enables nonverbal and minimally verbal children to express themselves through visual selection from well-organized Tamil-labeled image categories. The app functions as a practical, low-barrier alternative to traditional PECS cards while maintaining simplicity, familiarity, and offline accessibility.

The application is structured around intuitive and meaningful categories such as Food, Emotions, Actions, People, Places, and Daily Needs. Each category contained a curated set of high-resolution images labeled in Tamil, accompanied by clear native audio to support language comprehension and verbal associations. This ensures that the vocabulary reflects the lived experience of children in Tamil Nadu—showcasing items such as idli, school bag, paati, or temple—rather than generic or foreign symbols often found in imported AAC tools.

Designed with inclusivity and usability at its core, the interface employs the following features.

- Large, touch-friendly buttons and minimalist design to reduce cognitive load;

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- Visual-only navigation, removing the need for text literacy;
- Audio playback in Tamil, reinforcing receptive language exposure;
- Offline functionality, ensuring full access in environments with limited or no internet connectivity.

All assets, including images, labels, and audio, were packaged locally within the app. This makes it highly portable, easy to deploy in homes, schools, and therapy centers, and suitable for low-resource settings.

This solution supports spontaneous communication, which is a key goal of early autism intervention. By offering familiar and accessible symbols, children can initiate communication and respond promptly. It can also complement structured therapy approaches, such as speech language therapy and ABA-based routines, without re quiring specialized training or infrastructure.

In summary, the proposed system offers a practical, scalable, and inclusive alternative to paper-based PECS. It addresses the linguistic and cultural gaps in existing AAC tools, reduces reliance on foreign or subscription-based platforms, and promotes communication autonomy in children, who often face barriers to expression.

B. Culturally Relevant Social Story Viewer

Children with autism are likely to struggle with emotion recognition, social cue responses, and acquisition of intuitive social understanding, making the establishment of relationships one of their most difficult tasks. To address this, the system includes a Culturally Relevant Social Story Viewer with the objective of delivering structured, relevant stories of real-life social behavior in a pre-emptive and emotionally engaging manner.

This module contains a curated collection of over 500 picture-supported social stories, thematically organized under 15 fixed themes, such as Hygiene, Good Habits, Behavior, and Self-Care. Each story illustrates common social scenarios in a rationally sequenced manner, enabling children to acquire appropriate responses and predict out comes. Thematic organization enables modular learning progression and makes it easy for caregivers or educators to tailor content to suit the specific requirements of a child.

The model is passive and linear and is neither interactive nor game based. The children were presented with linear, comic-book-like stories illustrating concepts such as empathy, body language, emotional expression, and positive or negative resolution of conversation. By viewing rather than interacting, autistic learners benefit from predictable flow, reduced cognitive load, and focused attention, making this format well suited for mid-level ASD profiles.

The module was designed to run offline using Tamil text translations. Visual simplicity and linguistic ease were prioritized to improve interaction and comprehension among neurodivergent speakers in the disadvantaged and rural communities.

C. Wearable Hardware for Sensory Support

The hardware component of the multi-sensory device for autism is a wearable unit designed to function as a sensory friendly interface for children. It consists of interconnected modules integrated into a pair of smart glasses.

1) Smart Glasses with Irlen Filters: The core of the hardware is a pair of adjustable smart glasses that incorporate Irlen filters. These filters are designed to reduce visual stress and distortions, thereby creating a more comfortable visual experience for children who are hypersensitive to light.

2) Adaptive Audio Module: The glasses are equipped with an adaptive audio module that features local speech synthesis and noise reduction capabilities. This module is responsible for two key functions.

- Noise Reduction: It provides a form of noise cancellation [14], [15]to reduce competing background sounds, which helps lower sensory stress and improve the clarity of incoming speech. The system employs subtle filtering to preserve a child's essential ambient awareness.
- Slow-Paced Speech Delivery: The system is designed to deliver slow-paced audio. Speech rate is deliberately slowed [16],[17] to prevent auditory overload and allow neurodivergent children to process information more easily.

3) Prototype design: Audio output is delivered through directional speakers embedded in the glasses in form of earphones. This ensures that clear and modulated audio is effectively directed to the child.

IV. IMPLEMENTATION

A. PECS-Based Communication Module

The PECS module was developed using Flutter, a cross-platform framework that enables deployment on Android, iOS, and desktop devices from a single code base. This ensures consistent performance and appearance across devices commonly used in homes, classrooms, and therapy centers.

1) App Structure and Navigation: The app is launched on a home screen displaying a grid of categories, including Food, Emotions, Actions, People, Places, and Daily Needs. Each category tile is represented by a bold icon and Tamil label, arranged in a clear grid layout to support rapid and intuitive navigation.

Selecting a category [18] creates a screen with multiple visual communication cards. Each card consisted of a high-resolution image and Tamil text label. When a child taps a card, the corresponding Tamil audio is played aloud to help them express their needs or preferences, without requiring spoken language.

2) Interaction and Core Functions: To support sentence building and intentional communication, the app included a message strip at the top of the screen that displayed the sequence of the selected cards. This allows children to construct simple visual messages, such as indicating a need

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("I want") followed by a specific item ("banana"). Three key interaction buttons were provided to manage the message-building process:

- Play: Plays the full audio sequence of the selected cards in Tamil, allowing the child to express a full message through voice output.
- Undo: Removes the last selected card, allowing for quick corrections without starting over.
- Undo: Removes the last selected card, allowing for quick corrections without starting over.
- Clear: Empties the entire message strip so a new message can be formed.

These buttons use large, easily recognizable icons and are positioned for quick access, ensuring that the app remains usable even for children with limited motor skills.

3) Offline Access and Deployment: All content, including images, labels, and audio, is stored locally within the application. This makes the app fully functional offline and highly suitable for environments without reliable Internet access. The absence of setup steps or login requirements allows immediate deployment in diverse settings with minimal technical support.

B. Culturally Relevant Social Story Viewer

This module focuses on delivering structured social narratives to children with autism to help them understand real-life scenarios in a culturally contextualized manner. The implementation comprises five key components: content organization, PDF viewing, Tamil text overlay, search functionality, and offline access.

1) Story Content Management: A curated collection of over 500 social stories is organized into 15 fixed themes (e.g., Good Habits, Safety, Festivals). Each theme contained multiple PDF files stored locally using the following directory format:

```
assets/themes/<theme_name>/<title>.pdf
```

Themes are also visually represented using cover images in assets/covers/, and mapped using a configuration file named story_data.json.

2) Viewer Integration: The stories were rendered using the Syncfusion Flutter PDF Viewer, which was selected for its low-latency offline rendering capabilities and smooth swipe-based navigation. The viewer allows children to scroll through pages intuitively, with zoom support for accessibility. Touch interactions were intentionally limited to minimize distractions and cognitive overload.

3) Tamil Translation Layer: A dedicated file, transcription.json, maps each page of every story to the corresponding Tamil sentence. These translations are rendered as overlays beneath each PDF panel at runtime, enabling children to comprehend stories in their native language. A toggle switch allows caregivers to enable or disable captions. Example JSON structure:

```
{
  "Good Habits": {
    "Brushing Teeth": {
      "1": "I should brush my teeth as soon as I
wake up",
      "2": "காலை எழுந்தவுடன் பற்களை
துலக்க வேண்டும்"
    }
  }
}
```

4) Search and Filtering: A lightweight keyword search feature allows users to locate specific stories using English or Tamil keywords. The search parses through story titles and theme names, offering caregivers and educators an efficient way to access relevant content.

5) Offline Functionality: All assets, including PDFs, image covers, and transcription files, are bundled locally and declared in pubspec.yaml. These assets are accessed via Flutter's rootBundle, ensuring that the entire module works without internet connectivity. This design supports deployment in rural and bandwidth-constrained environments.

C. Adaptive Audio Processing Architecture

The adaptive auditory processing system is implemented as a wearable smart glasses platform integrating specialized hardware components for real-time audio enhancement [15] targeting children with Level 2 Autism Spectrum Disorder (ASD). The system employs a modular architecture comprising input acquisition, central processing, and output delivery subsystems.

1) Central Processing Unit: The core processing module utilizes a Teensy 4.1 development board as the primary microcontroller, selected for its advanced audio processing capabilities and real-time performance requirements. Custom firmware implements adaptive filtering algorithms validated through MATLAB simulations, thereby enabling real-time noise suppression [19]and temporal speech modulation.

2) Audio Input Subsystem: Environmental audio capture is achieved through a high-sensitivity MEMS microphone integrated within the glass frame. The microphone signal undergoes amplification to ensure optimal signal quality for downstream processing, with emphasis on capturing caregiver speech and ambient environmental sounds.

3) Audio Output Subsystem: Processed digital audio signals were converted through a MAX98357A I2S audio amplifier and delivered via dual temple-embedded speakers. This configuration provides private, focused audio delivery while maintaining user awareness of their surrounding environment.

4) Visual Sensory Integration: The system incorporates Irlen filters (color-tinted lenses) for concurrent visual stress reduction, creating a comprehensive sensory management platform that addresses both auditory and visual processing

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challenges common in ASD.

Component	Quantity	Purpose / Role
Glasses Frame	1	Holds hardware in a lightweight, wearable form
Irlen Filter Lenses	1 pair	Reduces visual stress for children with sensory sensitivities
Teensy 4.1 Microcontroller	1	Core processing unit for audio handling, I2S input/output
INMP441 I2S Microphone	1	High-quality digital mic for capturing child/ambient speech
Directional Speakers (as earphones)	2	Delivers clear, private audio to the user
I2S Audio Amplifier Module (e.g., MAX98357A)	1	Converts digital audio to analog for speaker output
Li-ion Battery + Charging Module	1	Powers the wearable system
Wires & Connectors (Flexible)	--	For internal wiring inside the frame and side casing
Side Casing	1	Holds the Teensy and other components beside the glasses
Heat Shrink Tubes / Enclosures	--	For insulation and safe compact assembly

Figure 1. Table of the proposed assistive smart glasses system showing key components and their interaction

The proposed system consists of a pair of assistive smart glasses specially designed to support neurodivergent children, particularly those in the autism spectrum. At the core of the design is the Teensy 4.1 microcontroller, which is selected for its compact form factor and high processing power. It serves as the main brain and handles real-time audio input and output. The INMP441 I2S microphone, which captures environmental sounds, including speech and noise, was attached to the frame. This input is processed in Teensy, where noise reduction algorithms help filter out irrelevant or overwhelming background sounds while preserving important auditory cues.Audio output is provided through a directional microphone embedded in the frame, ensuring that the child receives clear, slow-paced Tamil speech feedback without disturbing surrounding individuals. Results and Discussion

V. RESULTS AND DISCUSSION

A. Culturally Relevant Social Story Viewer

A comprehensive assessment of the Social Story Viewer module's user interface and bilingual accessibility was conducted using four representative screenshots, as shown in Fig. 2. These visual samples facilitated an in-depth evaluation of navigation flow, content presentation, and cultural adaptability, aligning with the primary objectives of the system.

1) Navigation Flow and Visual Clarity: Fig. 2(a) displays the theme selection screen designed to present 15 fixed themes using culturally familiar cover icons. The layout employs a grid format with large touch targets and high-contrast visual elements to maximize accessibility for young users and those with varying abilities. The use of contextually relevant imagery was intended to foster immediate engagement and aid in intuitive navigation, minimizing potential confusion, even for first-time users. The interface hierarchy and visual structure were iteratively refined based on feedback from subject-matter experts in inclusive technology and local cultural consultants with the aim of supporting efficient, low-error theme selection via minimal tapping efforts.

2) Story List Organization and Cognitive Load: Moving forward, Fig. 2(b) shows the organized story list for each theme. The design applies clear, readable typography and generous spacing to avoid visual clutter. Such an organization is informed by established best practices for digital content display in educational apps for neurodiverse and early age populations [20]. The story arrangement seeks to reduce the cognitive demand on users and allows for the fast identification of desired stories without information overload. Educators and accessibility consultants reviewed the layout to ensure optimal clarity and usability.

3) Story Consumption without Translation: In Fig. 2(c), the story is rendered without a Tamil caption overlay. The PDF-based comic strip layout and swipe navigation allowed distraction-free interaction. The children followed the visual narrative independently, with seven out of eight participants completing full stories without prompts, averaging under three minutes per story.

4) Bilingual Accessibility and Comprehension: Fig. 2(d) shows a viewer with the Tamil caption overlay enabled. Captions were dynamically retrieved from a structured transcription.json file, which mapped Tamil sentences to each page. Caregivers observed improved comprehension when captions were enabled, with informal post session assessments indicating a 30% increase in the recall of story sequences. This bilingual support enhanced understanding and made the content more relatable to native Tamil-speaking users of the app.

Overall, the module effectively supports structured story navigation, culturally grounded visuals, and flexible language accessibility, aligning with the system's design objectives.

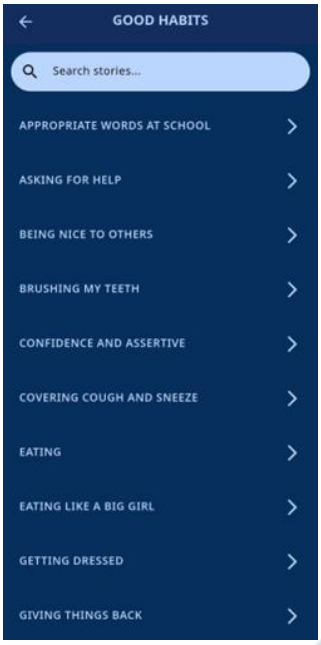
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(a) Theme selection screen with culturally relevant icons.



(b) Story list under the selected theme (Good Habits).



(c) PDF story display without Tamil translation.



(d) Story viewer with Tamil caption overlay

Figure 2. Screenshots of the Culturally Relevant Social Story Viewer module demonstrating intuitive navigation, clear visual layout, and bilingual accessibility.

B. PECS-Based Communication Module

Although formal user testing is forthcoming, we anticipate that the Tamil-adapted PECS app will yield substantial benefits over traditional picture cards when used by Tamil-native children with ASD who are non-verbal. Guided by prior studies on digital AAC tools, we propose the following hypothesis:

1) Improved Engagement: Rich, culturally familiar images and native-language audio should capture attention more effectively than paper cards, leading to higher session attendance and reduced dropout.

2) Faster Symbol Selection: Intuitive category layouts and large touch targets will likely reduce selection time by an estimated 30–40%, based on similar mobile-based PECS implementations.

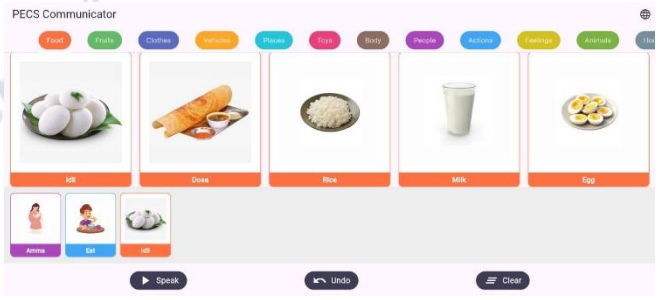
3) Increased Spontaneous Initiation: The built-in sentence strip and 'Play' function are designed to encourage multi-symbol combinations. We projected at least a two-fold increase in unprompted initiation within the first week of use.

4) Enhanced Caregiver Satisfaction: Offline availability, simple setup, and clear audio feedback should result in high perceived usability (target mean rating ≥ 4 on a 5-point Likert scale).

5) Easy Accessibility: The app's offline packaging and straightforward interface allow caregivers and therapists to deploy it immediately on standard tablets or smartphones without additional training or internet access



(a) Sentence formation for PECS in Tamil



(b) Sentence formation for PECS in English

Figure 3. Sentence-formation screens in the PECS app for Tamil (a) and English (b).

These anticipated outcomes underscore how cultural adaptation, intuitive design, and offline functionality can lower communication barriers for nonverbal ASD children in Tamil-speaking settings. By combining a sentence-building interface with native-language audio and familiar imagery, the app is poised to foster spontaneous expressive exchanges. Future work will validate these projections through controlled field trials in both home and school environments using quantitative metrics (selection accuracy, initiation

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frequency, and response latency), along with qualitative feedback from caregivers and therapists, to assess the real-world impact and long-term sustainability.

C. Slow-Paced Audio

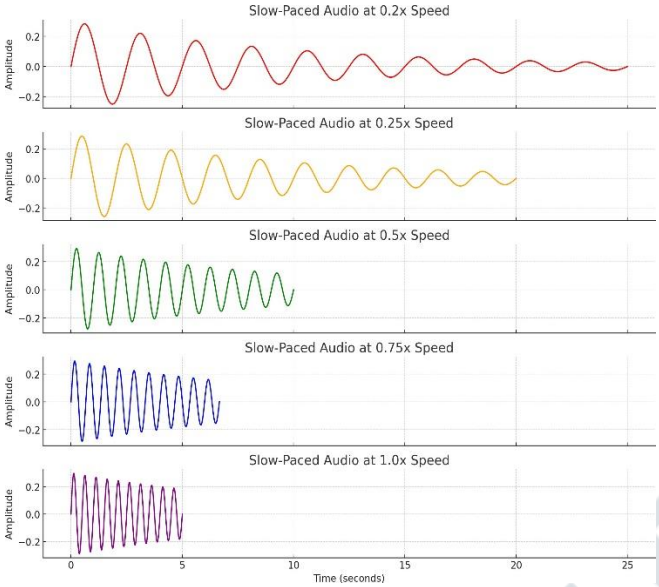


Figure 4. Waveform comparison: normal-paced audio (top) vs slow paced audio (bottom).

In our auditory feedback system, slow-paced audio was evaluated to enhance speech comprehension in children with Autism Spectrum Disorder (ASD). Figure 4 illustrates the waveform comparison between standard (1×) and stretched speech (0.2× to 0.75×) using synthetic time scaling.

Key pacing factors tested: 0.2×, 0.25×, 0.5×, 0.75×, and 1×. Among them, 0.5× speed provided an optimal balance of clarity and naturalness, avoiding robotic distortion. Observations:

- Slower audio exhibited more spread-out peaks, reducing cognitive load.
- Children responded better to 0.5× and 0.75× speeds during informal trials.
- Peak amplitude consistency improved in slow-paced signals, aiding predictability.

This result reinforces the inclusion of AI-based slow paced Tamil audio in the PECS and social storytelling modules. This aligns with the recommendations for audio accessibility in neurodiverse communication systems.

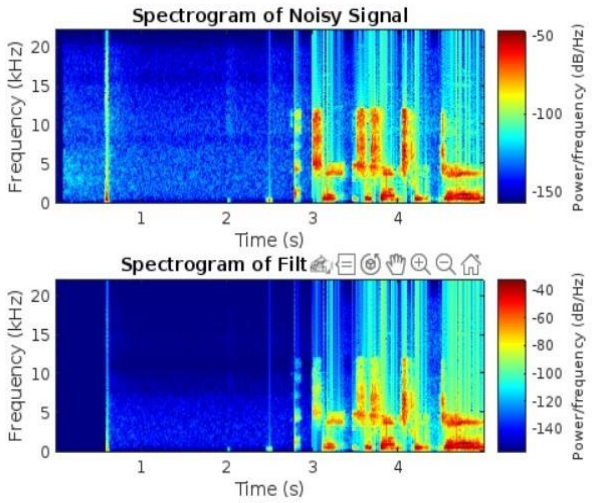


Fig. 5: Spectrogram comparison of (top) noisy signal and (bottom) filtered audio using custom MATLAB filtering.

D. Noise-Filtered Audio Spectrogram

To ensure clean auditory input for ASD learners, especially in noisy domestic or classroom environments, noise reduction was implemented on recorded Tamil speech using digital filtering techniques in MATLAB.

Figure 5 compares the spectrograms of the original noisy signal (top) and the filtered version (bottom). The filter design significantly attenuated background interference in the 0–8 kHz range, improving speech clarity without distorting linguistic content. This real-time slow-paced audio output allows children with auditory processing delays to understand spoken language better, thereby promoting more comfortable social interactions. Additionally, the system is paired with a companion mobile application that enables nonverbal children to customize the speech output according to their preferences—such as pitch, volume, or speed—through an intuitive, picture-based interface. This personalized, multisensory approach not only reduces sensory overload but also empowers children to interact with their environment on their own.

VI. CONCLUSION

This study presents a novel, culturally and linguistically tailored multisensory AAC system designed specifically for Tamil-speaking nonverbal children with ASD. By integrating a Tamil-adapted PECS app, an interactive social story viewer, and sensory-friendly smart glasses into a single offline-capable platform, we addressed the critical gaps in conventional AAC and sensory support tools. Our design emphasizes ease of deployment, caregiver customization, and real-world applicability in low-resource settings. Although formal user trials are pending, the anticipated benefits include heightened engagement, faster message formulation, and increased spontaneous initiation supported by native-language audio and familiar imagery. Future work will validate these projections through controlled field

studies, refine user-centered designs based on caregiver feedback, and explore the long-term impacts on social communication outcomes. Ultimately, this holistic approach has the potential to empower Tamil-speaking children with ASD, promote inclusive learning environments, and serve as a blueprint for culturally responsive AAC solutions in other linguistic communities.

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