INTERACTIVE, VISUAL LEARNING-BASED TOOL FOR HEARING IMPAIRED CHILDREN TO IMPROVE LANGUAGE

22_23-J 18

Project Proposal Report

M M Saluka Udbhasa

IT19188928

BSc (Hons) in Information Technology

Specializing in Data Science

Department of Information Technology

Sri Lanka Institute of Information Technology

Sri Lanka

October 2022

INTERACTIVE, VISUAL LEARNING-BASED TOOL FOR HEARING IMPAIRED CHILDREN TO IMPROVE LANGUAGE

22_23-J 18

Project Proposal Report

M M Saluka Udbhasa

IT19188928

BSc (Hons) in Information Technology

Specializing in Data Science

Department of Information Technology

Sri Lanka Institute of Information Technology

Sri Lanka

October 2022

DECLARATION

I declare that this is our own work, and this proposal does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any other university or Institute of higher learning, and to the best of our knowledge and belief, it does not contain any material previously published or written by another person except where the acknowledgment is made int he text.

Signature:  Date: 13/10/2022

Signature of the Supervisor: Date:

Signature of the Co-Supervisor: Date:

ABSTRACT

The sense of hearing is one of the fundamental needs of every person. When compared to all sense organs of an individual, the need of hearing is very essential for the coordination and the functioning of other sensory organs (speaking is based on hearing etc.). When considering the community with hearing impaired, the state of not having hearing sense is a challenge in their education. Researchers have shown that hearing impairment also affects reading and writing abilities because of low exposure to a natural language. To minimize those effects and to help these children with their education, an interactive solution should take place.

Improper parenting and lack of awareness also plays a major role where hearing impaired students falling behind in education because of not giving/referring the special education they need in their early childhood. Students with hearing impairment, who gain language skills in their early childhood show good improvement in reading writing and other cognitive tasks. The proposed application will be a student centric learning system with minimal involvement from the teachers or external parties. Here the students get an interactive environment where children can learn things from their surroundings and practice words/signs by themselves. Lessons will be presented to them in an attractive manner, and it should be simple to use. Within the learning process the level of student is monitored and the best course material is selected to the students. Also there are measures to improve the verbal communication using lip exercises and speech therapy where students will be trained regularly to pronounce the language and to get the sense of a natural language.

TABLE OF CONTENTS

1. INTRODUCTION

1.1 Background and literature survey

According to the data released by the Centre for Disease Control and Prevention, the prevalence of hearing loss in 2019 was 1.7 for 1000 babies screened for hearing loss.[1] In addition to that sample there may be babies didn't go through the screening test or there are conditions occur after later in the life which causes hearing loss. Accidents also contributes to the total population of children having hearing disabilities.

According to doctors specializing in this field suggest that around 98% of the population can be converted to live like a normal child by applying a hearing aid or advanced cochlear implant. Modern technological advancements help to design and manufacture hearing aid devices/implants with minimal distortion and higher amplification levels. Successful cochlear implant surgery can bring the perceived decibel range to a margin under 30dB which is sufficient for differentiating sounds and understanding a spoken language. The dynamic range or the micro stepping count varies based on the manufacturer but most of the available devices can give the child a sense of a spoken language.

Even though the child is capable of hearing sound with high dynamic range and distinguish sounds of words and sentences they are lacking the cognitive abilities of a regular child in specific areas like language development and audible memory.

Cognitive development is further divided into motor(physical) development, language and communicational development, and social/emotional development. Hearing impairment has a negative impact on language acquisition. Negative effects of language development delay, reflect throughout their life [5]. Hearing-impaired children require special care and attention in order to improve their linguistic skills. Taking alternative methods and techniques is as important as early detection of hearing loss, to raise a hearing-impaired child to have a normal life [4].

Brain plasticity in early childhood supports rapid language acquisition. By the age of five, a normal-hearing child essentially masters the phonological, lexical, and morpho-syntactic skills [1]. By the age of 5 children naturally become fluent in their native language as they are exposed to their surroundings on a regular and frequent basis. It is crucial to learn languages during the first 4,5 years as it [2]. The misconception of hearing aid solves everything worsen the situation as parents do not put effort further and wait for the child to speak miraculously at school [4]. But researchers have found that if the linguistic development phase (first five years) is passed, it is nearly impossible to recapture [5]. Since hearing-impaired children do not get exposed to a spoken language, their vocabulary is as limited to 400, 500 words by the age of 5 while hearing peers' vocabulary is around 20000 words. This effect heavily in their education as education is heavily biased towards verbal languages [3].

Community Child Health, Royal Children's Hospital, Australia conducted research to identify the impact on education in relation to the age of diagnosis and severity of hearing impairment [6]. The hypothesis of this study was the age of detection of hearing impairment has a relationship with education outcomes. For this study, 132 students from 7-8 years of age participated. To measure the educational outcomes, each individual student took a three-hour assessment under the supervision of a speech pathologist and a psychologist.

1.2 Research Gap

Speech therapy is a crucial factor in teaching children with hearing disabilities. Speech therapists are educators that work with children to ensure that they are communicating, participating, and learning. A speech therapist must teach the students speech, make sure that the child has learned essential speech skills, and put emphasis on learning speech to learn essential words. It also helps with forming auditory memory and the skill development solely relies on the effort and eth expertise of speech therapist.

Research have done visual and audio-based experiments to create a digital learning space for speech therapy but the child engaging factor is low or unable to make it persistent. Most research has relied on adult communication, not the ability of young children to communicate and learn. But learning is essential for children to engage with language, not just listen.

When children engage in speech, it activates the brain on a cognitive level. It improves their awareness of language as well as the process of learning. Children who are taught at early stages on how to speak and learn language have enhanced cognitive development.[6]

Talking to Teo, authored by A.A.Navarro Newballa, D.Loaizaa, C.Oviedoa, A.Castillob, A.Portillab, D.Linaresa, G.Álvareza[7] is a video game developed and based on verbal therapy and educational objectives, aimed at the rehabilitation of children with early diagnosed hearing disability, and who use aids such as cochlear implants. The software integrates speech recognition for user interaction and benefits from visual feedback.

It is a tool designed using speech recognition technologies which takes advantage of the graphic interaction and the narrative provided by the video games. Video games provide an easier and more engaging interaction but the tool is designed in a way to prioritize phonetics and spoke language development.

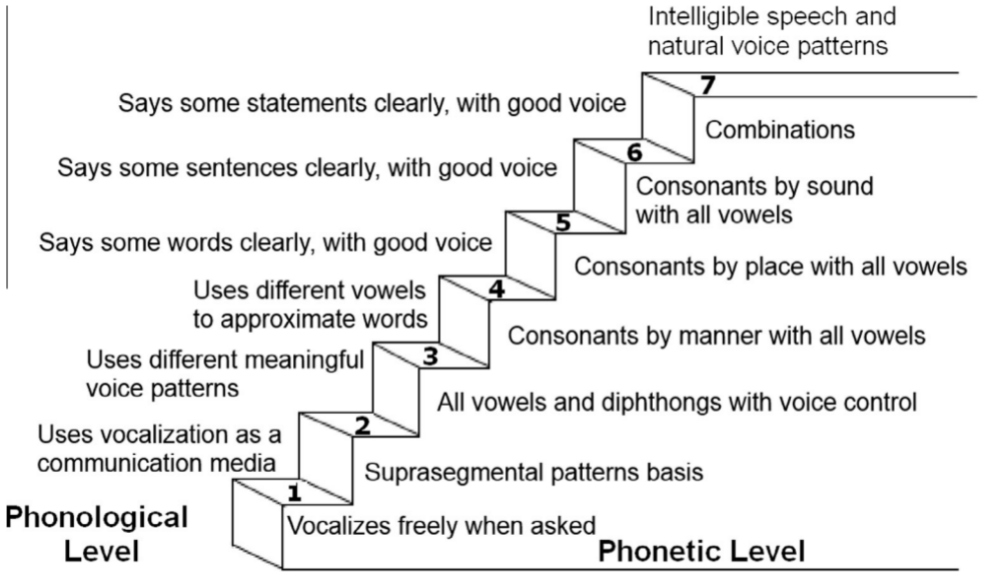


Figure 1 Phonetic development diagram from reference [6]

According to speech therapy experts, a single speech therapy session can be divided into seven subparts: speech therapy; cognitive therapy; educational; physical therapy; behavioral therapy; parenting; and therapeutic.

Above system lacks the cognitive and behavioral therapy as its primary goal is to develop knowledge in phonetics.

Another research was conducted by author Ahmad Hassanat on Visual Words for Automatic Lip-Reading[8] involves computer vision based approach for converting lip reading into words. Even though this publication doesn't discuss about the full implementation of an application, lip analyzation and translator part is explained.

Their approach consists of three major stages: detecting/ localizing human faces, lips localization and lip reading. For the first stage they propose a face localization

method, which is a hybrid of a knowledge-based approach, a template-matching approach and a feature invariant approach (Ex:skin colour).

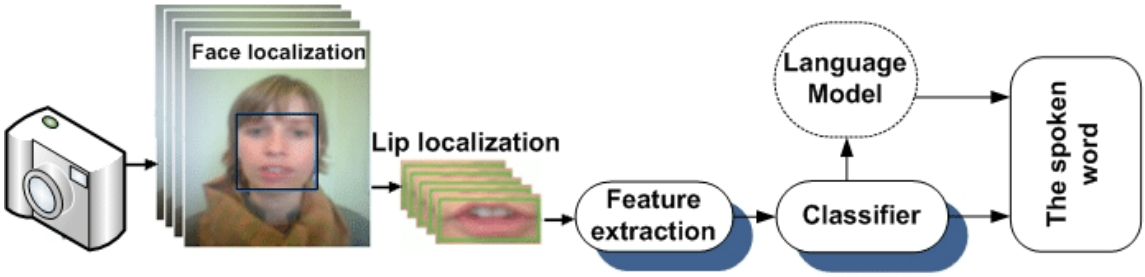
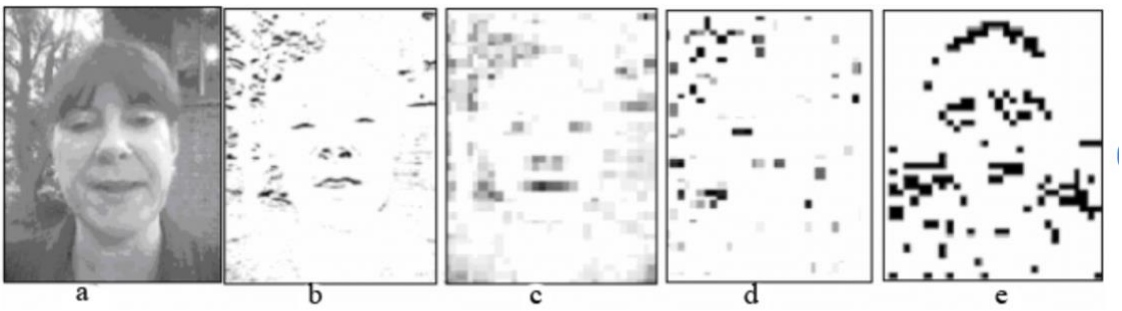


Figure 2 The proposed automatic lip-reading system from [8]

The multi-stage scheme is initiated with a special edge detection procedure that highlights the main facial features, and fuses wavelet information extracted from the transformed edge-highlighted image with color information extracted from a small number of candidate windows in the original RGB images.



11. Applying wavelet and resizing: a) original image, b) edge detection, c) LL 3 , d) resized to the size of LL 3 , e) binary image of LH 3

Figure3 The proposed automatic lip-reading system from [8]

Due to the nature of using classical computer vision techniques for feature extraction and pattern analysis this system is not reliable for practical usage and the accuracy of the detections vary based on the lighting, environment, camera hardware, etc.

1.3 Research Problem

Hearing impairment is a sensory disability that hinders linguistic development. Language proficiency among the hearing-impaired community is reported to be low compared to hearing peers. Research has proven that if a child has not acquired a first language in early childhood when the brain plasticity changes, there is a risk that the child might not be able to be completely fluent in any language in their life. Language acquisition at an early age is automatic if it is engaged regularly and meaningfully.

The brain matures in a relatively short time span compared to the rest of the human body. While other parts of the body reach full maturity between five and seven years, the human brain reaches full maturity in the first five years of a child's life. Therefore, early intervention is required during those ages to minimize the gap between a regular child and a hearing-impaired child.

There are many problems associated with introduction of digital solution/application to a child in their early ages. Inability to perceive the instructions provided using a language, poor interaction skills with digital devices (improper UI/UX designs supports this more) and risks associated with screen time are some of them. Another problem faced by kids when it comes to digital devices are always apps that bombard them with ads, in-app purchases and data use/tracking.

Regular children learn from their surroundings and the visual and audio cues they experience from birth but for hearing impaired children one of their senses is hindered and affect the learning rate and the exposure to the environment.

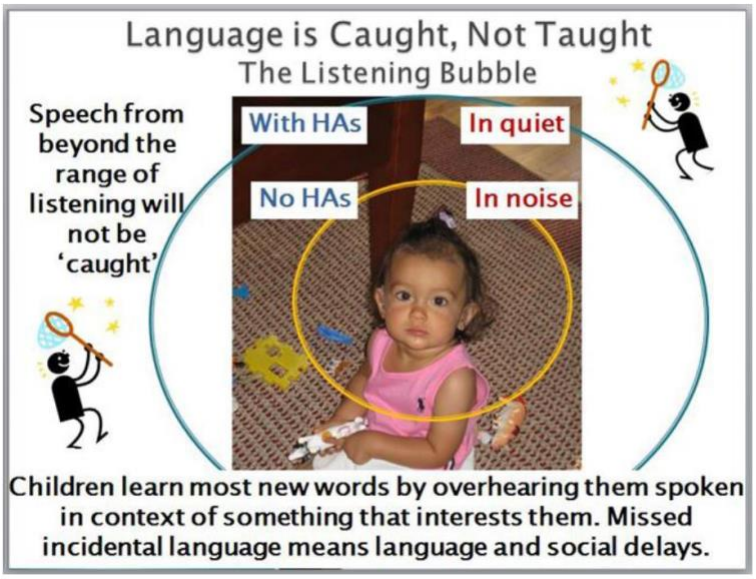


Figure 4 Source: http://mtbt.fpg.unc.edu/more-baby-talk

According to the research article published on **Effects of Early Language Deprivation on Brain Connectivity: Language Pathways in Deaf Native and Late First-Language Learners of American Sign Language[9],** lack of exposure to language in early childhood affects the development of brain connections which may cause other brain functions as well.

While researchers do not know exactly why these brain functions occur, it is possible that hearing loss affects these brain functions by altering the communication system between the auditory and visual systems. For example, research has shown that auditory perception and verbal memory are linked to auditory brain function, and vice versa. The result is that if a deaf child is not exposed to spoken language at an early age, he or she will have a difficult time using speech to express themselves and organize their thoughts. This problem is further exacerbated if a deaf child is exposed to language through American Sign Language.

Even-though the sign language is easy to teach, and solves the communication problem, it may seriously affect the future life of the child who may have the advantage of being a normal child with the help of speech therapy and the necessary aids (hearing aids/ cochlear implants).

Exercise of residual hearing helps children to increase the frequency and amplitude of their responses to sounds. It also helps to improve the cochlear functions. Practicing residual hearing and speech therapy at early ages can help the child develop language skills and other cognitive abilities, but for that purpose extra effort needs to be put by parents, teachers, and the care takers.

In countries like Sri Lanka, due to the lack of awareness and some other issues like poor education, financial issues, and social status, most parents tend to take no proper action against the hearing-impaired child until he/she develops to the schooling age. Some parents introduce the child to learn sign language as the first language by themselves or enrolling in to a school of deaf, but with proper medical guidance and implants/hearing aids followed by language trainings may help the child to have the opportunity to learn with other students and live a normal life.

After having a tuned hearing aid or a cochlear implant the child's hearing ability is improved but still lacks the cognitive part for language skills. For that purpose, special trainings are required like speech therapy and residual hearing exercises.

Speech therapy is usually performed by a speech therapist who has the domain knowledge in developing not only speech skills but also stimulating other cognitive areas in brain. Speech therapy needs to be performed regularly and the repetition is the key factor which affects the memorization and the performance of the child. Only few percentage of parents are ready for bearing the higher cost of speech therapy sessions and maintain a consistent pattern. Therefore, only a handful amount of children has got the opportunity to develop language skills and improve themselves.

If there's a way to provide speech therapy sessions using a software the accessibility will be improved and child can learn from their own environment with the help of this application. It would also create less friction maintaining a consistent learning pattern and encourages repetitive behavior.

Even though the market is filled with child learning apps, couldn’t find an application with great personalization(adapts to the profile of child) and speech therapy activities focuses more on the child’s feedback.

Having a visual or/and audio feedback mechanism is useful for speech therapy tasks since without that feedback mechanism it would be harder to interact with the student and measure the improvement. The mechanism should be smart enough to track the child’s face and lips to check whether the user tries to mimic the output sound and audio can be used for pronunciation correcting.

2. OBJECTIVE

2.1 Main Objective

Primary objective of this research is to provide a easily accessible software solution that helps hearing impaired children to improve their language skills and cognition. The application will help to minimize the gap between the learning ability of normal child and a hearing-impaired child, since the research have shown that language deprivation creates a barrier in many tasks due to the slight cognitive differences in brain.

Teaching sign language is discouraged here, since most of the hearing-impaired children have the ability to transform into a regular student with the modern technologies like Programmable hearing aids & Cochlear implants followed by consistent speech therapy sessions. Main objective is to provide an efficient, feedback driven language & cognition development application for hearing impaired children. Child focused design and the great accessibility will help this goal for better.

2.2 Sub-objectives

2.2.1 Developing a gamified activity for speech therapy

For doing speech therapy for hearing-impaired child there needs to be an interactive activity for them to involve while trying to pronounce the words. It needs to be solely dependent on the visual cues since the child won't be able to understand instructions given by any language. The activity may comprise of an attractive and simplified game to engage while trying to pronounce the words.

2.2.2 Lip movement and audio processing-based feedback mechanism

While engaging in the above-mentioned activity, there needs to have a feedback mechanism for progress tracking and similarity checking. Lips will be tracked using computer vision to check whether the child is trying to pronounce the word he/she is

listening and audio stream from the microphone will be used for checking pronunciation and similarity.

2.2.3 Generate homonyms for repeated practice

Speech therapy involves contextual learning and speech training. For speech training, after identifying the areas for improvement using the above feedback mechanism, new word lists can be generated according to the child's profile and the learnt preferences. This process continuously progresses until the child pronounces the sound correctly and it also helps with student learning new vocabulary.

3. METHODOLOGY

The proposed software solution is capable of exploring the environment using the camera and by using an object detection apparatus, surrounding objects are detected filtered and labeled after segmentation. The child can freely navigate and explore his/her surrounding for known/unknow objects where the app displays its word and outputs the sound.

After tapping/clicking on the highlighted object a new UI will open containing a gamified activity. This UI will help to teach the object's name and its sound to the child.

Several components are integrated in there where speech therapy component also works in the background to track the response from child while engaging in the activity. Based on the pronunciation accuracy the child is presented with new words for improvement.

In a separate module, student progress tracking will be done, where it helps to assess the performance of different tasks and it also helps with creating an adaptive learning environment for the student.

Course material generation helps to generate new content that can be presented as a daily task. It uses natural language processing generate new phrases using the context and similar objects are also generated to generalize the student's knowledge.

3.1 System architecture diagram

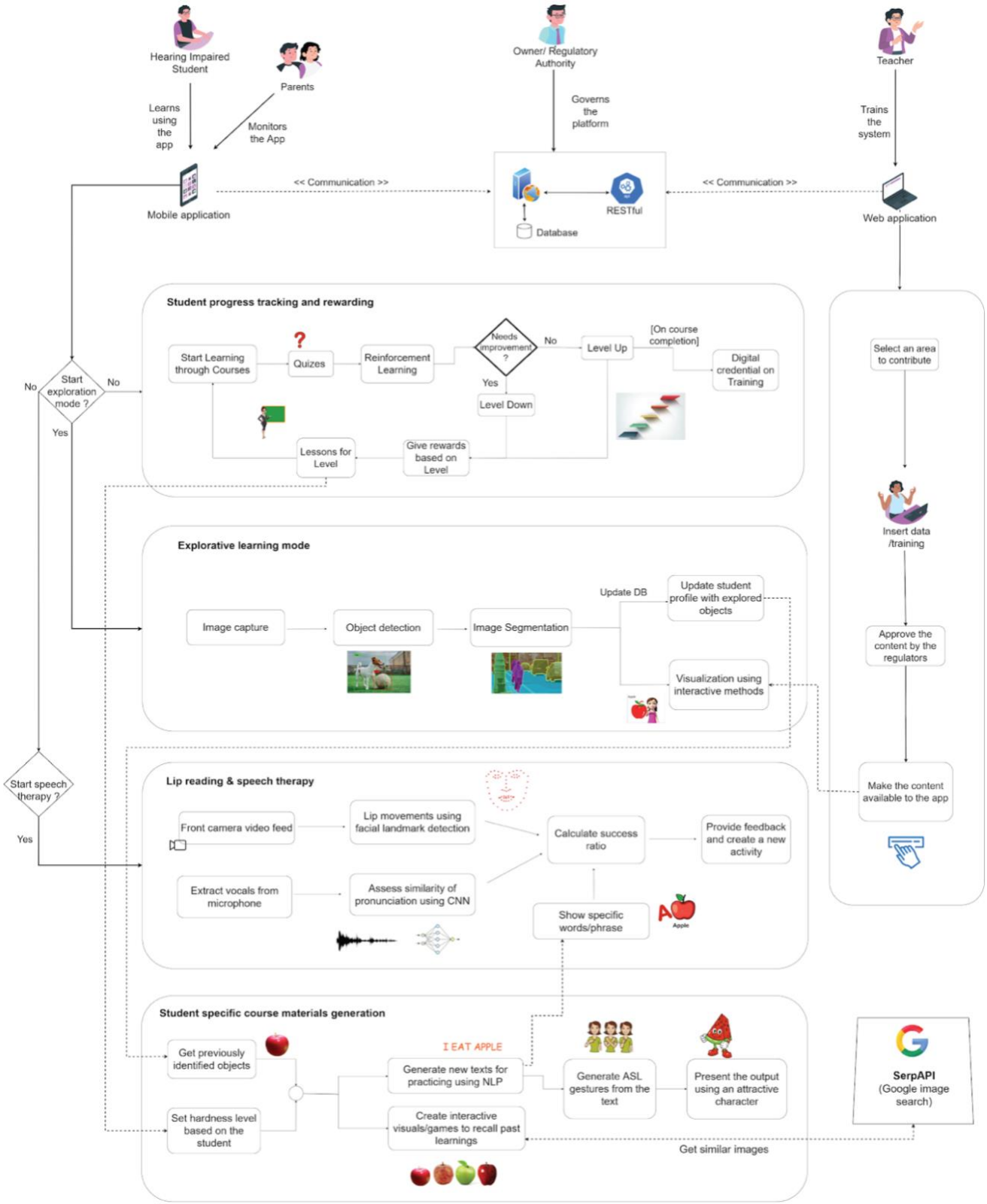


Figure 5 Overall system architecture diagram

As shown in the Figure 4, the overall system is divided into four main components. They are,

- Explorative learning module

Using the camera, surrounding objects are detected, filtered, and then highlighted for better user experience. YOLO algorithm will be used for detections and run it in real time on a video feed to give the ability to explore objects more easily without taking any photos. Once a segmented objected is tapped/clicked teaching process starts.

- Student progress tracking and rewarding module

A student can learn basics through a course series optimized to the level of user and there are quizzes designed for determining the level a user belongs to. Reinforcement learning is used in this and with that a user level is determined upon successful completion of a quiz.

Rewards are provided for the user to make the learning process more engaging and satisfying.

- New course material generation module

When the child has explored many objects using the explorative learning mode, the NLP module can generate new words and phrases relevant to the context.

The trained machine learning models are also in place to censor the content for children and explorative learning module relies on that service

- **Speech therapy module**

Speech therapy module employs techniques for training a hearing-impaired child for language skills and it also improves the cognition of the child by providing a gamified environment while doing the speech training.

Below is the high-level component diagram (Figure 5) for the speech therapy module.

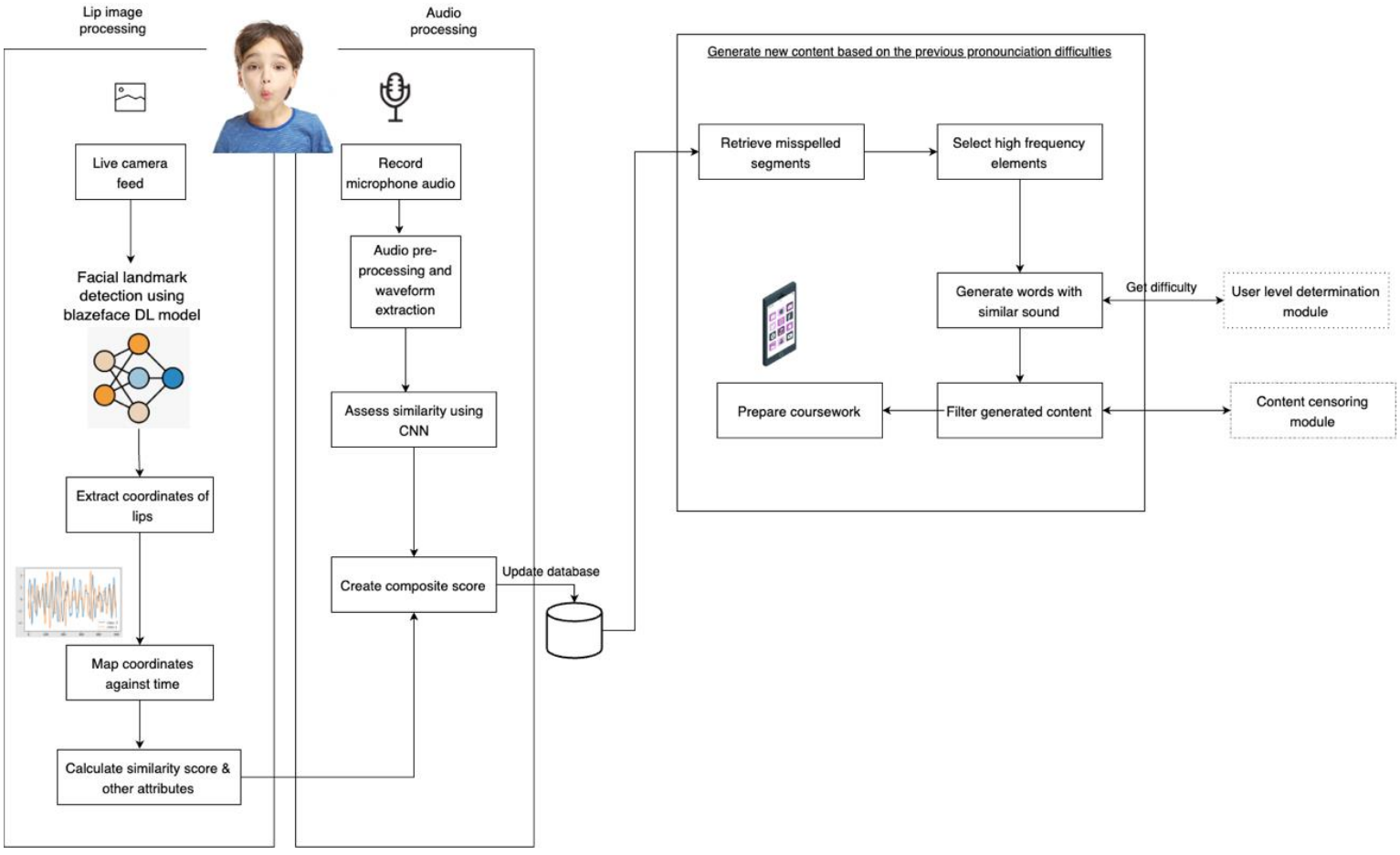


Figure 6 High level architecture diagram of the speech therapy module

Lip reading is the main mode of validating speech when noise is present. The input from the camera captures the facial landmarks and the lip movements.

For the facial landmark detection **blazeface deep learning model[10]** is used since it's optimized for running in mobile devices and it yields high accuracy for facial landmark detections. t runs at a speed of 200-1000+ FPS on flagship devices. This super-realtime performance enables it to be applied to any augmented reality pipeline that requires an accurate facial region of interest as an input for task-specific models, such as 2D/3D facial keypoint or geometry estimation, facial features or expression classification, and face region segmentation.

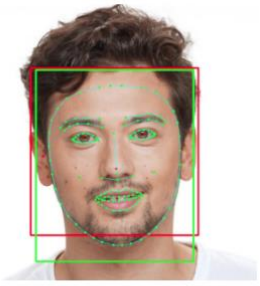


Figure 3. Pipeline example
(best viewed in color).
Red: BlazeFace output. Green:
Task-specific model output.

Figure7 Output from blazeface nn model. Source: Reference[10]

The coordinates relevant to the lips are extracted from the model output. When doing the training, a unique fingerprint is generated for specific pronounced word by mapping coordinates with time axis. When testing against the child pronunciation similarity score is calculated even the child's voice is not loud enough or noise is present.

The audio will also be captured concurrently to assess the similarity of pronunciation. It will be assessed using convolutional neural networks (CNN).A generated text will be shown, and corresponding lip movements also visualized for the pronunciation.

According to the user's pronunciation a composite score will be calculated based on both lip detection and the audio processing. Using the above-mentioned techniques, a feedback mechanism can be created where several speech therapy practices can be implemented in future.

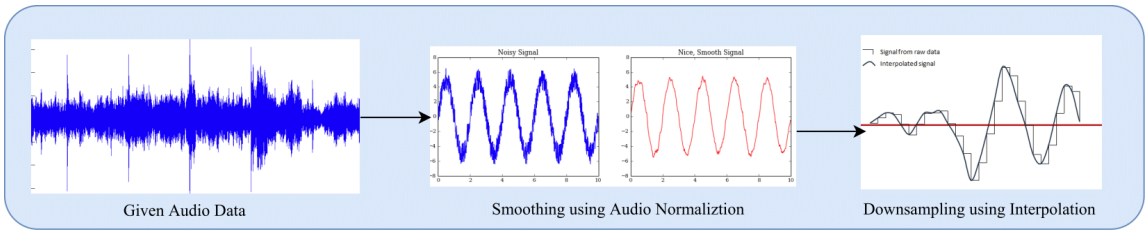


Figure 8 Multi class audio classification using Deep Learning (CNN, MLP)

In addition to the feedback mechanism, homonyms will be generated for repeated practice. The new content will be generated on similar pronunciation and the student profile where student improvement areas are recognized.

Technology Selection

Table 1 Table of technology selection

Libraries and frameworks : Tensorflow, Pytorch, OpenCV,Flask/Django,React Native
Database : MongoDB
Cloud provider: Azure
Other tools : Unity game engine, Android studio, Pycharm

3.1.1 Software solution

When developing a software, a systematic process should be followed. Being able to adopt fast when the requirements are changed, agile methodology is best suited for this project.

By studying previous successful projects, analyzing project management processes and identifying requirements, all parties can agree on an agreed upon process that will maximize the time and cost efficiency of the software. This proactive approach can avoid the risk of software quality issues that would typically be detected at the end of the SDLC process.

Typically, agile development involves relatively short timelines and helps with rapid changes in the plan. It ensures quality in delivery of agreed, relevant, and effective software solutions. Achieve sufficient response times on the development and acceptance of software solutions. Incorporate feedback from a small group of the project stakeholders (usually between 3-20 people) to ensure effective problem solving and input to the ongoing improvement process.

- Requirement gathering

1. Requirements gathering from Lady Ridgeway Children hospital
2. Field visits to Rathmala blind and deaf school for conducting a survery.
3. Data and parameter collection from Rathmalana Dialog Audiology centre

- Feasibility study

Economic feasibility: Check whether the proposed system can be implemented with the expected cost and it also analyze whether this expenditure is beneficial.

Scheduled feasibility: Check whether the project can be completed within the planned timeframe

Technical feasibility: Technical feasibility evaluates the technical complexity of the system and often involves determining whether the expert system can be implemented with state-of-the-art techniques and tools.

- Design

After requirement gathering and proposing a feasible solution architecture diagrams and wireframes were designed for better understandability of the system going to implement.

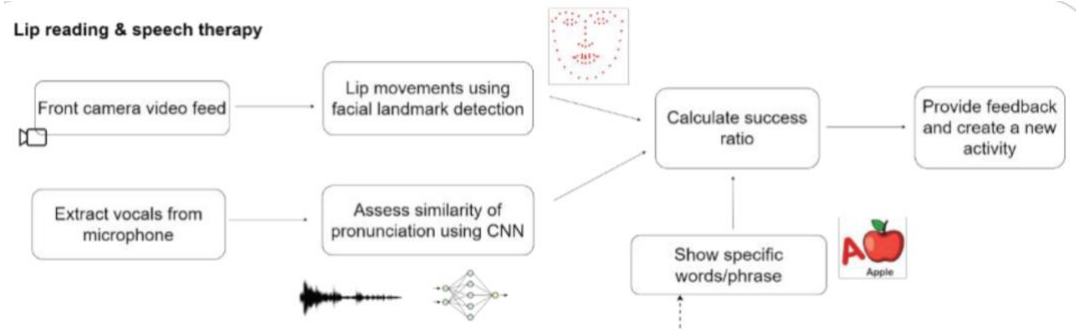


Figure 9 Wireframes of the proposed application

- Development

This stage focuses on the implementation and satisfies the requirements gathered during the planning stage. Development includes following but not limited to,

  - Implementation of image processing pipeline for lip reading and use blazeface deep learning model for on device facial landmark detection.
  - The audio analyzer development for checking similar pronunciation using convolutional neural networks (CNN).
  - Building application frontend using child friendly UI/UX design
  - Development of Backend functionalities and infrastructure configurations for backend services.

- Testing

Testing phase check whether user requirements are satisfied and ensures quality software is delivered without any errors and bugs. Several tests are performed to check whether it's ready for deployment

3.1.2 Commercialization

The developed application can be introduced directly to the consumers through the play store and/or app store. As a revenue stream freemium model can be followed where some features are restricted and provided with a limited quota for free users while paid users can unlock all features with unlimited usage. It will be a one time cost.

As an example daily detection limit can be employed for free users and they will also face a daily time limit for the application usage. After exploring the features in the free version a user may convert into a paid user if parents/caretakers observe some usefulness of the application.

From the other branch partnership is in progress with the Wickramarachchi hearing care center to introduce this application for their customers under a agreement. If deployed, it will be a subscription-based payment model.

4. PROJECT REQUIREMENTS

4.1 Functional Requirements

1. System should be able generate contextually similar new words based on the previously learned contents.
2. System should be able to extract relevant images for the generated words.
3. System should be able to present the generated contents in a meaningful manner.
4. All the contents presented through the application must be kid friendly.
5. Content filtration must not allow any false negatives.

4.2 Non-functional Requirements

1. User-friendliness – Since the proposed system is an education tool for kid's, system UI must be attractive yet simple in design.

2. Integrity – System must only present the accurate contents.

3. Compatibility – System should be compatible with major mobile operating systems and should be able to run the application without any performance issues on majority of the mobile devices that are currently used in the community.

4. Reliability – All of the different functionalities of the system should be able to smoothly run on mobile devices without causing errors.

4.3 User Requirements

1. Parents – Parents use this application to give their hearing-impaired child a natural language learning experience that addresses the obstacles that preventing the child having a natural language learning experience.
2. Educators – Educators use this application to improve the quality of education provide from their institutes by encouraging children to learn by their own experiences.

4.4 System requirements

When system requirements are met the deployed system can properly operate on both client side and the server side.

- **Smartphone with compatible operating system (IOS/Android)**
  Any smartphone released after 2016 can properly run the app application
- **Cloud infrastructure which supports mongo dB database deployments and python code execution**

Work Breakdown Structure

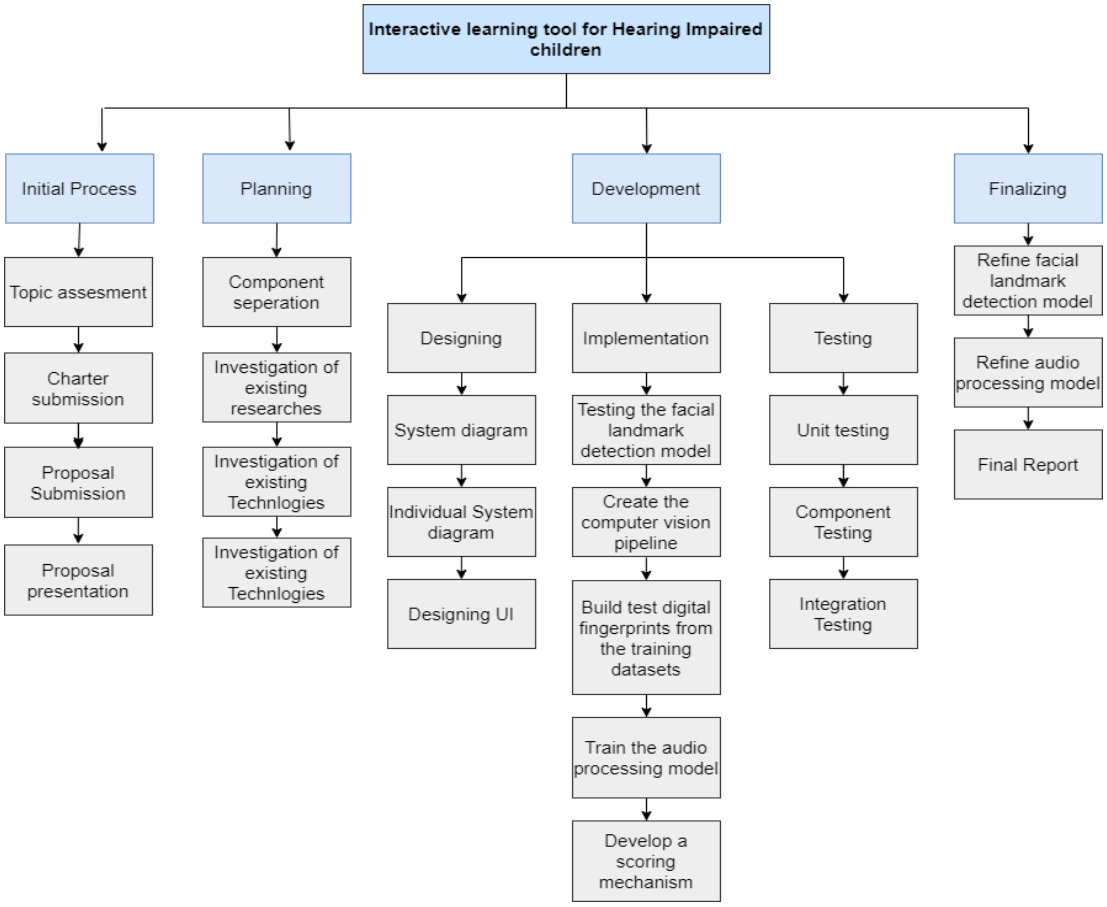


Figure 10 Work Breakdown Chart

Gantt Chart

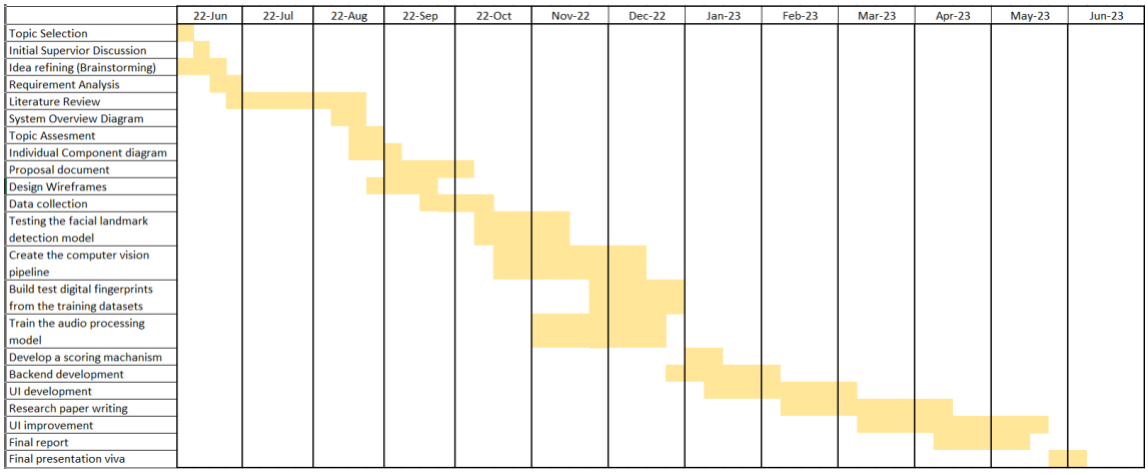


Figure 11 Gantt Chart

4.5 Budget and Justification

Table 2: Table of expenses related to proposed system

Requirement	Payment type	Estimated cost
Azure Content Moderator Service	Every extra transaction per second $1 per transaction (0-1M transactions)	$40 /month
Google SerpAPI	5,000 searches / month	$50 / month
Hosting Cost(Azure)	$0.075/hour	$50/ month
Google Play Store	One time payment	$25
Apple App Store	Annual fee	$99

REFERENCES

[1] Erika Hoff PhD, "Language Development at an Early Age: Learning Mechanisms and Outcomes from Birth to Five Years", Department of Psychology, Florida Atlantic University, USA, 2009.

[2] T. Humphries et al., "Language acquisition for deaf children: Reducing the harms of zero tolerance to the use of alternative approaches", Harm Reduction Journal, vol. 9, no. 1, 2012. Available: 10.1186/1477-7517-9-16 [Accessed 8 October 2022].

[3] S. Dixon, "Two Years: Language Leaps**The chapter is dedicated to Elizabeth Bates, Ph.D. (1947–2003), for her early contribution to this work and for her studies of child language worldwide.", Encounters with Children, pp. 382-409, 2006. Available: 10.1016/b0-32-302915-9/50020-3 [Accessed 8 October 2022].

[4] McNeill, D. “The capacity for language acquisition. In Research on behavioral aspects of deafness”, National Research Conference on Behavioral Aspects of Deafness, New Orleans, LA. Vocational Rehabilitation Administration, 1965

[5] Meadow, Kathryn P. “Early Manual Communication in Relation to the Deaf Child’s Intellectual, Social, and Communicative Functioning.” Journal of Deaf Studies and Deaf Education, vol. 10, no. 4, 2005, pp. 321–29. *JSTOR*, http://www.jstor.org/stable/42658773. Accessed 9 Oct. 2022.

[6] L. Zauche, T. Thul, A. Mahoney and J. Stapel-Wax, "Influence of language nutrition on children’s language and cognitive development: An integrated review", Early Childhood Research Quarterly, vol. 36, pp. 318-333, 2016. Available: 10.1016/j.ecresq.2016.01.015.

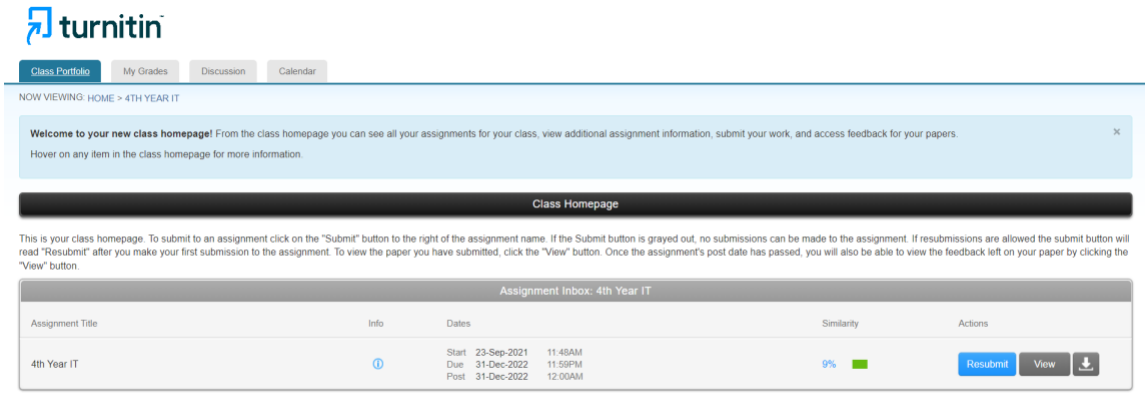
[7] A. Navarro-Newball et al., "Talking to Teo: Video game supported speech therapy", Entertainment Computing, vol. 5, no. 4, pp. 401-412, 2014. Available: 10.1016/j.entcom.2014.10.005.

[8] A. Hassanat, " Visual Words for Automatic Lip-Reading ", Available: https://www.researchgate.net/publication/266024193_Visual_Words_for_Automatic_Lip-Reading

[9] Q. Cheng, A. Roth, E. Halgren and R. Mayberry, "Effects of Early Language Deprivation on Brain Connectivity: Language Pathways in Deaf Native and Late First-Language Learners of American Sign Language", https://www.frontiersin.org/articles/10.3389/fnhum.2019.00320/full, 2022.

APPENDIX

Appendix 1: Plagiarism report



Appendix 2: Blazeface model accuracy comparison with MobileNet V2

Model	Average Precision	Inference Time, ms (iPhone XS)
MobileNetV2-SSD	97.95%	2.1
Ours	**98.61%**	**0.6**

Table 1. Frontal camera face detection performance

Appendix 3: Blazeface gpu inference speed comparison

Device	MobileNetV2-SSD, ms	Ours, ms
Apple iPhone 7	4.2	**1.8**
Apple iPhone XS	2.1	**0.6**
Google Pixel 3	7.2	**3.4**
Huawei P20	21.3	**5.8**
Samsung Galaxy S9+ (SM-G965U1)	7.2	**3.7**

Table 2. Inference speed across several mobile devices