Low-Cost, Socially Assistive Robot for Accessible Autism Spectrum Disorder (ASD) Intervention in Pakistan

Abstract

Autism Spectrum Disorder (ASD) is a significant and growing neurodevelopmental challenge globally, with a pronounced accessibility gap for diagnostic and therapeutic services in developing nations like Pakistan. This proposal addresses the critical need for affordable and scalable intervention tools by outlining the design, development, and evaluation of a low-cost, socially assistive robot (SAR). The project is designed to bridge the chasm between the high demand for ASD therapy and the limited availability of trained professionals, geographical barriers, and the prohibitive cost of existing solutions. The proposed SAR will be a culturally adapted, interactive platform designed to engage children with ASD in therapeutic activities that target core deficits in social communication, imitation, and joint attention. This project integrates a multi-phase methodology, beginning with hardware and software development focused on cost-effectiveness and local adaptability, followed by the creation of evidence-based intervention modules. A subsequent pilot study, conducted in collaboration with local autism centers in Pakistan, will assess the robot's usability, effectiveness, and user acceptance. The primary objective is to develop a functional and affordable SAR prototype that demonstrates a measurable positive impact on the social skills of children with ASD. Expected outcomes include a validated open-source robotic platform, empirical data on the efficacy of robot-assisted therapy in a Pakistani context, and a sustainable model for scaling up access to ASD interventions. This research holds significant potential to enhance the quality of life for children with ASD and their families, build local capacity in robotics and special education, and offer a replicable framework for leveraging technology to address healthcare disparities in other developing regions.

1. Introduction

1.1. Background: The Growing Need for ASD Intervention

Autism Spectrum Disorder (ASD) is a complex neurodevelopmental condition characterized by persistent challenges in social communication and interaction, alongside restricted and repetitive patterns of behavior, interests, or activities. Globally, the prevalence of ASD has seen a notable increase in recent decades, attributed to improved diagnostic practices and greater public awareness (Ullah, 2025). This rising prevalence underscores a growing global public health concern, demanding more effective, accessible, and scalable intervention strategies to support the developmental needs of affected individuals (Zahid, 2025).

Early and intensive behavioral interventions are widely recognized as the most effective approach to improving long-term outcomes for children with ASD. These interventions aim to enhance communication, social skills, and adaptive behaviors, thereby fostering greater independence and quality of life. However, the delivery of these therapies is resource-intensive, requiring specialized training, significant time commitment from professionals and caregivers, and substantial financial investment. In many parts of the world, particularly in low- and middle-income countries, the infrastructure to support such intensive intervention is severely lacking, creating a significant gap between the need for and the availability of care. This disparity highlights the urgent need for innovative solutions that can augment traditional therapeutic models and extend the reach of evidence-based support to underserved populations.

1.2. Problem Statement: The Accessibility Gap in Pakistan

In Pakistan, the challenge of providing adequate care for children with ASD is particularly acute. While precise epidemiological data remains limited, a growing number of children are being identified with the condition, placing immense pressure on an already strained healthcare and educational system (Khalid, 2025). The country faces a severe shortage of trained professionals, including developmental pediatricians, child psychologists, speech therapists, and behavioral analysts specializing in ASD. The limited number of qualified practitioners are predominantly concentrated in major urban centers like Islamabad, Karachi, and Lahore, leaving vast rural and remote populations with virtually no access to specialized diagnostic or therapeutic services (Zahid, 2024).

This scarcity of human resources is compounded by significant economic and social barriers. The cost of private therapy is prohibitive for the vast majority of families, creating a two-tiered system where quality care is a privilege of the affluent. Furthermore, social stigma and a lack of public awareness surrounding ASD often lead to delayed diagnosis, social isolation, and reliance on unproven or ineffective treatments. Existing special education facilities are overburdened and often ill-equipped to provide the individualized, intensive support that children with ASD require. Consequently, a significant number of Pakistani children with ASD are deprived of the early intervention critical for their development, leading to poorer long-term outcomes and immense emotional and financial strain on their families. This systemic failure to provide accessible, affordable, and evidence-based care constitutes a critical public health and social justice issue that demands an innovative and contextually appropriate solution.

1.3. Proposed Solution: A Low-Cost Socially Assistive Robot (SAR)

To address the profound accessibility gap in ASD intervention within Pakistan, this project proposes the development, implementation, and evaluation of a low-cost, culturally adapted Socially Assistive Robot (SAR). SARs are a class of robots designed to assist users through social, rather than physical, interaction (Nadeem, 2025). In the context of autism therapy, SARs have demonstrated significant potential as tools to engage children, facilitate social learning, and deliver structured interventions in a predictable and non-judgmental manner. Children with ASD often show a natural affinity for technology and may find interacting with a robot less intimidating and more engaging than interacting with a human therapist.

The core innovation of this project lies in its explicit focus on affordability and accessibility. While sophisticated therapeutic robots exist, their high cost renders them impractical for widespread adoption in developing nations. This project will prioritize the use of open-source software, locally sourced components where possible, and modular design principles to create a platform that is not only inexpensive to produce but also easier to maintain and adapt (Jobaida, 2024). Recent advancements in edge-based AI and low-cost robotics have made such initiatives more feasible than ever before (Kohli, 2023). The robot will be designed to function as a therapeutic tool, administered under the guidance of a therapist, teacher, or trained caregiver. It will be equipped with a suite of interactive modules targeting foundational skills such as joint attention, imitation, turn-taking, and emotion recognition. By providing a consistent, engaging, and endlessly patient interactive partner, the SAR can augment the work of human therapists, enabling them to serve more children more effectively and empowering parents to continue therapeutic activities at home.

1.4. Research Aims and Objectives

The primary aim of this project is to design, build, and validate a low-cost socially assistive robot that can serve as an effective tool for delivering accessible ASD interventions in Pakistan. This overarching aim is supported by the following specific objectives:

1. **To Design and Develop a Low-Cost SAR Hardware Platform:** To engineer a robust, safe, and affordable robotic prototype using accessible materials and open-source hardware. The design will focus on expressive capability (e.g., head movements, simple gestures, visual displays) sufficient for therapeutic interaction while minimizing manufacturing costs.
2. **To Create Culturally Adapted, Evidence-Based Intervention Software:** To develop a suite of interactive software modules for the SAR that are grounded in established therapeutic principles (e.g., Applied Behavior Analysis - ABA). These modules will be designed in collaboration with Pakistani ASD specialists to ensure they are culturally and linguistically appropriate for the target population.
3. **To Evaluate the Usability and Acceptance of the SAR:** To conduct a pilot study with children with ASD, their parents, and therapists in Pakistan to assess the usability of the robot, user engagement levels, and overall acceptance of the technology within a clinical and home setting.
4. **To Assess the Preliminary Efficacy of the Robot-Assisted Intervention:** To measure the impact of the SAR-based interventions on key social and communication skills in a cohort of children with ASD. This will involve pre- and post-intervention assessments using standardized behavioral metrics.
5. **To Develop a Sustainable Model for Deployment and Scalability:** To analyze the cost-effectiveness of the SAR intervention compared to traditional therapy models and outline a strategic framework for future production, distribution, and support within Pakistan.

1.5. Significance of the Project

This project holds significant potential for transformative impact on multiple levels. For children with ASD in Pakistan and their families, it offers the prospect of access to an affordable and engaging therapeutic tool that can supplement limited professional services and empower caregivers. By reducing the financial and logistical barriers to intervention, this project can directly improve developmental outcomes and enhance the quality of life for one of the nation's most vulnerable populations.

For the Pakistani healthcare and education sectors, this research will provide a validated, evidence-based technological solution tailored to local needs. It will contribute valuable data on the efficacy and implementation of robot-assisted therapy in a developing country context, a field that is currently underexplored. The development of an open-source platform can foster local innovation, creating opportunities for technical capacity building in robotics, software development, and digital health.

Scientifically, this project will contribute to the broader field of socially assistive robotics by providing a crucial case study on the design and deployment of low-cost solutions in resource-constrained environments. It addresses critical questions regarding the affordability, efficacy, and cultural adaptability of SARs (Kohli, 2023). By successfully demonstrating a viable model, this work could serve as a blueprint for similar initiatives in other low- and middle-income countries facing similar challenges in providing adequate care for individuals with developmental disabilities. Ultimately, this project is not merely about developing a robot; it is about leveraging technology to create a more equitable and inclusive system of care.

2. Literature Review

This section provides a comprehensive review of the existing literature pertinent to the development of a low-cost, socially assistive robot for Autism Spectrum Disorder (ASD) intervention in Pakistan. It begins by examining the current landscape of ASD in Pakistan, highlighting the prevalence and the significant challenges in accessing care. Subsequently, it explores the established role and efficacy of Socially Assistive Robotics (SARs) in global autism therapy. The review then focuses on the critical need for low-cost robotic solutions, particularly within the context of developing nations. Finally, it addresses the technological and ethical considerations inherent in robot-assisted therapy and identifies the specific research gap this project aims to fill.

2.1. The State of Autism Spectrum Disorder (ASD) in Pakistan

Autism Spectrum Disorder (ASD) is a complex neurodevelopmental condition characterized by persistent challenges in social communication, social interaction, and the presence of restricted, repetitive patterns of behavior, interests, or activities. Globally, the prevalence of ASD has been on the rise, creating significant public health challenges (Nadeem, 2025). While comprehensive national epidemiological data for Pakistan remains limited, localized studies and clinical observations suggest a substantial and growing population of individuals with ASD. This increasing prevalence places immense pressure on an already strained healthcare system, which faces considerable infrastructural and resource limitations (Alivia, 2025).

The challenges for families affected by ASD in Pakistan are multifaceted. A primary obstacle is the severe shortage of trained professionals, including developmental pediatricians, child psychologists, behavioral therapists, and special education teachers. This scarcity leads to long waiting lists for diagnosis and intervention, delaying critical early-life support that is known to improve long-term outcomes. Furthermore, the available services are often concentrated in a few major urban centers like Islamabad, Karachi, and Lahore, creating a profound accessibility gap for the majority of the population residing in rural or semi-urban areas (Zahid, 2024).

Compounding the issue of accessibility is the prohibitive cost of private therapy. For many Pakistani families, the financial burden of sustained, high-quality intervention is insurmountable. This economic barrier excludes a large segment of the population from receiving any form of structured support. Social stigma surrounding mental health and developmental disorders adds another layer of complexity, often leading to delayed help-seeking behaviors, social isolation for families, and a lack of community and institutional support. The convergence of limited awareness, a deficit in specialized infrastructure, high costs, and significant geographical and social barriers creates a critical unmet need for innovative, scalable, and affordable ASD intervention solutions tailored to the Pakistani context.

2.2. Socially Assistive Robotics (SARs) in Autism Therapy

In response to the global challenges in delivering consistent and accessible autism therapy, Socially Assistive Robotics (SARs) has emerged as a highly promising field of research and application over the past two decades. SARs are a class of robots designed to assist individuals through social interaction, providing support in therapeutic, educational, and healthcare settings (Nadeem, 2025). Unlike service robots that perform physical tasks, SARs focus on coaching, motivating, and mediating social behaviors. For children with ASD, who often struggle with human social cues but may show a keen interest in predictable, technology-based systems, SARs offer a unique and effective medium for intervention (Narejo, 2024).

A growing body of research has demonstrated the efficacy of SARs in targeting core deficits associated with ASD. Robots provide a simplified, predictable, and non-judgmental social partner, which can reduce the anxiety that children with ASD often feel during human-to-human interaction. This controlled environment allows them to practice fundamental social skills in a safe and repeatable manner. Studies have shown that interactions with SARs can lead to significant improvements in key areas such as joint attention, imitation, turn-taking, and emotion recognition—foundational skills for social communication (Zahid, 2024). For instance, robots can be programmed to run structured therapeutic protocols, such as those based on Applied Behavior Analysis (ABA), ensuring consistent delivery of evidence-based interventions (Nadeem, 2025).

The use of SARs extends across various therapeutic applications, from diagnostic assessment to skill-building exercises. Researchers have developed numerous robotic platforms, from humanoids like Zeno and NAO to more abstract forms, to facilitate these interventions (Alnajjar, 2020). These technologies are increasingly recognized not as replacements for human therapists but as powerful tools that can augment traditional therapy. They can automate repetitive drills, collect objective data on a child's performance, and provide a novel and engaging platform that maintains a child's attention for longer periods. As healthcare systems globally face mounting pressures, robotics offers a pathway to increase therapeutic productivity and extend the reach of trained professionals, enabling more children to receive the support they need (Irshad, 2025). The consistent findings on the benefits of SARs in improving social engagement and foundational skills in children with ASD provide a strong rationale for their application in contexts where human-led therapeutic resources are scarce.

2.3. The Imperative for Low-Cost Robotic Solutions in Developing Nations

While the therapeutic potential of SARs is well-established, their widespread adoption has been severely limited by the high cost of commercially available platforms. Sophisticated humanoid robots used in many research studies can cost tens of thousands of dollars, placing them far beyond the reach of healthcare systems, schools, and families in low- and middle-income countries (LMICs). This economic barrier perpetuates the global disparity in healthcare access, where the most advanced therapeutic tools are unavailable to the populations that could benefit most from scalable solutions. This has created a clear and urgent imperative for the research and development of low-cost, accessible, and user-friendly robotic systems specifically designed for resource-constrained environments (Alshammari, 2022).

The movement towards affordable robotics is gaining momentum, driven by advancements in open-source hardware and software, as well as innovations in edge-based AI and low-cost manufacturing techniques like 3D printing (Kohli, 2023). Researchers are increasingly focusing on creating platforms that deliver core therapeutic functionalities without the prohibitive expense of their commercial counterparts. Projects aimed at developing affordable educational robots for children with ASD, such as the "TINY" robot in Bangladesh, demonstrate the feasibility and local impact of such initiatives (Jobaida, 2024). These projects prioritize functionality over cosmetic complexity, focusing on essential interaction capabilities like voice interaction, facial expressions, and programmable learning modules.

The development of low-cost robotic systems is not merely a matter of reducing component costs; it is a strategic approach to democratizing access to healthcare technology. An affordable platform can be deployed at a much larger scale, reaching community centers, local clinics, and even individual homes in underserved regions. This model shifts the paradigm from a few high-cost robots in specialized centers to a distributed network of accessible tools. For a country like Pakistan, where the vast majority of the population cannot afford existing therapeutic options, a low-cost SAR represents a disruptive innovation with the potential to fundamentally alter the landscape of ASD care. By focusing on affordability from the outset, this project aligns with a critical global trend aimed at making advanced rehabilitation technologies equitable and accessible for all (Alshammari, 2022), addressing a significant gap in the current market of socially assistive technology.

2.4. Technological and Ethical Considerations in Robot-Assisted Therapy

The integration of SARs into therapeutic practice necessitates careful consideration of both technological and ethical challenges to ensure safe, effective, and responsible implementation. From a technological standpoint, the design of the robot must be grounded in evidence-based therapeutic principles. This involves a multidisciplinary approach, combining expertise in robotics, artificial intelligence (AI), child psychology, and special education. The robot's interaction design—including its appearance, voice, movements, and communication style—must be carefully calibrated to be engaging but not overstimulating for children with ASD. Developing robust and adaptive software that can personalize interventions based on a child's individual progress is a key technical challenge, often requiring sophisticated AI and machine learning algorithms (Alivia, 2025). Furthermore, ensuring the robot's physical safety and operational reliability is paramount, particularly when it is intended for use by vulnerable populations with minimal technical supervision (Jobaida, 2024).

Alongside these technical hurdles are significant ethical considerations that must be proactively addressed. A primary concern is data privacy and security. SARs used in therapy will inevitably collect sensitive data about a child's behavior, performance, and health status. It is crucial to establish clear protocols for data collection, storage, and usage that comply with ethical standards and protect the privacy of the child and their family. Another major ethical question revolves around the potential for over-reliance on technology and the risk of reducing essential human-to-human contact. It is universally agreed that SARs should serve as tools to augment and support the work of human therapists and caregivers, not to replace them (Zapata, 2025). The goal is to use the robot to foster skills that generalize to human social interaction, and the intervention design must explicitly facilitate this transfer.

Moreover, issues of affordability, equitable access, and the potential for creating a "digital divide" in therapy must be managed. If not designed and implemented thoughtfully, even low-cost solutions can exacerbate existing inequalities (Kohli, 2023). This requires a strategy for deployment and training that reaches across socioeconomic strata. Finally, obtaining informed consent from parents or guardians is a critical step, requiring clear communication about the robot's capabilities, the goals of the therapy, the data being collected, and the potential risks and benefits. Addressing these technological and ethical dimensions is fundamental to building trust and ensuring the long-term success and positive impact of robot-assisted interventions.

2.5. Identifying the Research Gap

The preceding review of the literature reveals a confluence of a critical need and a promising technological opportunity. On one hand, Pakistan faces a significant and growing challenge in providing adequate and accessible care for children with ASD due to a lack of trained professionals, high costs, and geographical disparities (Zahid, 2024). On the other hand, Socially Assistive Robotics has been proven globally as an effective tool for augmenting ASD therapy, with a growing emphasis on developing low-cost platforms to enhance accessibility in resource-limited settings (Kohli, 2023)(Alshammari, 2022).

However, a distinct research gap exists at the intersection of these domains. While some initial explorations into technology-assisted therapy have occurred in Pakistan, such as the evaluation of a computer-assisted system (Zahid, 2024), there has been no documented effort to design, develop, and validate a complete, low-cost, culturally-contextualized socially assistive robot specifically for the Pakistani environment. Most existing SARs have been developed and tested in Western or East Asian contexts, and their design, social cues, and language capabilities may not be directly transferable or culturally appropriate for Pakistani children.

Therefore, this project addresses the following specific gaps:

1. **Lack of an Affordable, Complete Robotic Platform:** There is no existing SAR platform that is both technologically robust for ASD intervention and financially accessible to the vast majority of Pakistani families and institutions.
2. **Need for Cultural and Linguistic Adaptation:** Current robotic solutions are not designed with Pakistani cultural norms, social cues, or local languages (such as Urdu) in mind, which is a critical factor for user acceptance and therapeutic effectiveness.
3. **Absence of Localized Efficacy Data:** There is a lack of empirical research validating the efficacy and usability of a SAR-based intervention within the Pakistani socio-cultural and healthcare context.

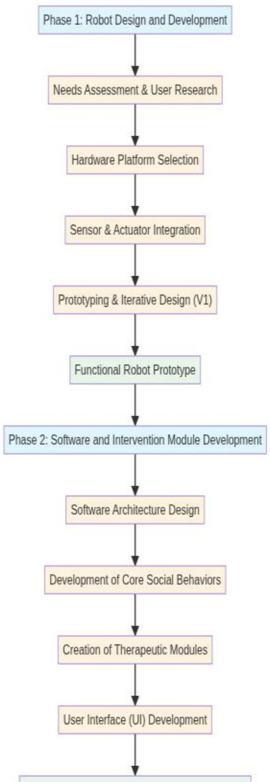
This project directly targets this critical research gap by proposing the end-to-end development and pilot testing of a low-cost SAR, designed from the ground up to be affordable, culturally and linguistically appropriate, and effective for ASD intervention in Pakistan. By doing so, it aims to provide a locally-relevant evidence base for a novel therapeutic modality and create a scalable solution to address a pressing national healthcare challenge.

3. Methodology and Technical Design

The successful realization of a low-cost, socially assistive robot for ASD intervention in Pakistan requires a systematic, phased, and iterative methodology. This chapter outlines the comprehensive research framework, technical design, development process, and validation strategy that will guide the project from conception to pilot implementation. The methodology is grounded in principles of user-centered design, agile development, and rigorous empirical evaluation to ensure the final product is not only technologically sound but also clinically relevant, culturally appropriate, and economically viable for the Pakistani context.

3.1. Overall Research Framework

This project will employ a multi-phase, mixed-methods research framework that integrates engineering design with clinical and social science research. The framework is designed to be iterative, allowing for continuous feedback and refinement throughout the project lifecycle. It is structured into three primary phases: (1) Robot Design and Development, (2) Software and Intervention Module Development, and (3) Pilot Study Design and Implementation.



This phased approach ensures that each component of the project is built upon a solid foundation. Qualitative methods, such as interviews and focus groups with Pakistani therapists, educators, and parents of children with ASD, will be used in the initial stages to inform the robot's design requirements. This user-centered approach is critical for ensuring cultural appropriateness and user acceptance. Subsequent phases will employ quantitative methods to evaluate the robot's performance, usability, and therapeutic efficacy. This mixed-methods design provides a holistic approach to understanding both the technical feasibility and the real-world impact of the proposed solution. The entire process will be guided by an agile development philosophy, characterized by short development cycles ("sprints"), iterative prototyping, and continuous stakeholder feedback to adapt to emerging challenges and insights.

3.2. Phase 1: Robot Design and Development

The primary objective of Phase 1 is to develop a functional, low-cost, and robust robotic hardware platform that is safe and engaging for children with ASD. The design philosophy emphasizes affordability, modularity, and local manufacturability, which are crucial for sustainability in a developing country with limited technology resources (Alshammari, 2022).

3.2.1. Needs Assessment and Co-Design Workshops

Before any hardware is selected, a comprehensive needs assessment will be conducted. This will involve:

- **Stakeholder Interviews:** In-depth, semi-structured interviews with ASD therapists, special education teachers, pediatricians, and parents of children with ASD in major urban centers (e.g., Karachi, Lahore) and semi-urban areas of Pakistan. The goal is to understand current therapeutic practices, challenges, and perceived opportunities for a robotic tool.

• **Co-Design Workshops:** Participatory design workshops will be held with stakeholders to collaboratively brainstorm and sketch initial concepts for the robot's physical appearance, size, and features. This process will ensure the design is culturally sensitive, non-intimidating, and aligns with user expectations. Key design considerations will include color palettes, facial expressions, and overall form factor (humanoid vs. abstract) to maximize engagement without overstimulation (Alnajjar, 2020).

3.2.2. Hardware Platform Selection and Customization

The core of the low-cost strategy is the careful selection of hardware components, prioritizing open-source platforms and readily available electronics.

• **Core Controller:** A single-board computer, such as a Raspberry Pi 4 or a similar alternative, will serve as the central processing unit. These boards offer a powerful combination of computational capability, versatile I/O ports (GPIO, USB, CSI), and extensive community support, all at a low cost.

• **Chassis and Body:** The robot's body will be designed using 3D modeling software (e.g., Blender, Fusion 360) and fabricated using 3D printing with materials like PLA or PETG. This approach allows for rapid prototyping, easy customization, and low-volume local manufacturing, drastically reducing costs compared to traditional injection molding. The design will be modular, allowing for easy repair and replacement of parts.

• **Actuators and Movement:** Standard, low-cost servo motors will be used to provide movement in the head, neck, and arms. The range of motion will be intentionally limited to simple, expressive gestures such as nodding, head-turning, and arm-waving to convey social cues without complex and expensive mechanics. The focus is on creating meaningful social expressiveness rather than complex manipulation capabilities.

• **Sensory Input:**

• **Vision:** A standard USB webcam or a Raspberry Pi Camera Module will be used for visual input, enabling functionalities like face detection and object tracking.

• **Audio:** A microphone array will be integrated for sound localization and basic voice command recognition. A speaker will provide auditory output for speech and sound effects.

• **Physiological Sensing (Exploratory):** In line with emerging research, we will explore the integration of low-cost, non-invasive physiological sensors, such as a heart rate sensor, to gather data on the child's emotional state (Alivia, 2025). The use of physiological signals for emotion detection is a growing area in healthcare robotics and could provide valuable objective feedback on a child's engagement and arousal levels (Riaz, 2025).

3.2.3. Safety and Durability

Safety is a paramount concern when designing a robot for interaction with children (Jobaida, 2024). The design will incorporate multiple safety features:

• **Physical Safety:** All moving parts will have torque limits to prevent injury. The 3D-printed body will have rounded edges and no sharp protrusions. The robot will be designed to be stable and difficult to knock over.

- **Material Safety:** All materials will be non-toxic and durable. Wires and electronic components will be fully enclosed within the chassis.
- **Electrical Safety:** The robot will be powered by a low-voltage battery pack, eliminating the risk of electric shock. A robust power management system will be implemented to prevent overheating.

3.3. Phase 2: Software and Intervention Module Development

In this phase, the hardware prototype from Phase 1 will be brought to life through the development of a sophisticated software stack and a library of evidence-based therapeutic intervention modules. The software architecture will be modular and extensible, facilitating future development and collaboration.

3.3.1. Software Architecture

The software will be developed on a Linux-based operating system (e.g., Raspberry Pi OS) and will utilize the Robot Operating System (ROS). ROS is an open-source framework that provides a standardized communication layer between different hardware and software components, making the system modular and scalable. The architecture will consist of several key components:

- **Perception Layer:** This layer processes data from the sensors. It will include software nodes for face detection (using OpenCV), voice activity detection, and basic speech-to-text processing for commands.
- **Cognition/Decision-Making Layer:** This is the "brain" of the robot. A state machine architecture will be implemented to manage the robot's behavior and control the flow of interaction during therapy sessions. This layer will select appropriate responses and actions based on sensory input and the current state of the therapeutic module.
- **Action/Control Layer:** This layer translates high-level commands from the cognition layer into low-level control signals for the servo motors and speakers, generating the robot's physical and verbal actions.

3.3.2. Development of Core Social Behaviors

To be "socially assistive," the robot must exhibit a set of fundamental social behaviors that promote engagement. These behaviors will be developed and refined through an iterative process:

- **Gaze Following:** The robot will use its camera to detect the child's face and orient its head to maintain eye contact, a critical component of social engagement.
- **Expressive Gestures:** A library of pre-programmed gestures (e.g., nodding for 'yes', shaking head for 'no', celebratory arm movements) will be created and linked to specific conversational contexts.
- **Affective Vocalization:** A text-to-speech (TTS) engine will be used for verbal communication. The pitch, speed, and tone of the voice will be modulated to convey basic emotions like happiness, encouragement, and neutrality. Both English and Urdu language capabilities will be developed.

3.3.3. Design of Therapeutic Intervention Modules

The core of the project's therapeutic value lies in its intervention modules. These modules will be designed in close collaboration with Pakistani ASD therapists to ensure they are based on established principles of Applied Behavior Analysis (ABA) and developmental psychology, while also being culturally adapted. Each module will be a structured, game-like activity targeting a specific skill.

Example Intervention Modules:

• **Joint Attention Module ("Look at That!"):** The robot will use its head and gaze to direct the child's attention to an object or a picture on a screen. The robot will provide positive reinforcement (e.g., a happy sound, a celebratory gesture) when the child follows its gaze. This targets a core deficit in ASD.

• **Emotion Recognition Module ("How Do They Feel?"):** The robot will display facial expressions on a small integrated screen or ask the child to identify emotions in pictures. It will prompt the child with questions like, "Is this person happy or sad?" and provide feedback.

• **Turn-Taking Module ("My Turn, Your Turn"):** The robot will engage the child in a simple, structured game (e.g., telling a story piece by piece, building a virtual block tower) that requires turn-taking, teaching patience and social reciprocity.

• **Imitation Module ("Do What I Do"):** The robot will perform a simple sequence of gestures (e.g., raise left arm, nod head) and encourage the child to imitate it. This builds observational learning and motor planning skills.

3.3.4. Therapist/Caregiver Control Interface

A simple, intuitive user interface (UI) will be developed as a web-based application accessible via a tablet or laptop. This UI will allow the therapist or caregiver to:

• Select and launch specific intervention modules.

• Adjust the difficulty level of the activities in real-time.

• Manually trigger specific robot behaviors (e.g., provide praise, repeat an instruction).

• View session progress and collect basic performance data (e.g., number of correct responses, response time).

This "Wizard-of-Oz" control capability is essential, as it allows the human therapist to remain in control of the session, adapting the interaction to the child's unique and immediate needs, a critical aspect for effective robot-assisted therapy.

3.4. Phase 3: Pilot Study Design and Implementation

The goal of Phase 3 is to empirically evaluate the usability, acceptance, and preliminary efficacy of the SAR prototype in a controlled setting. This phase will transition the project from development to clinical research.

3.4.1. Research Design

A quasi-experimental, within-subject pre-test/post-test design will be employed. This design allows each participant to serve as their own control, which is suitable for an initial pilot study with a small sample size.

• **Participants:** We will aim to recruit a sample of 15-20 children aged 4-8 years, diagnosed with ASD, from partner clinics and special education centers in a major Pakistani city. Inclusion criteria will include a formal ASD diagnosis and verbal or minimally verbal communication skills.

• **Setting:** The study will take place in a quiet, dedicated room at a partner institution to ensure a consistent and controlled environment.

• **Procedure:**

- **Baseline Assessment (Pre-Test):** Each child's baseline social communication skills will be assessed using standardized instruments (e.g., subscales of the Vineland Adaptive Behavior Scales) and direct observation metrics (e.g., frequency of eye contact, response to joint attention bids).
- **Intervention Phase:** Each child will participate in twice-weekly, 30-minute intervention sessions with the robot for a period of 8 weeks. A trained researcher or therapist will facilitate the sessions using the control interface.
- **Post-Intervention Assessment (Post-Test):** The baseline assessments will be repeated immediately following the 8-week intervention period to measure any changes in the targeted skills.
- **Follow-up Assessment:** A follow-up assessment will be conducted 4 weeks after the intervention ends to evaluate the maintenance of any observed gains.

3.4.2. Ethical Considerations

The study will be conducted in strict adherence to ethical guidelines for research involving human subjects, particularly children with disabilities. Ethical approval will be obtained from the Institutional Review Board (IRB) of the principal investigator's institution as well as any partner institutions in Pakistan. Key ethical measures will include:

- **Informed Consent:** Written informed consent will be obtained from the parents or legal guardians of all participants.
- **Child Assent:** Verbal or non-verbal assent will be sought from the children themselves, and they will be informed that they can stop the session at any time.
- **Confidentiality:** All collected data will be anonymized to protect the identity of the participants.
- **Beneficence:** The intervention is designed to be beneficial. Researchers will constantly monitor for any signs of distress, and sessions will be terminated if a child becomes uncomfortable.

3.5. Data Collection and Analysis Plan

A mixed-methods approach will be used for data collection and analysis to provide a comprehensive evaluation of the robot.

3.5.1. Quantitative Data Collection and Analysis

- **Efficacy Measures:** Standardized assessment scores from the pre-test, post-test, and follow-up phases will be the primary outcome measures. In-session performance data (e.g., percentage of correct responses in emotion recognition tasks, latency to respond to joint attention cues) will be automatically logged by the system.
- **Analysis:** Paired-samples t-tests or their non-parametric equivalent (Wilcoxon signed-rank test) will be used to compare pre- and post-intervention scores to determine if there is a statistically significant improvement in the targeted skills.

3.5.2. Qualitative Data Collection and Analysis

- **Usability and Acceptance Measures:** Semi-structured interviews will be conducted with the participating therapists and parents after the intervention period to gather their feedback on the robot's usability, cultural appropriateness, and perceived benefits and drawbacks.

- **Observational Data:** Video recordings of the intervention sessions (with consent) will be analyzed using a behavioral coding scheme to quantify behaviors such as child engagement, spontaneous initiations of interaction with the robot, and instances of positive affect.
- **Analysis:** Thematic analysis will be applied to the interview transcripts to identify recurring themes related to user experience. The coded observational data will be used to triangulate and provide context to the quantitative findings.

By integrating rigorous technical development with a user-centered design philosophy and a robust empirical evaluation plan, this methodology provides a clear pathway to developing an effective, affordable, and accessible socially assistive robot that can make a meaningful impact on ASD intervention in Pakistan (Johnson, 2024). The iterative nature of the framework ensures that the final product will be finely tuned to the unique needs of its target users.

4. Implementation and Project Management

The successful execution of this project hinges on a structured implementation plan, meticulous project management, and a proactive approach to risk mitigation. This chapter outlines the project timeline, budget, team composition, risk assessment, and ethical considerations, providing a comprehensive roadmap from development to pilot deployment.

4.1. Project Timeline and Milestones

The project is structured into four distinct phases over a 24-month period. Each phase includes specific activities and key milestones to ensure progress is tracked and objectives are met in a timely manner. The timeline is designed to be ambitious yet realistic, allowing for iterative development, testing, and refinement based on stakeholder feedback.

Phase 1: Planning, Design, and Procurement (Months 1-6)

- **Activities:** Conduct a detailed needs assessment with partner clinics in Islamabad and Karachi. Finalize the robot's technical specifications and cultural design elements. Source and procure all necessary hardware components, prioritizing locally available parts to control costs. Submit the research protocol for ethical review and approval.
- **Milestone 1:** Finalized technical and design specifications document. Ethical approval granted by the Institutional Review Board (IRB).

Phase 2: Hardware and Software Development (Months 6-15)

- **Activities:** Assemble the first functional hardware prototype (Alpha version). Develop the core software architecture, including the robot's operating system, control APIs, and the user interface for therapists. Begin development of the initial set of therapeutic intervention modules based on evidence-based practices like imitation, joint attention, and emotion recognition.
- **Milestone 2:** A functional Alpha hardware prototype capable of basic movements and interactions, controlled via the core software.

Phase 3: Integration and Pilot Preparation (Months 15-22)

• **Activities:** Integrate the intervention software modules with the hardware prototype. Conduct rigorous internal testing and debugging to ensure system stability and reliability. Refine the hardware and software based on feedback, leading to the development of several Beta prototypes for the pilot study. Develop the detailed pilot study protocol and training materials for participating therapists and families.

• **Milestone 3:** Three pilot-ready Beta SAR units, fully integrated with therapeutic software, along with a finalized study protocol and trained personnel.

Phase 4: Pilot Study, Analysis, and Dissemination (Months 22-24)

• **Activities:** Implement the 12-week pilot study at partner centers. Collect quantitative and qualitative data on the robot's usability, efficacy, and user acceptance. Analyze the collected data to evaluate the project's primary and secondary objectives. Prepare the final project report, manuscripts for publication in peer-reviewed journals, and present findings at relevant academic conferences and stakeholder workshops.

• **Milestone 4:** Completion of the pilot study, data analysis, and dissemination of results through a final report and initial publications.

4.2. Budget and Resource Allocation

The project is designed to be cost-effective, aligning with its central objective of creating an affordable solution. The total estimated budget for the 24-month project is PKR 15,000,000. The allocation is strategically distributed across key areas to maximize impact while maintaining fiscal discipline. The emphasis on low-cost components and open-source software is a core tenet of the financial plan (Alshammari, 2022).

• **Personnel (45%):** This is the largest budget component, covering salaries for the core research team, including the Principal Investigator, robotics engineers, software developers, a child psychologist/ASD specialist, and research assistants.

• **Robot Hardware & Prototyping (25%):** This includes costs for all electronic components, sensors, actuators, 3D printing materials, and the fabrication of multiple prototypes. This allocation is managed carefully to adhere to the low-cost design principle, leveraging affordable microcontrollers and off-the-shelf parts where possible (Jobaida, 2024).

• **Software & Tools (10%):** While the project will primarily use open-source software, this allocation covers specialized development tools, cloud computing resources for machine learning model training, and any necessary software licenses.

• **Pilot Study & Logistics (10%):** This covers costs associated with running the pilot study, including travel to partner sites in Islamabad and Karachi, compensation for participant families' time and travel, and materials required for therapy sessions (Zahid, 2025).

• **Dissemination & Overheads (10%):** This includes publication fees for open-access journals, conference registration and travel, costs for hosting stakeholder workshops, and institutional overheads.

4.3. Team Composition and Expertise

The project's success relies on a multidisciplinary team with expertise spanning robotics, software engineering, clinical psychology, and human-computer interaction. The team will be led by a Principal Investigator with a strong background in assistive technology research.

- **Principal Investigator (PI):** An experienced researcher in Human-Robot Interaction or Assistive Technology, responsible for overall project direction, management, and reporting.
- **Robotics Engineer (1 FTE):** Specializes in mechatronics and hardware design. Responsible for the design, prototyping, and fabrication of the physical robot.
- **Software Engineer (2 FTE):** One specializing in embedded systems and robot control, and another in user interface (UI/UX) design and application development. They will develop the robot’s operating system, control software, and therapist interface.
- **AI/ML Specialist (Part-Time Consultant):** An expert in developing and implementing machine learning models for social signal processing and adaptive interaction.
- **Child Psychologist / ASD Specialist (Part-Time Consultant):** A board-certified professional with clinical experience in ASD interventions in Pakistan. They will guide the design of therapeutic modules, develop the pilot study protocol, and oversee clinical implementation to ensure it is effective and culturally appropriate.
- **Research Assistants (2 Part-Time):** Graduate students who will assist with literature reviews, data collection, participant recruitment, and administrative tasks.
- **Advisory Board:** Comprising local ASD experts, representatives from NGOs, parents of children with ASD, and international researchers in socially assistive robotics to provide strategic guidance and ensure the project remains aligned with community needs.

4.4. Risk Assessment and Mitigation Strategies

A proactive approach to risk management is essential. Potential risks have been identified across technical, logistical, and ethical domains, with corresponding mitigation strategies.

Risk Category	Identified Risk	Likelihood	Impact	Mitigation Strategy
Technical	Delays in sourcing key electronic components due to supply chain issues.	Medium	High	Identify alternative suppliers and components in advance. Maintain a buffer stock of critical parts. Prioritize components available through local distributors in Pakistan.

Technical	Integration challenges between custom hardware and software modules.	High	Medium	Adopt a modular design philosophy. Implement continuous integration and rigorous testing throughout the development cycle. Allocate buffer time in the project timeline for debugging.
Logistical	Difficulty in recruiting and retaining participants for the pilot study.	Medium	High	Build strong partnerships with established autism centers. Offer fair compensation for participants' time and travel. Develop a culturally sensitive and clear communication plan for families.
Project Management	Scope creep, where new features are continuously added, delaying the project.	Medium	Medium	Adhere strictly to the finalized specifications document from Phase 1. Implement a formal change control process for any proposed modifications to the project scope.
Ethical/Social	Low acceptance of the robot by children or families due to cultural or aesthetic reasons.	Medium	High	Involve parents, therapists, and children in the design process from the outset (co-design). Conduct small-scale usability tests with mock-

				ups before finalizing the design.
Financial	Budget overruns due to unexpected increases in component costs or development time.	Low	Medium	Secure detailed quotes from multiple suppliers. Build a 10% contingency into the budget. Regularly review expenditures against the project plan.

4.5. Ethical Considerations and Approval

The project places the highest priority on the ethical treatment of its participants and the responsible development of technology. Given the involvement of a vulnerable population (children with ASD), the ethical protocol will be rigorous and comprehensive.

1. **Institutional Review Board (IRB) Approval:** Prior to any participant recruitment, the complete research protocol will be submitted to and approved by the IRBs of the collaborating academic institution and partner clinical centers in Pakistan.
2. **Informed Consent:** A detailed, multi-stage informed consent process will be implemented. Information sheets will be provided in both English and Urdu, explaining the study's purpose, procedures, potential risks, and benefits in clear, non-technical language. Written consent will be obtained from the parents or legal guardians of all child participants.
3. **Child Assent:** In addition to parental consent, the assent of each child will be sought in an age-appropriate manner. Researchers will explain the activities involving the robot and will respect any verbal or non-verbal indication of unwillingness to participate. Participation is entirely voluntary, and families can withdraw at any time without penalty.
4. **Data Privacy and Confidentiality:** All data collected will be anonymized to protect participant identity. Video recordings of sessions will be stored on encrypted hard drives with restricted access. Data used for analysis and publication will be aggregated and de-identified.
5. **Minimizing Risk:** The robot's design will prioritize physical and psychological safety (Jobaida, 2024). It will be lightweight, with no sharp edges, and operate at low speeds. The therapeutic interactions are designed to be positive and encouraging, and a trained therapist will be present during all robot-child interactions to monitor the child's well-being and intervene if any signs of distress are observed. This human-in-the-loop approach is fundamental to ensuring the technology augments, rather than replaces, human care. The ethical imperative is not only to do no harm but also to ensure the technology is deployed in a way that is genuinely beneficial and respects the dignity of the individuals it is designed to serve (Johnson, 2024).

5. Expected Outcomes and Impact

This project is poised to deliver significant contributions across research, technology, and society. The outcomes are designed to be measurable, scalable, and impactful, directly addressing the critical gap in accessible ASD intervention in Pakistan.

5.1. Anticipated Research Contributions

The project will generate novel insights and tangible outputs that advance the fields of socially assistive robotics, human-computer interaction, and ASD therapy, particularly within the context of developing nations.

- **A Validated Low-Cost SAR Platform:** The primary output will be a fully functional, open-source hardware and software platform for a socially assistive robot. This platform, validated through a pilot study, will serve as a blueprint for affordable robotic solutions. Its design specifications, code, and performance data will be made publicly available, enabling other researchers to replicate, adapt, and build upon this work (Alshammari, 2022).
- **Culturally-Adapted Intervention Models:** The research will produce a set of evidence-based therapeutic modules specifically designed and validated for the cultural context of Pakistan. This contribution addresses a significant gap in the literature, as most existing SAR interventions are developed in Western contexts. Findings will offer insights into how robot appearance, interaction style, and language can be tailored to enhance engagement and efficacy in diverse cultural settings.
- **Efficacy and Usability Data:** The project will yield crucial data on the efficacy of a low-cost SAR in improving social-communicative skills (e.g., joint attention, imitation, emotion recognition) in Pakistani children with ASD. Quantitative data from standardized assessments and qualitative data from therapist and parent interviews will provide a comprehensive evaluation of the robot's performance and user acceptance. This will be among the first studies of its kind conducted in the region, contributing vital evidence to the global understanding of robot-assisted therapy (Zahid, 2024).
- **Framework for SAR Deployment in Low-Resource Settings:** The project will develop and document a framework for the design, development, and deployment of assistive technologies in resource-constrained environments. This includes best practices for stakeholder engagement, co-design methodologies, and navigating logistical and ethical challenges, providing a valuable guide for future technology-for-development projects.

5.2. Potential for Scalability and Sustainability

A core principle of this project is to create a solution that can be scaled and sustained beyond the initial research phase. Several strategies are embedded in the project design to facilitate this long-term vision.

- **Low-Cost and Localized Production:** By utilizing off-the-shelf components, 3D-printed parts, and open-source software, the final cost per robot unit is projected to be significantly lower than commercially available SARs. The design will be optimized for local manufacturing and assembly in Pakistan, reducing reliance on expensive imports and creating opportunities for local technical enterprises. This approach directly addresses the affordability barrier that has limited the adoption of such technologies (Kohli, 2023).
- **Train-the-Trainer Model:** The project will develop a comprehensive training curriculum for therapists, educators, and healthcare workers on how to effectively use the SAR as a therapeutic tool. By implementing a "train-the-trainer" model in

partnership with local institutions, the project aims to build local capacity and ensure that the knowledge and skills required to operate the system can be disseminated independently of the core research team. This addresses the shortage of trained professionals in Pakistan (Khalid, 2025).

• **Partnerships with NGOs and Government Bodies:** From the outset, the project will engage with key stakeholders, including the Autism Society of Pakistan, healthcare providers, and potentially provincial Ministries of Health and Special Education. These partnerships are crucial for long-term adoption. The goal is to demonstrate the robot's cost-effectiveness and clinical benefits, paving the way for its integration into existing public health and special education programs.

• **Open-Source Community:** By releasing the project's hardware designs and software code under an open-source license, we aim to foster a community of developers, researchers, and clinicians in Pakistan and beyond. This will enable continuous improvement, adaptation of the platform for other therapeutic uses, and long-term maintenance of the software, ensuring the project's legacy endures.

5.3. Broader Social and Economic Impact for Pakistan

The successful implementation of this project has the potential to create a ripple effect, generating significant social and economic benefits for Pakistan.

• **Increased Access to Therapy:** The most direct impact will be on children with ASD and their families. By providing an affordable and accessible therapeutic tool, the project can help bridge the significant service delivery gap, particularly for families in remote or underserved areas and those with limited financial resources. This can lead to earlier interventions and better developmental outcomes for children.

• **Reduced Burden on Families and Healthcare System:** Autism care can place a significant emotional and financial burden on families. By providing a tool that can be used in clinics and potentially at home to supplement therapy, the project can empower parents and reduce the frequency of costly clinical visits. This can also help alleviate pressure on Pakistan’s already strained healthcare system, which faces increasing demands (Irshad, 2025).

• **Empowerment and Destigmatization:** The introduction of an innovative, non-judgmental technological tool may help reduce the stigma associated with ASD. The robot can provide a safe and predictable interaction partner for children, fostering skill development in a positive context. Public engagement and dissemination activities will also raise awareness and promote a more inclusive understanding of autism in society.

• **Economic Development and Skill Building:** The project can act as a catalyst for technological innovation in Pakistan. By focusing on local production, it can foster the development of a local industry around assistive robotics. It will also contribute to building a skilled workforce with expertise in robotics, artificial intelligence, and software development, areas critical for the country's economic future. This aligns with a growing global interest in developing user-friendly robotic systems for developing country contexts (Alshammari, 2022).

5.4. Dissemination Plan

A robust dissemination plan is essential to maximize the project's impact and ensure its findings reach relevant academic, clinical, and public audiences.

• **Academic Publications:** Findings will be submitted for publication in high-impact, peer-reviewed journals in the fields of robotics (e.g., *IEEE Transactions on Robotics*), human-computer interaction (e.g., *ACM/IEEE HRI Conference*), and clinical psychology/autism research (e.g., *Journal of Autism and Developmental Disorders*).

• **Conferences and Presentations:** The project team will present research findings at major international and national conferences to engage with the academic community, solicit feedback, and foster collaborations.

• **Stakeholder Workshops:** At the conclusion of the project, a series of workshops will be held in key Pakistani cities (Islamabad, Karachi, Lahore). These workshops will bring together clinicians, educators, policymakers, NGOs, and families to demonstrate the robot, share pilot study results, and discuss pathways for wider adoption.

• **Open-Source Repository:** All software code, hardware design files (e.g., CAD models), and training materials will be made publicly available on a platform like GitHub. This will ensure that the project's outputs are accessible to a global audience of researchers and developers.

• **Policy Briefs and Media Outreach:** Concise policy briefs summarizing the project's findings and recommendations will be prepared for government health and education departments. The project will also engage with local media to raise public awareness about ASD and the potential of technology to support individuals with disabilities.

6. Conclusion

The increasing prevalence of Autism Spectrum Disorder in Pakistan, coupled with a severe deficit in accessible, affordable, and specialized intervention services, presents a formidable public health challenge (Ullah, 2025). Families across the country face significant barriers—financial, geographical, and social—in securing the support their children need. This project proposes a direct and innovative response to this crisis: the development and pilot testing of a low-cost, culturally-adapted, socially assistive robot designed specifically for the Pakistani context.

This proposal has articulated a clear pathway from problem identification to impactful solution. By leveraging advances in low-cost robotics, open-source software, and artificial intelligence, we aim to create a tool that is not only technologically sophisticated but also economically viable and socially acceptable (Kohli, 2023). The project's methodology is grounded in a multi-phase, user-centered design process that ensures the final product is both clinically relevant and aligned with the needs of children, parents, and therapists in Pakistan. Through a rigorous pilot study conducted in collaboration with local autism centers, we will generate critical evidence on the robot's efficacy in improving core social-communicative skills, its usability, and its potential for integration into existing therapeutic practices.

The anticipated outcomes extend far beyond a single technological artifact. This research will contribute a validated open-source platform to the global scientific community, offer a new model for culturally-aware intervention design, and provide a framework for deploying assistive technology in resource-constrained environments. For Pakistan, the potential impact is transformative. This project promises to enhance access to therapy, reduce the burden on families and the healthcare system, combat stigma, and stimulate local innovation and technical capacity building.

Ultimately, this project is driven by the conviction that technological innovation must be inclusive and equitable (Johnson, 2024). By focusing on affordability and accessibility, we aim to break the cycle where advanced therapeutic solutions remain the privilege of the few. This socially assistive robot represents a tangible step towards a future where every child with ASD in Pakistan has the opportunity to reach their full potential, supported by tools that are as compassionate and intelligent as they are accessible. We are confident that with the proposed plan, team, and resources, this project will deliver a meaningful and lasting contribution to the well-being of the autism community in Pakistan and serve as a model for similar initiatives worldwide.

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