DESIGN OF AN AUGMENTED REALITY-BASED LEARNING SIMULATION FOR INDIVIDUALS WITH DYSCALCULIA

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November 2023

TECHNOLOGICAL INSTITUTE OF THE PHILIPPINES
Quezon City

Major (Capstone) Design Experience Information
CPE 029 PROJECT DESIGN 1

1st Semester, SY 2023-2024

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Project Title	**Design of an Augmented Reality-based Learning Simulation for Individuals with Dyscalculia**
Project Concentration Area	Augmented Reality

Design Objectives	**General Objective:**
	The general objective of the project is to develop a system that enhances the learning process of special learners with dyscalculia in solving worded math problems by creating a game-based learning simulation using augmented reality. It must meet the needs of the client in compliance with engineering and other relevant standards, while taking into consideration the constraints including economic, efficiency, performance, environmental, safety, public health, social, global, and cultural along with computation of trade-offs from selected constraints.
	
	Specific Objectives:
	● Develop a simulation that:
	    ● Displays in real-time the 3D virtual objects including a simulated character guide, alphanumeric characters, and basic shapes.
	    ● Accepts interaction from users that manipulate virtual 3D objects by physical movements namely pushing, pulling, dragging and dropping.
	    ● Provides real-time audio-visual feedback to the user based on the interactions with the virtual 3D objects.
	● Design a system that monitors the completion progress of the users compliant with the educational content for a Mathematics or English course.
	● Test and evaluate the system's accuracy.

Constraints	
Economic (Development Costs)	The economic constraint pertains to the monetary requirements for the overall cost of the project. Development Cost refers to the expenses

	associated with the system's development. Factors that may contribute to development costs are specialized software or hardware required in creating the design as well as the hiring of experts to validate the created design. The less development cost value that the design requires, the more economical the design. Therefore, the design with the lowest developmental cost is considered the best design (GAO-20-195G, 2020)
Efficiency (Application Size)	The efficiency constraint refers to the proper use of computational resources of the system. Application size refers to the memory space required for the AR application. The application size can put a strain on the performance of the system; larger applications will require more processing power and memory than smaller applications, which leads to performance issues such as lag or stuttering on older or less powerful devices (Schumann et al., 2021). Therefore, the design with the lowest application size offers more performance and is considered the best design.
Performance(Response Time)	The performance constraint refers to the ability of the system to process data and accomplish tasks. Response Time is the time it takes for the system to provide results after accepting input and processing data and events. A low response time means that the system can respond to data and events quickly and has higher performance (Silberschatz et al., 2018). Therefore, the design with the lowest response time will be considered as the best design.
Environmental (Storage Consumption)	The environmental constraint refers to the factors that affect the computation space of the system. Storage Consumption pertains to the amount of memory in gigabytes (GB) consumed by the design to properly function. This is indicated by measuring storage through the use of storage measurement tools such as Android Storage Analyzer and iOS Storage, third-party applications are also applicable. The less storage that the design consumes, the more environmentally-friendly. Therefore, the design with the least amount of storage consumption is considered the best design.
Safety (Frames Per Second)	The safety constraint refers to the ability of the system to not cause any harm or discomfort to the users. Frames per second is used to measure the reliability of the system to provide a smooth projection of the virtual. A smooth projection of the 3D virtual objects is required so that the users don't experience disorientation when using the system (Stanney et al., 2020). Therefore, the design with the highest frames per second will be considered the best design.
Other constraints: These constraints do not affect each design; therefore, these were not included in selecting the best design.	

Public Health	Public health protects and improves community health. It refers to environmental safety and illness prevention. It prevents designs from harming public health. It is guaranteed that none of the designs influence public health.
Social	Social refers to the device's ability to meet human needs and handle societal problems, including informal standards. The social constraint ensures that no social norms are violated. It can be guaranteed that none of the designs affect social constraints.
Global	Engineering design considers worldwide restrictions, including international production, sourcing, outsourcing, and supply chain management. This limitation makes the design global and functional. None of the designs certainly have an impact on the global constraints.
Cultural	People do certain things, which are prescriptive cultural constraints, or they do not do certain things, which are also prescriptive cultural constraints. It affects the choices people make and how the person, or self, is formed. None of the designs have an impact on culture.
Standards	
ISO/IEC 24775-7:2021 Information technology - Augmented reality (AR) - Part 7: Requirements for AR systems used in education and training	This standard specifies requirements for augmented reality (AR) systems used in education and training. It covers a range of topics including functionality, usability, accessibility, performance, reliability and security. This standard was used to ensure that AR systems used in education and training meet the needs of learners and educators, and that they are safe and effective.
ISO/IEC 18038:2019 Information technology - computer graphics, image processing and environmental representation	The standard provides a framework and information reference model for representing sensor-based 3D mixed-reality worlds. This standard was developed to enable the seamless integration of real and virtual worlds. This standard was used to develop a game-based augmented reality learning experience that is engaging, effective and accessible for special learners with dyscalculia.
ISO/IEC DIS 5927 Augmented and Virtual Reality safety - Guidance on safe immersion, set up and usage	The standard provides guidance on safe immersion, set up and usage of augmented and virtual reality systems. The standard was used to ensure that the learners are safe during the simulations. Additionally adherence to the standard can provide assurance that the team took proper precaution to minimize the risk of harm or injury to the learners during the implementation of the augmented reality learning environment system.
ISO/IEC/IEEE 12207:2017 System and software	The standard specifies a life cycle model and it defines software development processes to ensure that software is developed and maintained in a responsible and consistent manner. The processes

engineering - Software life cycle processes	include planning, implementation, assessment and maintenance. The standard was used to ensure the augmented reality learning environment system is developed and maintained in a robust and reliable manner. Specifically, the standard has requirements for planning, which include requirements management, project planning and project monitor and control and these are essential to ensure the successful development of the system.
ISO/IEC/IEEE 29119:2022 Software and system engineering - Software testing	The standard provides a comprehensive process model for software testing that covers the planning, design, execution and reporting of software testing. And specifies testing processes, documentation and techniques for both functional and non-functional software testing. The standard was used to ensure the software testing process follows a structured and comprehensive approach. Leading to a higher quality software that meets client's requirements and expectations.

Abstract

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CHAPTER 1: THE PROJECT AND ITS BACKGROUND

The project and its background include a description and the reasons for its foundation. It includes the aims and constraints of the project when it comes to design creation, discussion with the target client about its constraints, engineering standards relevant to the project, and the design process used in the project.

1.1 The Problem

Dyscalculia is a learning disorder that severely impacts a person’s mathematical capabilities, particularly in dealing with numbers, mental calculations, and mathematical symbols (Avila-Pesantez et al., 2018). Approximately seven (7) percent of the global population, equivalent to about 1 in every 15 individuals, face challenges with mathematics as a result of dyscalculia (Triplett, 2023). Dyscalculia can affect children's academic performance. There are identified compromised cognitive domains such as attention, and processing speed, in children with math challenges. These domains are vital for math learning, influencing both academic performance and mental development. Assessing these functions in diagnostics is essential for customizing interventions for individual children. (Agostini, et al., 2022).

In the Philippines, it is one of the most common mental disorders amongst children, affecting an estimated 3% to 5% of the population (Michalopoulou et al., 2023). It represents persistent hurdles in understanding fundamental math concepts and arithmetic, hindering math proficiency and effective learning. The key challenge is to develop a project-based strategy to provide dedicated learning materials to cater individuals with Dyscalculia.

There are several existing technologies meant to address the learning gaps in children with learning disabilities. Augmented reality utilized in platforms that employ a natural user interface leveraging 3D virtual environments and Kinect, it is meant to facilitate experiential learning through experimentation and physical movement. It also offers adaptability by adjusting difficulty levels based on individual player capabilities (Avila-Pesantez et al., 2018). Similarly, some web-based platforms offer an expansive design canvas, enabling students to create larger AR projects with intuitive controls for object manipulation (Mileva, 2021). Developing a solution in the form of mobile computing is viable for enhanced accessibility, transitioning traditional teaching materials into a simulation with the use of augmented reality. However, these only offer a restricted range of activities, and difficulty level, and only utilizes one form of augmented reality.

Considering the aforementioned issues, there is a need to develop a learning environment simulation that utilizes immersive technology, specifically augmented reality, for students with learning disabilities. This strives to provide a personalized and adaptive learning experience within a supportive and engaging environment for students with dyscalculia. Additionally, it aims to contribute to the attainment of quality education (SDG 4: Quality Education), guaranteeing inclusive and accessible special education that addresses the unique needs of individuals with disabilities and special requirements.

1.2 The Client

The special educators in the Antipolo City SPED Center use various ways to modify the delivery of the K-12 curriculum to educate their students with special needs. The client-expert of this project, Mrs. Gemma Picardal, is a SPED teacher III at the Antipolo City SPED Center, who also has a Masters of Arts in Education Major in Special Education.

Figure 1-1 School Logo

The difficulties encountered are caused by the constant need of modifications in the teaching materials, along with the repetitive style of teaching students with disabilities. In an interview conducted, Mrs. Picardal stated that they require an enhanced learning and teaching experience for the students with disabilities, especially to lessen the repetitive teaching and constant monitoring of the students. The client originally requests a gamified application, however, the team decided to create a learning environment simulation that takes advantage of immersive technology.

Table 1-1. Client and Engineering Requirements of the Project

Client Requirements	Engineering Requirements
The system should be affordable.	The total cost of the system should not exceed **PHP 20,000.**
The system should efficiently run on computer units.	The system should not exceed **10GB** storage consumption.
The system should be accessible during classes.	The system should be operational for **at least 8 hours**.

>

1.3 The Project

A system that simulates a learning environment that enhances mathematical reasoning and grasping arithmetic concepts for students with dyscalculia. The system will be running on a network architecture and use augmented reality to deliver the content that will be created by the team and approved by the client based on the given curriculum.

The network architecture is the physical and functional connection of the system that will be implemented to meet the accessibility needs of the client. The architecture will determine the limitations and capabilities that the system can handle. It is important to have the proper design to accommodate the resources needed for the simulation.

Augmented reality is the superimposition of digital information on the physical world. The technology is currently being used in many applications such as in manufacturing, healthcare and education in particular. The use of augmented reality in education creates an engaging and interactive learning experience for the learners. Implementing augmented reality to the project will help in enhancing the learning environment simulation that will be created for the special learners. The type of augmented reality will also determine the extent to which the learners can interact with simulation.

The simulation system will provide special learners with interactive learning activities that mimic real-world applications of mathematics specifically designed to address challenges they face when studying. Difficulty levels will be implemented in the simulations so that the special learners can choose the appropriate challenges for their skill level. Additionally, progress tracking will be implemented in the system so that the special educators can gather relevant information that will help in determining the level of knowledge of the special learners.

1.4 Project Objectives

The general objective of the project is to develop a system that enhances the learning process of special learners with dyscalculia in solving worded math problems by creating a game-based learning simulation using augmented reality. It must meet the needs of the client in compliance with engineering and other relevant standards, while taking into consideration the constraints including economic, efficiency, performance, environmental, safety, public health, social, global, and cultural along with computation of trade-offs from selected constraints.

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1.5 Scope and Delimitation

The project focuses on developing an augmented reality (AR)-driven system specifically tailored to enable the math learning process and experience of special learners with dyscalculia through simulated learning environments. The primary end-users of the project are the special learners with dyscalculia and will not cover other disabilities due to the level of personalization required for each type of disability.

The AR-driven system delivers an interactive, gamified learning experience that adheres to requirements based on ISO/IEC 18039:2019 for AR systems used in computer graphics and image processing.

Additionally, it will adhere to ISO/IEC DIS 5927, the standard for Augmented and Virtual Reality Safety. The ISO/IEC/IEEE 12207 Software life cycle processes that provide a framework that can be applied for testing scenarios, and ISO/IEC/IEEE 29119 for Software Testing which includes the processes, documentation, and techniques. These AR testing standards will ensure that the AR system meets the specific needs of special learners with dyscalculia and is effective and safe to use. This system only covers worded problems related to addition and subtraction.

1.6 Design Constraints

Several constraints were considered when planning the project, and these constraints limit the system's technological features while also aiding in the refinement of design possibilities during development. However, only the first three limitations were applied in the project's development process because the remaining constraints had no direct impact on the project.

Economic (Development Costs)
The economic constraint pertains to the monetary requirements for the overall cost of the project. Development Cost refers to the expenses associated with the system’s development. Factors that may contribute to development costs are specialized software or hardware required in creating the design as well as the hiring of experts to validate the created design. The less development cost value that the design requires, the more economical the design. Therefore, the design with the lowest developmental cost is considered the best design (GAO-20-195G, 2020)

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Cultural
People do certain things, which are prescriptive cultural constraints, or they do not do certain things, which are also prescriptive cultural constraints. It affects the choices people make and how the person, or self, is formed. None of the designs have an impact on culture.

1.7 Software Design and Engineering Standards

The engineering standards serve as the foundation for the overall design and functionality of the project. To ensure that all specifications and requirements are carried out in compliance with these standards, the project adheres to the following guidelines:

ISO/IEC 24775-7:2021 Information technology - Augmented reality (AR) - Part 7: Requirements for AR systems used in education and training
This standard specifies requirements for augmented reality (AR) systems used in education and training. It covers a range of topics including functionality, usability, accessibility, performance, reliability and security. This standard was used to ensure that AR systems used in education and training meet the needs of learners and educators, and that they are safe and effective.

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ISO/IEC/IEEE 12207:2017 System and software engineering - Software life cycle processes

The standard specifies a life cycle model and it defines software development processes to ensure that software is developed and maintained in a responsible and consistent manner. The processes include planning, implementation, assessment and maintenance. The standard was used to ensure the augmented reality learning environment system is developed and maintained in a robust and reliable manner. Specifically, the standard has requirements for planning, which include requirements management, project planning and project monitor and control and these are essential to ensure the successful development of the system.

ISO/IEC/IEEE 29119:2022 Software and system engineering - Software testing

The standard provides a comprehensive process model for software testing that covers the planning, design, execution and reporting of software testing. And specifies testing processes, documentation and techniques for both functional and non-functional software testing. The standard was used to ensure the software testing process follows a structured and comprehensive approach. Leading to a higher quality software that meets client’s requirements and expectations.

1.8 Engineering Design Process

The engineering design process offers engineers a set of rules for addressing and resolving difficulties. It is an iterative approach that allows engineers to repeat processes as needed, resulting in continual improvement. Users of this approach can discover new possibilities by learning from failures, allowing them to arrive at unique and successful solutions. The iterative nature of the design process supports growth and motivates engineers to push boundaries, resulting in the development of exceptional solutions. (TeachEngineering, 2023).

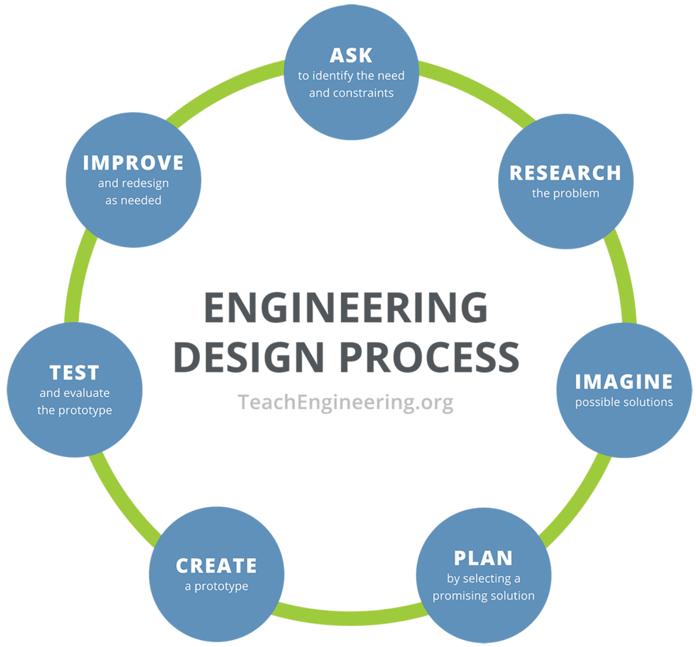

Figure 1.2 The Engineering Design Process (TeachEngineering, 2023)

Figure 1.2 depicts the seven engineering design process steps for project development. The steps strengthen the understanding of the open-ended design and emphasize creativity and practicality (TeachEngineering, 2023). Detailed explanations of each step in the Engineering Design Processes are discussed in this section.

1.8.1 Ask: Identify The Needs and Constraints

To identify the needs and constraints, the team shared different types of ideas that are related to issues that are in the Philippines. It is important to identify the sectors where problems arise in order for solutions to be created and deployed. In the Philippines, there has been an increasing concern in the areas of agriculture, healthcare, transportation, education, etc. The sector that we have determined to give attention to is the education sector, specifically the special education sector where development in the Philippines has been minimal. We have conducted an interview with a special education teacher, Mrs. Gemma Picardal, at the SPED Center Antipolo to further identify the needs and constraints that are within the sector. The existing problems we have identified were the repetitive nature of teaching the Intellectually Disabled and the time consuming process of catering the curriculum to the specific disability of the SPED student. One of the proposed solutions that was said during the interview was a gamification of the curriculum catered to the Intellectually Disabled. Another existing problem we identified is the difficulty special learners with dyscalculia face in solving mathematical problems so the team also proposed to develop an augmented reality (AR) learning environment tailored to the special learners with dyscalculia. The AR learning environment will have mathematical concepts including basic arithmetic, geometry and other topics customized to the specific needs of special learners with dyscalculia.

1.8.2 Research the Problem

After identifying the needs and constraints of the client, the problems discovered are researched further to discover the areas where solutions could be created. The process of research will help in collecting a body of knowledge that will guide the team in determining the steps that should be taken to make the design. There were minimal studies that are related to the design but through inference from multiple related studies and information gathered from the client, the existing problem of the difficulty of special learners with dyscalculia to solve mathematical problems was expounded. More consultations with the client and adviser of the team, as well as research, were conducted to create a feasible solution.

1.8.3 Imagine: Develop a Possible Solution

The proposed solution is to develop an augmented reality (AR) learning environment suited for special learners with dyscalculia. In this phase, the information gathered from the previous step will be used to create the different designs that will solve the identified problem. The chosen design should be able to meet the requirements of the client and engineering standards of the project.

1.8.4 Plan: Select a Promising Solution

After developing for possible solutions, the team assessed each design based on its feasibility, alignment with client requirements and compliance to engineering standards. The development of an augmented reality (AR) learning environment turns up as the most promising solution due to its potential to address the identified problems effectively. This solution is considered suitable for enhancing the learning experience of students with dyscalculia

1.8.5 Create: Build a Prototype

With the selected solution in mind, the team proceeded to develop a prototype of the augmented reality (AR) learning environment. This involved the choosing for the best design from the three design options namely marker-based using mobile computing, markerless using edge computing, and projection-based using cloud computing in order to deliver an interactive learning environment that suited the needs of special learners with dyscalculia.

1.8.6 Test and Evaluate Prototype

The prototype undergoes rigorous testing to assess its effectiveness in improving the mathematical abilities of special learners with dyscalculia. The accuracy of problem-solving, the time taken to complete tasks, and the level of engagement are used to measure effectiveness. We utilize the metric of measuring the accuracy of problems solved by special learners to assess their performance and comprehension, to determine the effectiveness of our prototype in aiding their improvement. Additionally, user outcome, client feedback and expert evaluations are collected for further refinement.

1.8.7 Improve: Redesign as Needed

The design will undergo iterative refinement based on the outcome of user testing, client feedback, and expert evaluations. This may involve adjustments to the difficulty levels, interface enhancements, or modifications to address specific user needs. The ultimate goal is to develop an AR learning environment simulation system that is as effective and user-friendly as possible.

CHAPTER 2: PROJECT DESIGN

The project's design establishes its viability and effectiveness. This covers the discussion of three designs focusing on design description, system flowchart, illustrative diagram, system algorithm, data flow diagram, design standard, and design constraint. It also includes algorithms, training and validation, datasets, web application, mobile application, hardware design, schematic diagram, illustrative diagram, and hardware cost.

2.1 Description of the Design Solution

2.1.1 Design Description

The three alternative designs of the project revolve around creating an augmented reality-based learning environment simulation system for learners with dyscalculia. Each design will use a different type of augmented reality, specifically Marker-based, Markerless and Location-based AR. The designs consist of a hardware, software, algorithm and application component that meets the objectives and considers the constraints of the project to create the solution producing the required outputs.

The hardware component of the designs will be a mobile device, specifically the sensors that are built-in mobile devices in order to gather the positional information required in deploying the virtual objects. The sensors in particular that will be used depending on the type of AR are the camera, accelerometer, barometer, gyroscope and global positioning system (GPS).

The software component of the designs will be developed using the Vuforia Engine in Unity that specializes in augmented reality development. This means that the main programming language that will be used is C# for all of the designs.

The algorithm components that will be used in the designs that are required in rendering the virtual objects are already included in the vuforia library, an example would be the Visual-Inertial Simultaneous Localization And Mapping (VISLAM) that combines the benefits of Visual-Inertial Odometry (VIO) and Simultaneous Localization And Mapping (SLAM).

The application component of the designs will be created based on the MERN stack, specifically the React Native MERN stack for mobile application development, for monitoring the progress of the users.

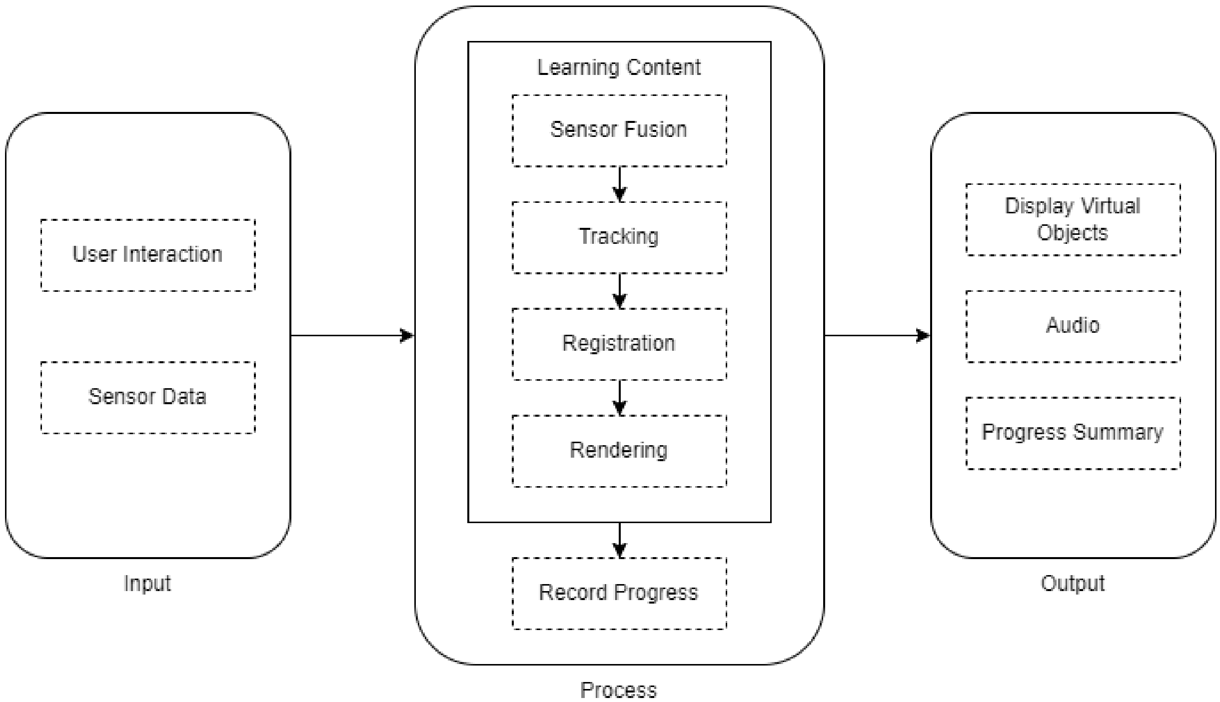

Figure 2-1 General Input-Process-Output (IPO) Diagram of Designs

2.1.2 Engineering Principles Involved

Augmented Reality

Augmented Reality (AR) integrates computer-generated virtual information, such as text, images, 3D models, music, and video, into the real world through simulation, creating a complementary relationship between the two types of information to enhance the real-world experience. AR offers users an enriched reality, incorporating 3D visual effects, sounds, and other sensory stimuli to provide an altered and immersive version of reality (Chen et al., 2019).

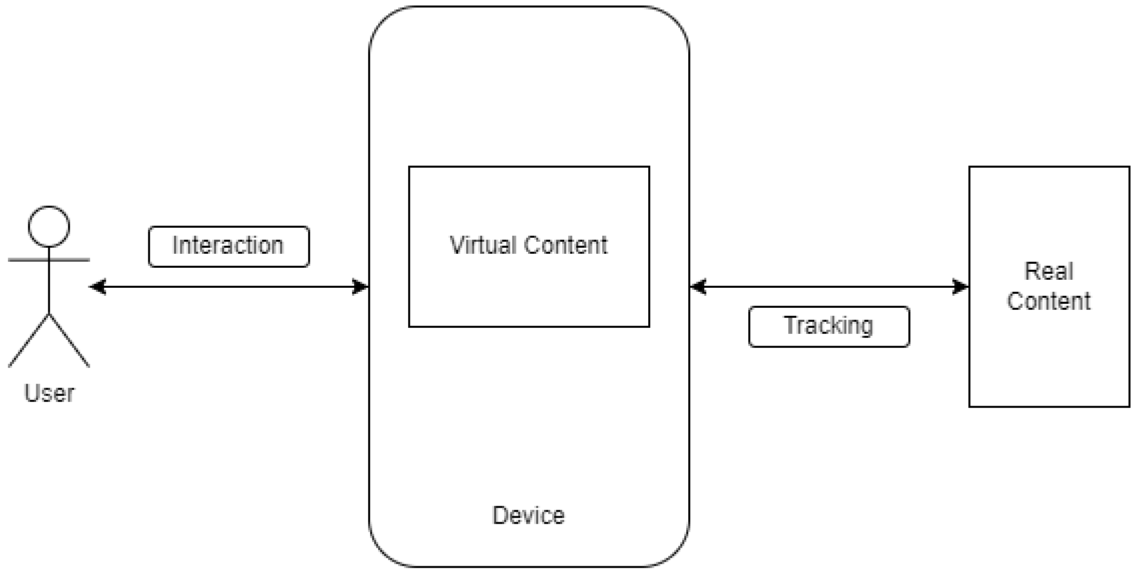

Figure 2-2 AR Architecture

Camera

A camera serves as a tool for capturing and recording images and videos, employing a lens to focus light onto a photosensitive surface for image or video acquisition. Digital cameras utilize light sensors to convert light into digital signals, enabling digital processing and storage. Specialized cameras cater to distinct applications such as medical imaging or surveillance (Steinman et al., 2021). The camera in augmented reality captures real-world images for integration with virtual objects, creating an augmented environment. It is crucial in AR research for camera-based registration methods, facilitating marker recognition like fiducial markers to locate and track objects in the environment (Makhataeva&Varol, 2020).

Accelerometer

An accelerometer sensor is designed to capture activity readings, enabling the inference of intricate user motions like tilt, swing, or rotation. Embedded in devices such as smartphones or wearables, it measures changes in linear acceleration. The data gathered from accelerometer sensors facilitates the analysis and identification of various physical activities, including walking, jogging, sitting, standing, and navigating stairs (Javed et al., 2020). The accelerometer sensor gauges acceleration across three axes. Within an augmented reality (AR) application, utilizing the accelerometer enhances the natural feel of children interacting with virtual objects in the AR scene. This immersive learning environment captivates children’s attention, fostering increased focus in the classroom. The accelerometer’s role in AR applications enables children to engage with virtual objects through actions like touching, shaking, or detecting motion within AR scenes (Yusof et al., 2020).

Gyroscope

A gyroscope sensor, commonly present in smartphones, gauges the rate of rotation or angular velocity across three axes: x, y, and z. As the device undergoes rotations or twisting along any of these axes, the gyroscope detects and registers the corresponding movement. This sensor enables the detection of parameters such as the rotation direction, angle, and vibration (Nuwantoro et al., 2020). In augmented reality, the gyroscope directs the player’s in-game movement based on the smartphone’s orientation.

Consequently, the player's position and movements in the physical world directly influence the game, enhancing immersion and engagement. This distinctive feature contributes to a more interactive and captivating gameplay experience (Yulianto et al., 2020).

Global Positioning System (GPS)
The Global Positioning System is a satellite-based navigation system designed by the US Department of Defense for military purposes. Today, it finds widespread civilian applications, including personal navigation devices, tracking systems, precisions agriculture, and surveying. Utilizing signals transmitted between satellites and ground-based GPS receivers, it calculates receiver locations based on their distances from the satellites. However, GPS effectiveness is limited in indoor environments where line-of-sight with orbiting satellites is compromised (Kunkoth et al., 2020). In augmented reality, GPS is employed by location-based applications to enable location tracking, facilitating a markerless AR approach. This involves combining GPS with computer vision algorithms for enhanced functionality (Hurst et al., 2021).

Unity
Unity, a user-friendly and cost-free game engine, is adept at crafting augmented reality (AR) applications, facilitating the development of interactive AR animations and experiences. Its capabilities in handling AR features make it a valuable tool for developers. Furthermore, Unity, in conjunction with Vuforia, is employed for the creation of 3D assets (Desierto et al., 2020).

Vuforia Engine
The vuforia engine, a software development kit (SDK), empowers developers to craft augmented reality (AR) applications for mobile devices, employing advanced computer vision technology to recognize and capture images, surfaces, or physical 3D objects in real-time. By utilizing the device's camera, the engine allows developers to position virtual information dynamically and calculate its alignment with the lens. Vuforia proves crucial in object recognition technology, effectively addressing diverse challenges and finding successful applications in fields like manufacturing, education, and training, enriching learning experiences by seamlessly integrating virtual information with the real world (Hameed et al., 2022).

Visual-Inertial Odometry (VIO)
Visual-inertial odometry is a technology that combines visual information from a camera with data from an inertial measurement unit (IMU) to calculate the camera's motion in 3D space. This technology estimates the position and orientation of a moving camera by utilizing visual features from its image and the accelerations and rotational velocities measured by the IMU. Widely applied in SLAM applications, VIO is instrumental in addressing challenges like initialization and drift SLAM systems (Piao & Kim, 2019).

Simultaneous Localization And Mapping (SLAM)
SLAM is a technology enabling a robot to simultaneously create a map of an unfamiliar environment and determine its position based on that map. This capability allows robots to navigate accurately without the need for an external positioning system, making it valuable in the field of robotics (Alsadik, B., & Karam, S., 2021).

Visual-Inertial Simultaneous Localization And Mapping (VISLAM)
The visual-inertial simultaneous localization and mapping (SLAM) system integrates multisensor data, ensuring globally consistent trajectory tracking and mapping. High-quality lines, acting as primitives within the SLAM problem's scene structures, offer additional constraints for accurate camera pose estimation.

This study focuses on designing a pipeline for a dynamically fused point-line visual-inertial navigation system (VINS) (Xia et al., 2022).

Mobile Application Development Framework

The React Native MERN stack is a technology combination for full-stack web and mobile app development, featuring MongoDB for data storage, Express.js for the server, React Native for cross-platform mobile UIs, and Node.js for server-side logic. This stack enables developers to build scalable, efficient applications with a unified codebase, leveraging React Native for native-like cross-platform experiences and Node.js for scalable server-side operations. This approach supports the creation of modern applications with features such as real-time data updates and push notifications (Awasthi, 2022).

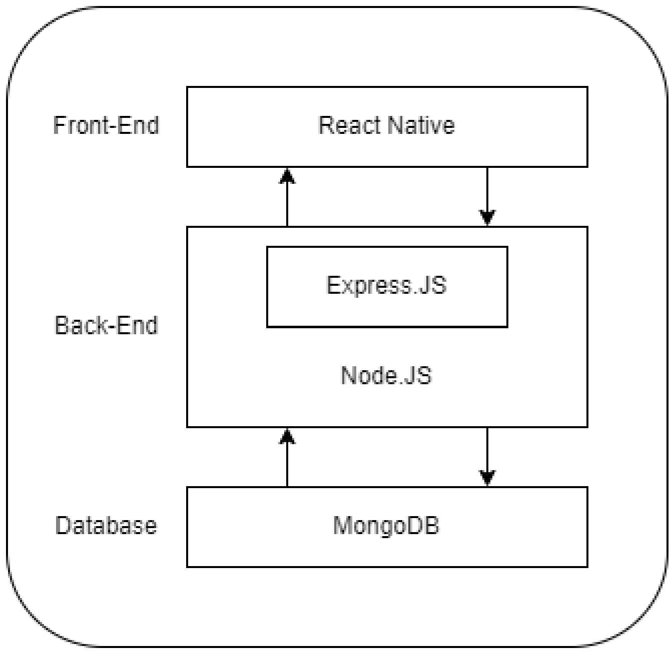

Figure 2-3 React Native MERN Stack Architecture

In figure 2-3, the React native MERN stack architecture is visualized. Within the React Native MERN stack architecture, React Native is responsible for managing the front-end of the mobile application, while Express.js and Node.js oversee the server-side logic. MongoDB is employed as the database for data storage and retrieval. This architectural setup facilitates the creation of a comprehensive mobile application using a cohesive JavaScript stack, providing benefits such as code reusability and a uniform development experience across various platforms.

2.1.3 Prior Arts Analysis

Discusses the existing solutions, patents, projects already done, and compares it with the design project.
Features of existing solutions that are particularly of interest should be discussed.
Matrix Format is preferred, in addition to narratives.

Table 2-1 Prior Art Analysis Matrix

Designs	Features

	Progress Monitoring	Mobile Integration	3D Virtual Objects Rendering	Difficulty Levels of Content
ATHYNOS: Design of an Augmented Reality Serious Game for Children with Dyscalculia	☑	☐	☐	☑
AR Book: Books & Magic's The Little Mermaid	☐	☑	☑	☐
Nestor: In-Place Augmented Reality 3D Sketching	☐	☑	☑	☐
CultureClic: Augmented Culture on Mobile	☐	☑	☐	☐
PROJECT	☑	☑	☑	☑

Explain this table.
In this table, we compare our project to four existing augmented reality solutions for dyscalculia: ATHYNOS, AR book, Nestor and CultureClic. We compare the project based on the following features: Progress monitoring, Mobile Integration, 3D virtual objects rendering and difficulty levels of content. As you can see, our project is the most comprehensive of the five projects. It includes all of the features that make it a more versatile and effective solution for individuals with dyscalculia.

2.1.4 Standards Involved in the Design

This section presents the standards followed by the design, including their references.
Matrix may be used to show how standards are used in each specific design.

Table 2-2

Standard	Brief Description	DESIGNS		
		Marker-Based	Markerless	Location-Based

IEC 60950	Product Safety Standard for electronic and computing products.	Used in enclosure, power supply leakage, ESD, wiring, and connectors.	Used in enclosure, power supply leakage, ESD, wiring, and connectors.	Used in enclosure, power supply leakage, ESD, wiring, and connectors.
Philippine National Standards for Drinking Water (PNSDW)	Standards for drinking-water quality, water sampling and examination and evaluation.	Used in conditional statements to determine if water is drinkable.	Used in conditional statements to determine if water is drinkable.	Used in conditional statements to determine if water is drinkable.
IEEE 1309-2013	Standard for Calibration of Electromagnetic Field Sensors and Probes	NA	NA	Calibration of sensor used in detecting heavy metals.
IEEE 1858-2016	IEEE Standard for Camera Phone Image Quality	Reference for image processing camera.	NA	NA

Explain this table and end with a summary.
>

2.2 General System Architecture
This section does NOT cover definitions of the architectural elements. (that was already done earlier) Rather, this section talks about HOW the engineering concepts/elements were implemented.

2.2.1 Hardware Elements
2.2.1.1 Hardware Design
>

2.2.1.2 Physical / Mechanical Components
>

2.2.2 Software Elements
2.2.2.1 Embedded Software
>

2.2.2.2 Application Software
>

2.2.2.3 Key Algorithms Used

>

2.3 Design Alternatives

2.3.1 Rationale for Design Alternatives

In order to meet the client requirements and project objectives, it is important the three designs would focus on the type of augmented reality that will deliver the content. The type of augmented reality is important to consider because each type offers different kinds of interactiveness and differs in how the virtual objects are deployed. The hardware and software requirements also differ in each type of augmented reality. The design alternatives matter because:

- marker-based AR requires the least amount of resources when it comes to sensors but needs a physical anchor to work;
- markerless AR doesn't require any physical anchors but heavily relies on multiple sensors to properly deploy virtual objects;
- location-based AR is similar to markerless but focuses more on longitudinal and latitudinal data to interact with users

2.3.2 Design Constraints

The best design of the system is determined by comparing and measuring the constraints of each alternate design of the project. The selected constraints are Economic (Development Costs), Efficiency (Application Size), Performance (Response Time), Environmental (Storage Consumption), and Safety (Frames Per Second).

2.3.2.1 Economic (Development Costs)

The economic constraint refers to the required financial resources of the designs. To measure the development costs of each design, the expenses are compiled and summed up.

2.3.2.2 Efficiency (Application Size)

The efficiency constraint refers to the effectiveness of the designs to properly utilize resources. To measure the application size of each design, the properties of the compiled files and dependencies can be checked.

2.3.2.3 Performance (Response Time)

The performance constraint refers to the ability of the system to process and compute data. To measure the response time of each design, the recording and playback feature of the Vuforia Engine will be used to gather required data needed to get the response time.

2.3.2.4 Environmental (Storage Consumption)

The environmental constraint refers to the computational space where the system will run. To measure the storage consumption of each design, a benchmark will be conducted to gather the average resources used within a specific amount of time.

2.3.2.5 Safety (Frames Per Second)

The safety constraint refers to the ability of the system to consistently provide frames smoothly to avoid disorienting users. To measure the frames per second of each design, the recording and playback feature of the Vuforia Engine will be used to gather the frame rate data while running.

2.3.3 Design Alternatives
2.3.3.1 Design 1: Marker-based AR
2.3.3.1.1 Engineering Principle of Alternative
Marker-based AR

Marker-based augmented reality is a form of AR technology that utilizes predetermined visual markers, such as QR codes or other specific markers, to integrate virtual objects or content into the real world. Initially, the system employs computer vision techniques to detect and track these markers, subsequently leveraging this information to ascertain the position and orientation of the virtual content. This technology is particularly well-suited for tasks like space management and room measurements, employing 2D pictures, QR coded, or 3D objects as markers to anchor the position of virtual objects (Boonbrahm et al., 2020).

2.3.3.1.2 Architecture of Design Alternative
>

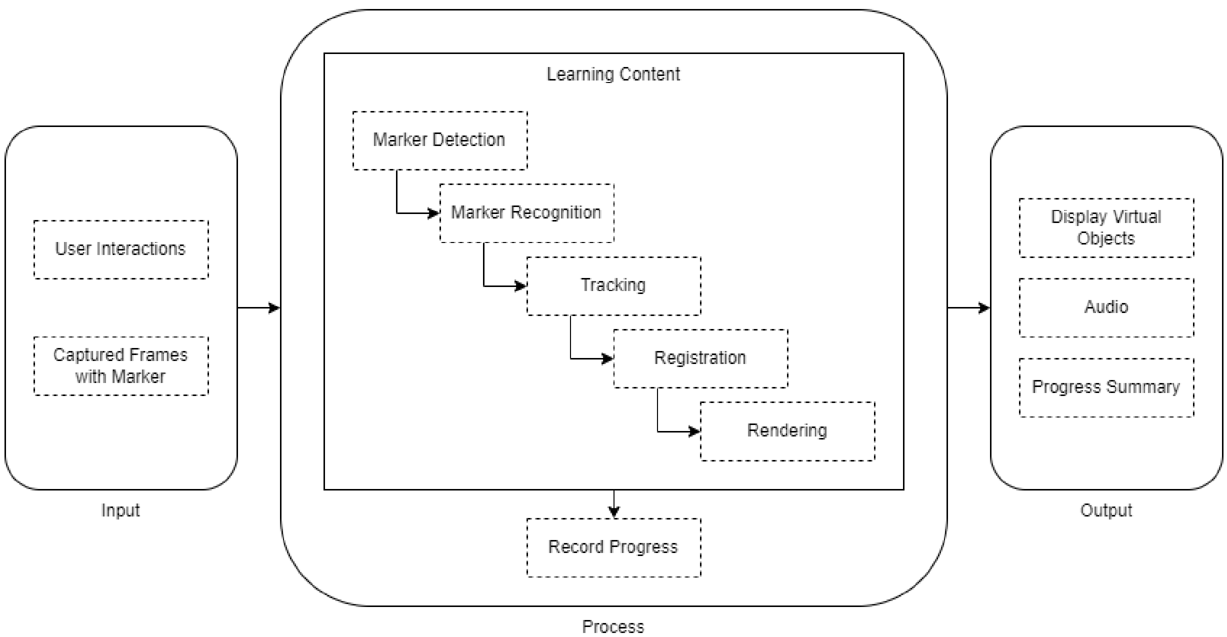

Figure 2-4 Marker-based AR IPO Diagram

>

2.3.3.1.3 Evaluation of Constraints
2.3.3.1.3.1 Economic

Development Costs	

2.3.3.1.3.2 Efficiency

Application Size	

2.3.3.1.3.3 Performance

Response Time	

2.3.3.1.3.4 Environmental

Storage Consumption	

2.3.3.1.3.5 Safety

Frames Per Second	

2.3.3.2 Design 2: Markerless AR
2.3.3.2.1 Engineering Principle of Alternative
Markerless AR

Markerless augmented reality integrates virtual objects into the real world without relying on specific visual markers or image targets. Instead, it employs Simultaneous Location and Mapping (SLAM) to detect the environment and identify suitable surfaces for virtual object placement. Unity 3D is utilized for markerless AR, utilizing the ground plane stage, resembling a green mesh, for the deployment of necessary virtual objects (Pooja et al., 2020).

2.3.3.2.2 Architecture of Design Alternative
>

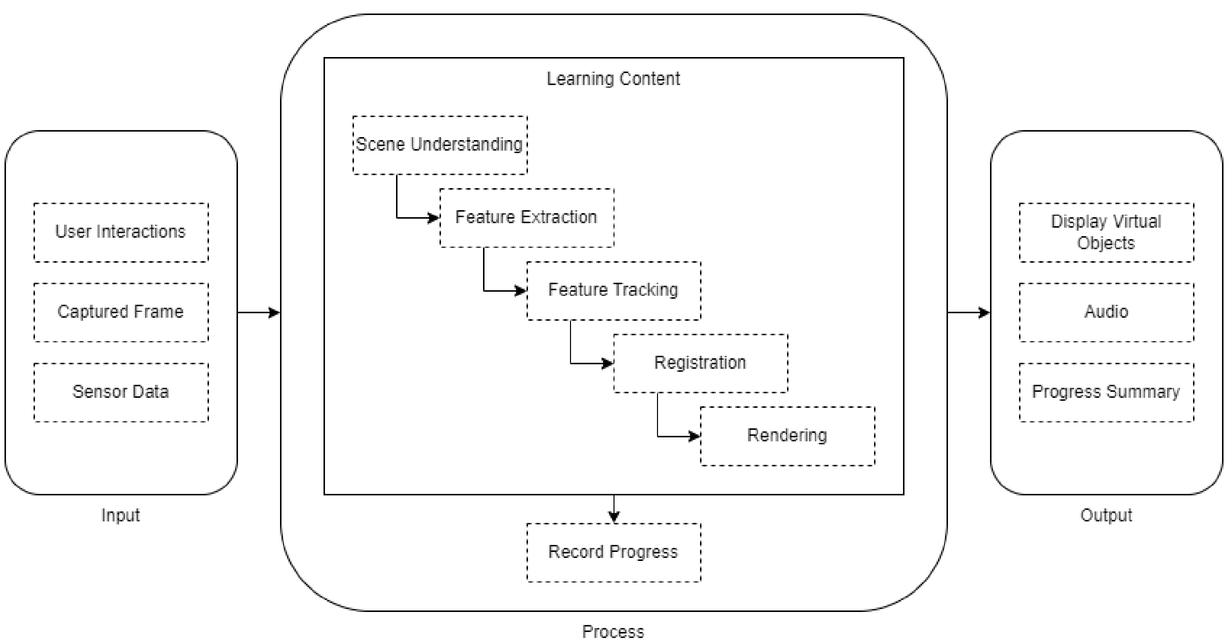

Figure 2-5 Markerless AR IPO Diagram

>

2.3.3.2.3 Evaluation of Constraints

2.3.3.2.3.1 Economic

Development Costs	

2.3.3.2.3.2 Efficiency

Application Size	

2.3.3.2.3.3 Performance

Response Time	

2.3.3.2.3.4 Environmental

Storage Consumption	

2.3.3.2.3.5 Safety

Frames Per Second	

2.3.3.3 Design 3: Location-based AR

2.3.3.3.1 Engineering Principle of Alternative

Location-based AR

Location-based augmented reality (AR) is a technology aiming to connect physical location coordinates with data processing environments, allowing users to view Point of Interest (POI) annotations for specific landmarks in the real world. This technology overlays the actual surroundings with virtually generated data, including graphics, text, video, and sound, enhancing and complementing reality. It provides an immersive capability for users to access content information, navigate, communicate, and transform their interaction with the environment (Brata & Liang, 2019).

2.3.3.3.2 Architecture of Design Alternative

>

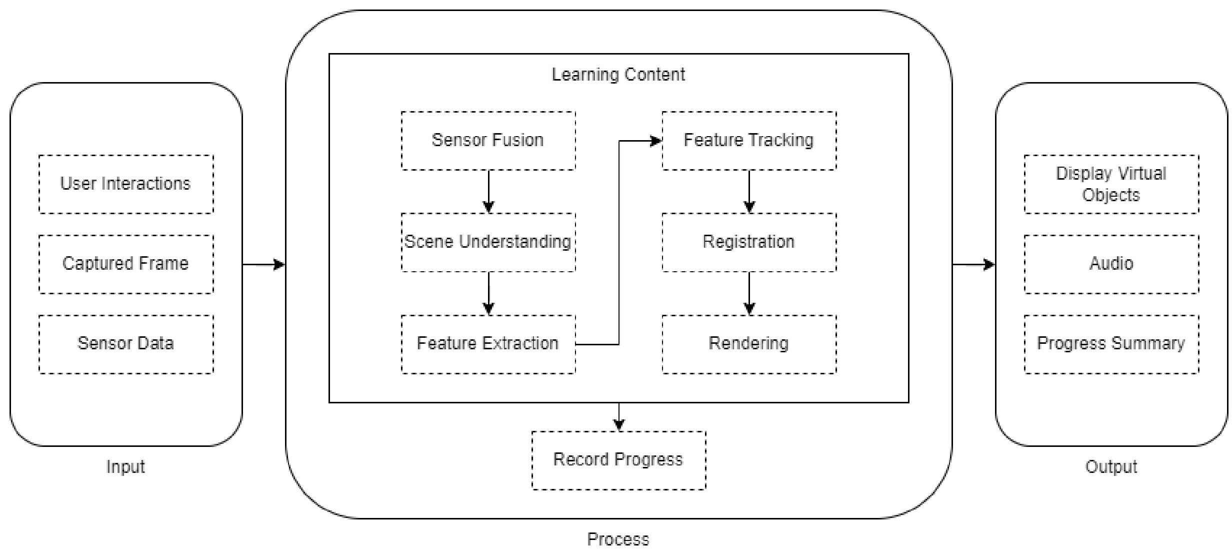

Figure 2-6 Location-based AR IPO Diagram

Explain Diagram

>

2.3.3.3.3 Evaluation of Constraints

2.3.3.3.3.1 Economic

Development Costs	

2.3.3.3.3.2 Efficiency

Application Size	

2.3.3.3.3.3 Performance

Response Time	

2.3.3.3.3.4 Environmental

Storage Consumption	

2.3.3.3.3.5 Safety

Frames Per Second	

2.3.4 Summary of Design Constraints

Introduce the summary.

Table 2-3 Summary of Design Constraints

Designs	Constraints				
	Economic (Development Cost)	Efficiency (Application Size)	Performance (Response Time)	Environmental (Storage Consumption)	Risk (Failure Rate)
Design 1: Marker-based AR					
Design 2: Markerless AR					
Design 3: Location-based AR					

CHAPTER 3: DESIGN TRADEOFFS

The chapter discusses the project's constraints, which are used to present the design trade-offs. A design trade-off is a decision that involves reducing or eliminating one quality, quantity, or feature of a set or design in exchange for improvements in other areas. It is a technique for getting the desired effect by increasing some design features while decreasing others or vice versa. This chapter compares five designs by lowering one attribute while raising others to find the best design that satisfies the client's needs. Each design is constrained by economic, efficiency, functionality, performance, and manufacturability factors. The discussion of sensitivity analysis provides insight to attain the highest rank on the combination of scores of the constraints.

3.1 Summary of Constraints

>

Table 3-1 Summary of Design Constraints

Designs	Constraints				
	Economic (Development Costs)	**Efficiency (Application Size)**	**Performance (Response Time)**	**Environmental (Storage Consumption)**	**Safety (Frames Per Second)**
Design 1: Marker-based AR					
Design 2: Markerless AR					
Design 3: Location-based AR					

>

3.2 Trade-offs

Trade-offs were used to determine which design aspects could be compromised to find the best solution given the various constraints. Trade-off studies are crucial to Decision-Making Analysis and Resolution (DAR). An issue is amenable to a trade-off analysis when it requires a selection between multiple options and that all of them be considered simultaneously (Bahlil & Madni, 2016). It specifies what factors must be considered while selecting the best design. In this chapter, the three designs are evaluated considering the five constraints.

In order to evaluate the three design alternatives for the creation of the design of a needle separator system with a syringe shredder device, Pareto Multi-Criteria Decision Making (MCDM) was utilized to apply the trade off-analysis technique to distinguish compromise designs, which the contending criteria are commonly fulfilled in a Pareto-ideal sense. Every model has been given a scale of 1 to 10, contingent upon its significance. To repeat, the plan, considered the best structure per standard, was given an estimation of 10.

The maximization case is computed by the equation:

$$PC_{norm} = 9\times\frac{PC_{raw}-Min_{raw}}{Max_{raw}-Min_{raw}} + 1 \qquad \text{Equation 3.1}$$

The minimization case is computed by the equation:

$$PC_{norm} = 9\times\frac{Max_{raw}-PC_{raw}}{Max_{raw}-Min_{raw}} + 1 \qquad \text{Equation 3.2}$$

Where:

$$PC_{norm} = Normalized\ Value\ of\ the\ Criteria$$

$$PC_{raw} = Raw\ value\ of\ the\ criteria\ to\ be\ normalized$$

$$Min_{raw} = Smallest\ possible\ value\ of\ the\ criteria\ among\ all\ designs$$

$$Max_{raw} = Largest\ possible\ value\ of\ the\ criteria\ among\ all\ designs$$

After normalizing the values based on the preference of the constraints, it is needed to summarize the result to compute the winning design. The equation to calculate the score of Design 1 is shown below.

$$Score_{d1} = PC_{c1} \times \%_{c1} + PC_{c2} \times \%_{c2} + PC_{c3} \times \%_{c3} \qquad \text{Equation 3.3}$$

Where:

$$Score_{d1} = Score\ of\ the\ Design\ 1$$

$$PC_{c1} = Normalize\ Value\ of\ Criterion\ 1\ for\ the\ design$$

$$\%_{c1} = Percentage\ of\ Importance\ for\ the\ Criterion\ 1\ of\ the\ design$$

$$PC_{c2} = Normalize\ Value\ of\ Criterion\ 2\ for\ the\ design$$

$$\%_{c2} = Percentage\ of\ Importance\ for\ the\ Criterion\ 2\ of\ the\ design$$

$$PC_{c3} = Normalize\ Value\ of\ Criterion\ 3\ for\ the\ design$$

$$\%_{c3} = Percentage\ of\ Importance\ for\ the\ Criterion\ 3\ of\ the\ design$$

The equation to compute the score of Design 2 is shown below.

$$Score_{d2} = PC_{c1} \times \%_{c1} + PC_{c2} \times \%_{c2} + PC_{c3} \times \%_{c3} \qquad \text{Equation 3.4}$$

Where:

$$Score_{d2} = Score\ of\ the\ Design\ 2$$

$$PC_{c1} = Normalize\ Value\ of\ Criterion\ 1\ for\ the\ design$$

$$\%_{c1} = Percentage\ of\ Importance\ for\ the\ Criterion\ 1\ of\ the\ design$$

$$PC_{c2} = Normalize\ Value\ of\ Criterion\ 2\ for\ the\ design$$

$$\%_{c2} = Percentage\ of\ Importance\ for\ the\ Criterion\ 2\ of\ the\ design$$

$$PC_{c3} = Normalize\ Value\ of\ Criterion\ 3\ for\ the\ design$$

$$\%_{c3} = Percentage\ of\ Importance\ for\ the\ Criterion\ 3\ of\ the\ design$$

The equation to compute the score of Design 3 is shown below.

$$Score_{d3} = PC_{c1} \times \%_{c1} + PC_{c2} \times \%_{c2} + PC_{c3} \times \%_{c3} \qquad \text{Equation 3.5}$$

Where:

$$Score_{d3} = Score\ of\ the\ Design\ 3$$

$$PC_{c1} = Normalize\ Value\ of\ Criterion\ 1\ for\ the\ design$$

$$\%_{c1} = Percentage\ of\ Importance\ for\ the\ Criterion\ 1\ of\ the\ design$$

$$PC_{c2} = Normalize\ Value\ of\ Criterion\ 2\ for\ the\ design$$

$$\%_{c2} = Percentage\ of\ Importance\ for\ the\ Criterion\ 2\ of\ the\ design$$

$$PC_{c3} = Normalize\ Value\ of\ Criterion\ 3\ for\ the\ design$$

$$\%_{c3} = Percentage\ of\ Importance\ for\ the\ Criterion\ 3\ of\ the\ design$$

Table 3-2 Preference and Importance of the Constraints

Constraint	Preference	Importance (raw)	% Importance
Economic (Development Costs)	Minimization	6	15.00%
Efficiency (Application Size)	Minimization	8	20.00%
Performance (Response Time)	Minimization	9	22.50%
Environmental (Storage Consumption)	Minimization	7	17.5%
Safety (Frames Per Second)	Maximization	10	25.00%

>

3.3 Analysis of Trade-offs

Analysis of trade-offs assesses the quantifiable characteristics of the designs, measures the important variables, and compares whether the pros of the design outweigh its cons. Through the analysis of trade-offs, each design's assets and liabilities would be laid out to assess which designs trade-offs gain the most while losing the least.

3.3.1 Trade-offs 1:

>

Table 3-3-1-1

Design No.	Design	
1		
2		
3		

>

3.3.1.1 Design 1:
>

3.3.1.2 Design 2:
>

3.3.1.3 Design 3:
>

Table 3-3-1-2:

Design No.	Design	
1		
2		
3		

>

3.3.2 Trade-offs 2:
>

Table 3-3-2-1 Overall Storage Consumption of Each Design

Design No.	Design	
1		
2		
3		

>

3.3.2.1 Design 1:
>

3.3.2.2 Design 2:
>

3.3.2.3 Design 3:
>

Table 3-3-2-2:

Design No.	Design	
1		

2		
3		

>

3.3.3 Trade-offs 3:
>

Table 3-3-3-1:

Design No.	Design	
1		
2		
3		

>

3.3.3.1 Design 1:
>

3.3.3.2 Design 2:
>

3.3.3.3 Design 3:
>

Table 3-3-3-2:

Design No.	Design	
1		
2		
3		

>

3.3.4 Trade-offs 4:
>

Table 3-3-4-1:

Design No.	Design	>
1		

2		
3		

3.3.4.1 Design 1:
>

3.3.4.2 Design 2:
>

3.3.4.3 Design 3:
>

Table 3-3-4-2:

Design No.	Design	
1		
2		
3		

3.3.5 Trade-offs 5:
>

Table 3-3-5-1:

Design No.	Design	
1		
2		
3		

>

3.3.5.1 Design 1:
>

3.3.5.2 Design 2:
>

3.3.5.3 Design 3:
>

Table 3-3-5-2:

Design No.	Design	
1		
2		
3		

3.4 Scoring of the Three (3) Designs

Table 3-4-1 Summary of Normalized Values of the Three Designs

Designs	Constraints				
Design 1: **Marker-based AR**					
Design 2: **Markerless AR**					
Design 3: **Location-based AR**					

Table 3-4-2 Scores of the Three Designs

Design No.	Design	Score
1		
2		
3		

3.5 Designers' Raw Ranking for the Three Designs

Table 3-5 Designers Raw Ranking for the Three Designs

Decision Criteria	Criterion's Importance (On a scale of 0 to 10)	Percentage (%)	Ability to satisfy the criterion (On a scale from 0 to 10)		
			Design 1:	**Design 2:**	**Design 3:**
Economic	6	15.00%			
Efficiency	8	20.00%			
Performance	9	22.50%			
Environmental	7	17.5%			
Safety	10	25.00%			
Total	**40**	**100%**			

3.6 Influence of Design Trade-offs in the Final Design
>

3.7 Sensitivity Analysis
>

3.7.1 First 24 Combination of Criterion's Importance
>

3.8 Summary of Sensitivity Analysis

Image

Figure 3.8 Sensitivity Analysis Results using Radar Graph

References
(Compiled in Gdrive)
Link: https://drive.google.com/drive/folders/1-vLaWWoYaEDbkpPt8-6PBL0NN3SHHBUf?usp=sharing

Appendices