NAVIGUIDE

(3D Indoor Navigation System)

Capstone Project Report

END SEMESTER EVALUATION

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ABSTRACT

The idea of “NAVIGUIDE 3D INDOOR NAVIGATION SYSTEM” stems because GPS cannot be used for indoor navigation because signals from the satellites are scattered and attenuated by walls, roofs and other objects. Other than that, the error range of many GPS chips can be greater than the indoor space itself. Thus, NAVIGUIDE 3D INDOOR NAVIGATION SYSTEM serves as the perfect solution. It has a wide variety of applications as it can be used in hospitals, shopping malls, university campuses, airports, office buildings, museums, amusement parks, zoos etc.

NAVIGUIDE 3D INDOOR NAVIGATION SYSTEM enables users to find their destination location through the shortest path within a desirable time. In this designed system, the user firstly scans the nearby Visual Marker (QR code) and then the available destinations are shown in the drop down menu from which the user selects his/her desired location where he/she wishes to go after that the optimal path is calculated and is displayed in the form of 3D arrows.

DECLARATION

We hereby declare that the design principles and working prototype model of the project entitled "NaviGuide (3D Indoor Navigation System)" is an authentic record of our own work carried out in the Computer Science and Engineering Department, TIET, Patiala, under the guidance of Ms. Anika during 6th and 7th Semester (2020).

Date: 22/12/2020

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Lastly, we would also like to thank our families for their unyielding love and encouragement. They always wanted the best for us and we admire their determination and sacrifice.

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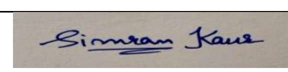
101703547	SIMRAN KAUR	
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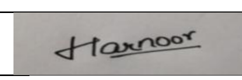
101883048	HARNOOR SANDHU	
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ABBREVIATION	FULL FORM
DFD	Data Flow Diagram
GPS	Global Positioning System
IPS	Indoor Positioning System
RFID	Radio Frequency Identification

CHAPTER 1: INTRODUCTION

1.1 Project Overview

Technological advances in the past decades have caused a rapid increase in personal locating technologies. The integration of these technologies to smartphones has further made lives easier. The shortest path to any destination is just a few clicks away. Navigation systems today offer greater usability and functionality than ever. The invention of GPS provided a standard protocol for navigation. Due to its cost effectiveness and relative accuracy outdoors, it easily became the best choice for outdoor navigation. However this technology might not be the best choice for Indoor Navigation purposes. Thus, through NaviGuide our aim is to provide a completely new technology which caters to the new challenges at hand by creating a navigation system which is inexpensive as well as produces sufficiently accurate results during indoor navigation.

1.1.1 Technical Terminology

Following are some of the technical terms used throughout the document:

1. **Positioning:** It is defined as the ability of the system to accurately and precisely determine one's location and orientation in a two-dimensional or three-dimensional environment.
2. **Rendering:** It is an image synthesis technique used to generate photorealistic or non photorealistic images from 2 dimensional or 3 dimensional models with the help of computer programs.
3. **Routing:** It is a technique which provides a variety of details regarding the route such as the best route to the destination etc.
4. **Localisation:** It is the technique by which the pointer present in the android application correctly and precisely locates and follows the user inside the building as he/she moves.
5. **Optimal Path:** It is the path from the source to the destination which has the least cost out of all the possible paths.

6. **NavMesh:** It is a class in Unity that helps to understand the spatial relationship between various key points in a map and is used to perform walkability tests.
7. **Unit Testing:** It is a type of testing in software engineering where we check individual modules to make sure they work correctly.
8. **System Integration Testing:** It is a type of testing in software engineering where we check the interconnected working of all the modules to make sure that all the modules, when integrated work perfectly.

1.1.2 Problem Statement

The global positioning system (GPS) has significantly impacted our lives by thoroughly simplifying the problem of navigation and location finding. However, the same system fails when implemented inside a building. The signals from the satellites get scattered and are attenuated by the building walls, roofs and other objects present inside it. Besides this, the results produced by a GPS device indoor may sometimes produce errors that are larger than the total indoor space itself.

1.1.3 Goal

Research into indoor positioning systems has identified some possible technologies, but none of these has been developed and distributed to consumers. Our focus through this capstone project is to propose a solution which provides users with an application that is accurate, easy to use and cost efficient. Thus through NaviGuide (3D Indoor Navigation System), our goal is to solve the existing problems faced by the global positioning system (GPS) indoors.

Some of the existing problems that we aim to solve through this project are:

- Finding the user’s current location within a building.
- Computing the optimal path from the user’s present location to the chosen destination.
- Guiding the user to the destination through the optimal path via the means of 3D pointers created using Augmented Reality.

1.1.4 Solution

Considering the problems/shortcomings in the existing indoor positioning systems, we aim to provide a system called ‘NaviGuide: A 3D Indoor Navigation System’ which is intended to provide the user’s with a real-time indoor positioning system in a 3D Augmented Reality Environment. This indoor navigation system combines the features of a GPS system with precision by making use of sensory information from automated devices. The system deals with navigation within the building, by precisely locating an individual within the building and guiding him/her through the building to their desired destination by making use of optimal paths. The optimal path so detected is formulated with the help of an optimization algorithm. This optimal path detected is rendered in an augmented environment which helps to guide the user through the path with the help of 3D arrows. All the user has to do is scan a QR code and select his/her desired destination. The application takes care of the rest.

This technique helps the user achieve his/her destination with reasonable accuracy. Since all the system requires to function are QR codes to scan which can be easily printed on paper, the system is fairly inexpensive and easy to use.

Thus, the proposed 3D indoor navigation system aims to provide nearly accurate navigation solutions to the user for indoor navigation through augmented and virtual reality techniques which may be further used in various domains of life.

1.2 Need Analysis

The Indoor navigation system can be used in many different applications. Besides using an indoor navigation system for finding destinations by people it can also be used by facilities coordinators and building managers. Indoor navigation system saves lots of time and money. It also helps impaired people. Following are some applications where an indoor navigation system can be used-

- **Hospitals:**

  Indoor navigation system can play a very important role in hospitals. In hospitals it can be used by doctors, patients, employees and visitors to find their destinations. In large hospitals it is always a problem to find destinations especially in a stressful or time-sensitive situation to overcome this type of problem an indoor navigation system can be useful.

- **Shopping malls:**

In order to find a particular store in shopping malls, an indoor navigation system can be used. It can also help customers to find a particular product in a large store. Indoor navigation system can also be used for marketing. For example, if a person passes by a particular store he/she will receive advertisement directly on their phone about that store.

- **University campuses:**

New students often face the problem of finding class rooms, labs in a university. For better campus experience for staff, students, visitors, an indoor navigation system can be used in order to find classes, labs, hostels, teachers cabin, library, auditorium and other locations within universities. Universities environment is changing rapidly. For example, meeting rooms are changed to classrooms and new buildings are added in the university. It will be very costly to create a new university map each time a change is made. Hence, the need for an indoor navigation system was found so that the map can be changed easily.

- **Airports:**

People often get lost in large airports because of that they get late for the flight. In order to reduce the risk of delays passengers can use indoor navigation system for finding the right gate on time. Other than gates indoor navigation system also helps passengers to find eating spots, restrooms, baggage claims etc. Indoor navigation system also provides information about flight timings, if they are on time or not etc.

- **Office buildings:**

Conference rooms, desks and restrooms can be found easily using indoor navigation system in offices. Other than finding places printers and tools can also be found using this system. System also tells if a conference room is empty or not.

1.3 Research Gaps

Research is the crucial and integral part of any system development. Research in the right direction is extremely important as it leads to right problem identification and hence crisp problem definition. The research can be carried out through different ways like literature survey, web exploration; existing systems review and so on. While going through the associated literature, the following research gaps were identified:

- The existing systems within the literature are not guiding the user through 3D arrows with the precision and accuracy of the proposed system.
- Most of the systems were built using beacons which are very expensive.
- Most of the systems were built on outdated technologies, without taking into consideration the scalability of the system.

1.4 Problem Definition and Scope

The global positioning system (GPS) has significantly impacted our lives by thoroughly simplifying the problem of navigation and location finding. However, the same system fails when implemented inside a building. The signals front the satellites get scattered and are attenuated by the building walls, roofs and other objects present inside it. Besides this, the results produced by a GPS device indoor may sometimes produce errors that are larger than the total indoor space itself. Thus through NaviGuide (3D Indoor Navigation System), our aim is to solve the existing problems faced by the global positioning system (GPS) indoors.

Some of the existing problems that we aim to solve through this project are:

- Finding the user's current location within a building.
- Computing the optimal path from the user's present location to the chosen destination.
- Guiding the user to the destination through the optimal path via the means of 3D pointers created using Augmented Reality.
- Guiding the user to the destination through the optimal path via voice commands (left, right, straight).

1.5 Assumptions and Constraints

Assumption and Constraints kept in mind while developing the proposed system are shown in Table 1 and Table 2 respectively.

Table 1: Assumptions under which the proposed indoor navigation system is developed

S. No.	Assumptions
1	It is assumed that the place where our navigation system shall be implemented has a strong Wi-Fi signal.
2	Our assumption about our indoor navigation system is that it shall always be used on mobile phones containing Android operating systems. The smart phones must be Wi-Fi enabled, as it is needed to extract the location of the user.
3	For scanning the visual markers, the mobile phones must either have a QR code scanner natively, or a third party QR code reader must be installed.

Table 2: Constraints under which the proposed indoor navigation system is developed

S. No.	Constraints
1	Our indoor navigation system shall be designed to work on Android smartphones. Since ARCore is supported by Android smartphones running Android 7.0 and later, our application shall be supported by these devices.
2	The indoor navigation system requires a great deal of accuracy because of the closeness of various reference points and destinations. We ideally require a technology that requires zero infrastructure and maintenance and provides an accurate path to the user. But no technology answers all the problems.
3	Due to the limited time frame, our indoor navigation system shall be implemented on a short scale, which can be further extended for the entire campus.

1.6 Standards

- **The ISO/IEC 24730 series:** Issued by the International Organization for Standardization and the International Electro technical Commission, it enables software applications to utilise RTLS (Real Time Locating system) to find systems with RTLS transmitters.
- **Mobile Location Protocol:** Defined by the Open Mobile Alliance Location Working Group, part of the Open Mobile Alliance (OMA), it provides a standard application-level protocol to receive the positions of mobile stations independent to the underlying network technology.

- **IndoorGML Encoding Standard:** Released by Open Geospatial Consortium (OGC), it specifically focuses on modelling of indoor spaces from a navigation point of view and enables a better integration of indoor and outdoor navigations systems as compared to a lot of alternatives.

- **ITU-T F.921 standard:** Developed by a London-based non-profit organisation called Wayfinder and approved by the International Telecommunications Union, it aims to empower visually impaired people through audio based navigation.

1.7 Approved Objectives

The proposed indoor navigation system aims to achieve the following targets by the end of the capstone project:

1. To generate self contained visual markers with cloud linkage.
2. Positioning: To find the current precise location of the user via device shaking.
3. Routing: To redirect the optimal path to destination through voice.
4. Rendering: To generate 3D virtual images.

1.8 Methodology

The proposed indoor navigation system (Figure 1) aims to provide near-optimal paths to any destination chosen by the user from his/her current location. The methodology to be used for the same is as follows.

1. We have designed a map of the building where the system has been implemented. The map includes the basic layout of the building in which the indoor navigation system is to be implemented. This map has been scaled such that 1m equals i unit in Unity.
2. The system will be initiated by scanning a self-contained QR marker at the entry of the building, after which the navigation can begin. After scanning the QR code, the user can choose from a list of destinations.
3. For displaying the path using Augmented Reality, the device needs to know the 3D position of the user. In order to achieve this, ARCore SLAM (Simultaneous Localisation

and Mapping) algorithm is used. The spatial relationship between various keypoints and the device's location is used to find the exact 3D position of the user, which thereafter is used to find the optimal path from start to the destination.

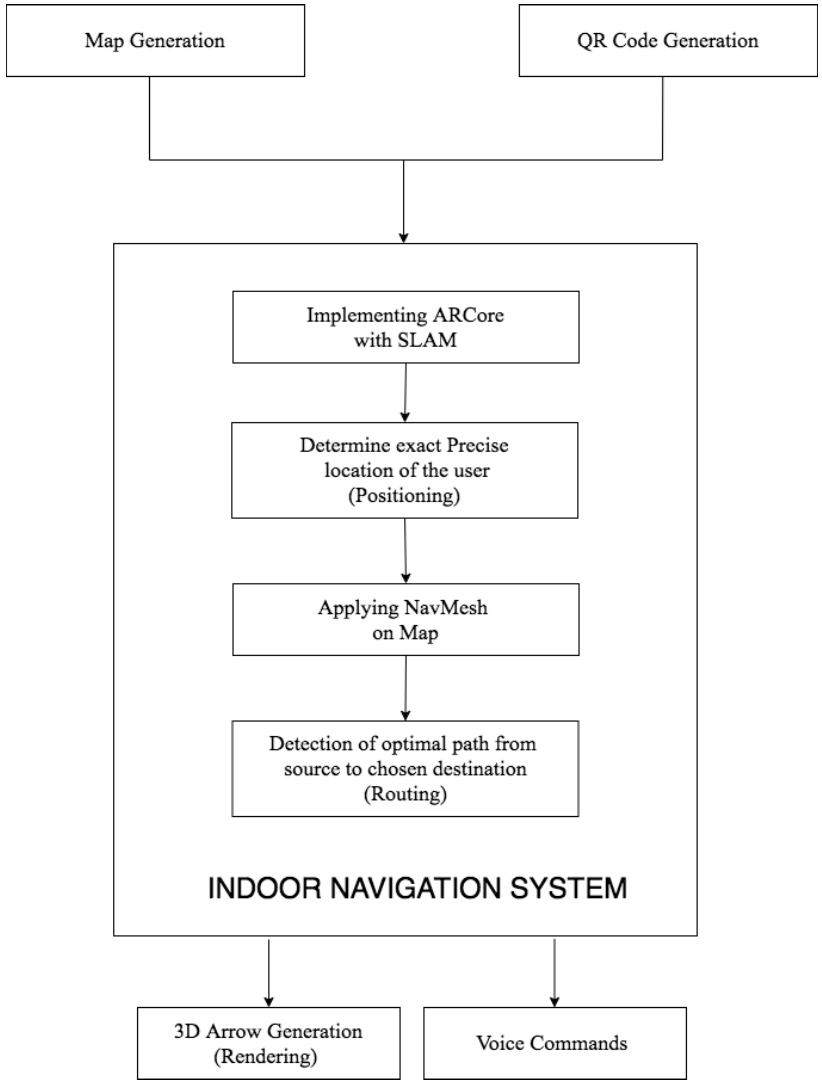


Figure 1: Flowchart representing the methodology to be followed to develop an indoor navigation system

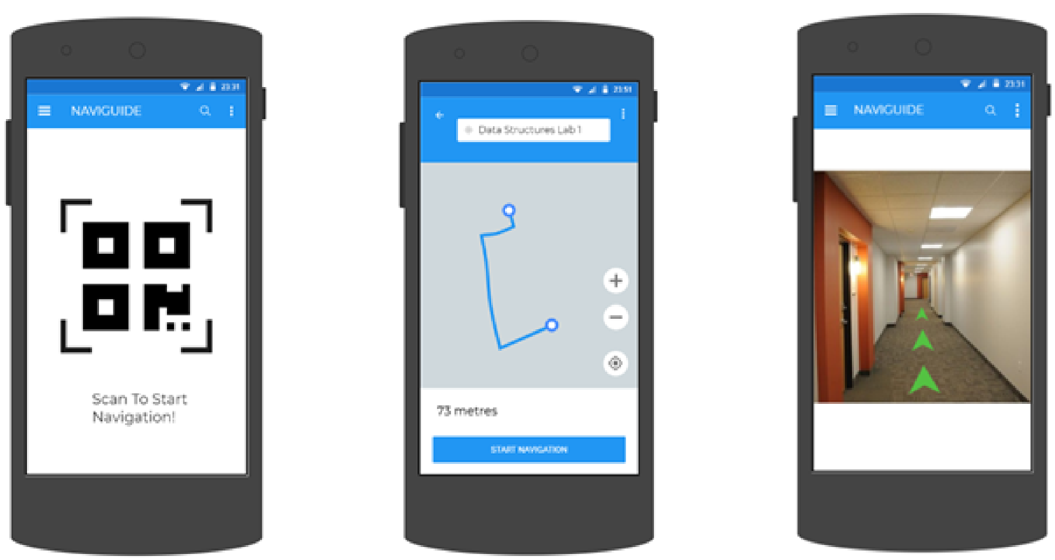
4. After getting details of the precise start location, the next step involves the generation of optimal paths to the chosen destination. An optimal path will be generated by making use of an optimal pathfinding algorithm that redirects the user to his/her destination.
5. The optimal path is generated by the system using the Navmesh algorithm. This involves marking regions on map as 'walkable' or 'not walkable' so that the system identifies the

surfaces that can be included in the generated path from the start position of the user to the destination.

6. The final stage involves the implementation of this optimal path in an augmented environment along with virtual 3D objects in ARCore for android, such as an arrow that provides directions to the user and pin indicators at the final destination.

1.9 Project Outcomes and Deliverables

The outcomes of the proposed indoor navigation system include generating visual markers that would be scanned by the user to start the navigation process. This helps to identify the location of the user. The type of visual markers that would be used for finding the current location of the user is shown in Figure 2(a). After the user selects the destination, the system would calculate the shortest path from the user's location to the selected destination and display it as shown in Figure 2(b). The system would guide the user towards the destination with the help of 3D arrows, thus facilitating the path finding process for indoors, as shown in the prototype in Figure 2(c). The user would also be guided to his/her destination by the means of voice commands (left, right, and straight) along with 3 dimensional arrow pointers.



(a) Scanning Visual Markers (b) Finding Optimal Path (c) 3D Arrows Generation

Figure 2: Prototypes of the proposed Indoor Navigation system

1.10 Novelty of Work

The Novelty of our project is that no such application exists till now that provides such easy functional operations, just scan the nearby QR code and then the user will choose the destination where he wants to go and then NaviGuide will guide him through shortest path through 3-D arrows and other functionality of NaviGuide is that current precise location of the user can be known by referring to the map in the mobile application. The product delivers sheer novelty which is first of its kind since no system till now has been embedded with similar features of making learning simple, hassle free and convenient for the potential users.

CHAPTER 2: REQUIREMENT ANALYSIS

2.1 LITERATURE SURVEY

The following section covers the Literature Survey regarding indoor navigation systems. It briefly explains some previous projects and works in this field, their features, their positive impacts, technologies used by them and their limitations. NaviGuide aims to incorporate some of the best features in these projects all the while trying to avoid their limitations.

2.1.1 Theory Associated With Problem Area

Over the years GPS has become a standard for navigation. Today all outdoor navigation is based on the technology of GPS. However, the same is implemented for indoor navigation, the results are not satisfactory. This is due to 2 main reasons:

- The accuracy of GPS is very poor for indoor navigation. The limited accuracy does not pose a problem in outdoor navigation since the area to be navigated is very vast, but in case of indoor navigation, the application should be able to guide the user though narrow corridors and small rooms. In fact in cases of small buildings, the error range of GPS may even be larger than the size of the building itself

- The GPS signals get attenuated due to the walls and roof of the buildings. This leads to a very weak GPS signal inside buildings which can cause a hindrance in its navigation capabilities and give poor results.

Hence, an alternate technology is required which can cater to the issues at hand and can guide the user inside a building accurately at an economical cost.

2.1.2 Existing Systems and Solutions

Some previously existing technologies and applications for indoor navigation system are listed below:

- **Indoor Navigation System Using Visual Positioning System with Augmented Reality [1]:** In this paper, augmented reality based indoor navigation system is proposed which can help one to navigate from one place to another within a large building. Paper aims to build Marker Recognition, Route Camera and Rendering Module. Marker Recognition Module finds trained markers if no markers are available then displays normal view. The Route Camera Module receives the current position from the marker recognition module and then the navigation system calculates the shortest path to guide the user. The Rendering Module creates 3D virtual objects in order to guide the user and the AR toolkit is used for the same.
- **INSAR: Indoor Navigation System using Augmented Reality [2]:** The paper has segregated the project into two phases namely Offline Training Phase and Online Phase. In offline training phase positioning is done using Wi-Fi fingerprinting. A database is maintained for this purpose. It contains information regarding selected reference points, destinations and direction from each reference point to a destination. In the online phase the Wi-Fi signals are scanned and are then compared with those stored in the database corresponding to each reference point and the current location of the user is found. This location is then used to determine the direction. The arrows for navigation are made to point in this direction using the digital compass in mobile phones.
- **A QR Code-based Indoor Navigation System Using Augmented Reality [3] :** This paper uses six modules which are Decode QR code, Initialise users current location, User select destination location, Calculate distance, Order a set of POIs by distance, Using AR view to draw directions. Technologies used in this paper are Android SDK, Java, QR code, ZXing library and Augmented reality. This paper is using QR codes because QR codes are a cheap and easiest method for positioning.
- **Combination of Real and Virtual World for Indoor Navigation using Mobile Application [4]:** This paper proposes a system that uses ARCore SDK. It uses places learning model based on Machine Learning and motion tracking to extract real world features according to the movement of user and orientation of the mobile device. It provides the user the option to create their own route or take assistance from the system by providing the destination. The features which can be extracted are uploaded in the database in json format. The marked points shall be indicated using virtual arrows.

- **Indoor Pedestrian Navigation System Using a Modern Smartphone [5]:** This paper presents the early development of an Indoor Navigation System based solely on the capabilities of a modern smartphone equipped with accelerometers, compass, camera and Internet connectivity. The application can support commercial activities such as the research of products in a large mall, but can also be deployed for security reasons: evacuation of complex buildings, route identification for visitors etc.
- **Indoor Navigation System for Visually Impaired [6]:** The paper presents a low-cost indoor navigation system, which is based on mobile terminals, supporting technology Near Field Communication (NFC), and Java program access to Radio Frequency Identification (RFID) tags. This information is stored in RFID tags in WAP Binary eXtensible Markup Language (WBXML) format. The system allows leaving audio messages that are recorded in RFID tags in Adaptive Multi Rate (AMR) format.
- **Low Cost Indoor Positioning System [7]:** This research paper presents a low cost solution for the indoor positioning system which makes use of combination of radio frequency and ultrasonics and is intended for use in wearable mobile and computers. The system makes use of trilateration to determine user's current location. The time of flight between ultrasonic receivers is used to compute distance between objects with the help of RF signals encoded in the form of packets consisting of identifiers bytes, IP address, room number and floor number bytes.
- **WiFi Based Indoor Positioning System [8]:**The solution proposed in this paper makes use of RSS values and MAC addresses of detected markings or APs to create radio maps that are used to compute user location. The proposed solution works in two modes, offline and online, both of which make use of the radio map. The samples of the radio map consists of location name and measurement vector for which measurement is taken from all four directions (north, south, east and west) in order to reduce the error. The distance between fingerprints is computed using the euclidean distance and interpolation technique is used to decrease the training time of the system.
- **MobiDev [9]:** MobiDev uses three modules for indoor navigation system which are Positioning, Mapping, Rendering. In the positioning module the system finds the exact location of the user. Mapping module with the help of map and coordinates finds a route from users' current location to the destination. Rendering module works in designing the AR content.

- **Let's nurture [10]:** It is a mobile application for both android and IOS. This wayfinding app will show the route to the destination along with other details, like distance and direction, with AR mapping experience on the mobile camera screen. The system uses Google APIs to facilitate a smooth transition when the user enters or exits indoors.
- **Dent Reality [11]:** figure out where the user currently is. It makes use of virtual paths and arrows to help the user find their destination. Technologies such as AR and AI are used in Dent Reality.
- **BlindSquare [12]:** It is a self-voicing IOS application. It is basically a GPS-app for blind and visually impaired people. BlindSquare automatically tracks destination on the entire path. Shake gesture settings are also available in which the user will shake the mobile phone in order to know his/her exact location. BlindSquare also provides a feature of automatic sleep mode which will help to reduce battery consumption of the mobile phone. This app is currently available in 25 languages.

2.1.3 Research Findings for Existing Literature

The following research papers were studied to gain knowledge about the existing technologies as shown in Table 3.

Table 3: Literature Survey of Indoor Navigation System

S. NO.	NAME	FEATURES	TECHNOLOGY USED	POSITIVES	LIMITATIONS	CITATION
1.	**Indoor Navigation System Using Visual Positioning System with Augmented Reality**	* After opening the application destination is entered by the user. * After that the camera mounted on the device will try	* Augmented reality * AR toolkit for displaying virtual objects like directions.	* If the lighting condition of the environment is the same where the marker is detected to where the	* An audio module can be added. * Camera calibration can be improved.	[1]

		to find the trained markers. If a marker is detected then it will calculate a shortest path between the current location and the destination. * Algorithm used for finding shortest path is Dijkstra's shortest path algorithm * If the shortest route is found then the next module is the rendering module.		marker is trained, then it is easy for the system to detect the marker.		
2.	**INSAR**	INSAR consists of four components: * Positioning system * Navigation system * Database * User Interface UI	* Works on Android smartphones and tablets. * SQLite is used for the database. * The algorithm used for positioning is the highest	* The system does not pre-calculate the path from the source to the destination, but stores the direction along with Wi-Fi signals from	* Since Wi-Fi is used to determine the position, fluctuation in Wi-Fi signals can cause inaccurate results. * The signals can reflect on the surfaces of the	[2]

			number of MACs and signals matching.	each reference point to the destination. * The system issues a two seconds vibration on reaching the destination.	work area and cause multipath effects. * During the day time, timestamps of strength of signal received can vary.	
3.	**A QR Code-based Indoor Navigation System Using Augmented Reality**	The application consists of six components: * Decode QR code * Initialise users current location * User select destination location * Calculate distance * Order a set of POIs by distance * Using AR view to draw directions	* Android SDK * Java * ZXing Library * QR code * Augmented reality	*QR codes are the cheapest and easiest positioning method used for an indoor navigation system. *AR interfaces are new visualisation method for locations and direction.	*User interface can be improved by adding extra information like a map with the shortest path.	[3]
4.	**Combination of Real and Virtual World for Indoor**	Proposed system has two phases: *Mapping	*Uses ARCore SDK for converting real world features	*The system uses a database to store the	* For places where no unique features are present, QR	[4]

	Navigation using Mobile Application	phase: In this phase, the route is created and features are extracted. *Testing phase: The user enters the destination according to which optimisation algorithm finds the best route.	to logical ones. *Stores the features in database in json format. *Android application for user interface.	features to make extraction easier. *The input of the surroundings is taken as a video feed along with the AR camera.	codes can be used as features.	
5.	**Indoor Pedestrian Navigation System Using a Modern Smartphone**	*Uses dead reckoning technique: the process of estimating the current position of a user based upon a previously known position, and advancing that position based upon measured or estimated speeds over elapsed time and course. *Uses the data from the motion sensors embedded in	***** Works on Android smartphones and tablets. *The application tracks the number of steps taken by the user based on the data generated by the smartphone's accelerometers. *The current orientation of the user is measured by the smartphone's digital compass	*The application based on the compass and the step counter modules, was able to detect accurately both orientation and displacement of an user in an indoor environment, for short runs (less than 100 m).	*improvement of the measurement method of the walking steps to overcome the shortcomings of the current-used fixed-value step length. *An alternative error correction method might be the use of the integrated smartphone's camera.	[5]

		the smartphone				
6.	**Indoor Navigation System for Visually Impaired**	*A cost effective, RFID-based mobile indoor navigation application for the people with visual disabilities. *Automatic activation of the application.	*hardware resources: NDEF formatted RFID tags, local FLASH disk of mobile terminal or external FLASH card, keyboard, microphone and speaker.	*Low cost and widely accessible. *Simplified and intuitive user interface * Local info caching to speed up response *Audio-enabled navigation. * Users can leave audio messages. *Floor-plan of a building and communication with WEB server are not required.	*Navigational information must be corrected if the user stray from the route between two reference points or get lost. * To access the RFID tags is proposed to use mobile terminals, smartphones should have supporting technology Near Field Communication (NFC)	[6]
7.	**Low Cost Indoor Positioning System**	*A cost effective indoor positioning system built using a combination of radio frequency	*Uses the concept of trilateration to determine user location.	* Makes use of minimal infrastructure and readily available components.	*The system may fail due to chirp signal obstruction. *The system	[7]

		and ultrasonics. *Intended to be used for wearable mobiles or computers.	*Determines time of flight using ‘pings’ and ‘chirps’ which is then used to compute distance between objects *Data is encoded in the form of rf signals or pings that consists of identifier byte,IP address, floor number and room number bytes.	*Simple to install and requires no calibration *Produces results comparable to a GPS system that works for outdoor outdoor navigation.	may create issues when a number of people crowd near the receiver. *The system is also affected by high level environmental ultrasonic noise.	
8.	**Wifi based indoor positioning system**	*A WiFi based indoor positioning system that uses RSS values and MAC addresses to create radio maps that are used to locate user indoors.. *Works in both online and offline mode.	*Offline mode requires creation of a radio map which stores RSS values and MAC addresses of detected marking position(APs) in a database. *In online mode, the sniffer component is used to collect RSS which is	*For each sample of measurement vector, data will be collected from all 4 directions to reduce error caused by human body attenuation. *The distance between two fingerprints is computed	*The system accuracy lacks and can be improved by making use of more signals such as bluetooth and GSM wireless technologies.	[8]

			used to locate users by comparing data with radio map. *Radio map consists of samples from specific locations which consists of location name and measurement vector.	using the euclidean distance which computes minimal distance. *Time spent on training will be reduced by interpolation technique.		
9.	**MobiDev**	Indoor Navigation using AR	***ARKit-Apple ***ARCore-Android. *** Visual Markers - AR-based indoor navigation solution *** Wi-Fi fingerprinting	*** To solve the problem of accuracy, new visual markers are added at an average distance of 50 meters *** The system suggests the use of an uninterrupte d session with the help of Wi-Fi RTT.	*** Since each visual marker has its own id that is used to get information from the cloud about the position of the marker, a large number of visual markers would slow down the performance of the system.	[9]
10.	**Let's nurture**	The application consists of 5	Basically, the system consists	*** Facilitates the	*** Highly expensive	[10]

		basic modules: * Positioning * Mapping * Routing * Analytics * Admin capabilities	of 2 components that are merged together: * ARKit: projection of the native world by the use of camera and motion information. * Current Location: determination of the current location of the user to a low degree of accuracy, by the use of wifi and GPS. * The application is available for both android and IOS devices.	independent movement of visually impaired users by the means of a mobile screen. * Seamlessly integrates with outdoor maps by the means of Google API.		
11.	**Dent Reality**	* It is an open-source project for mobile AR.	* Apple's indoor maps ecosystem. * Wi-Fi based indoor positioning + ML + proprietary algorithms.	* Apple's new Indoor Maps Program allows the system to achieve around 5mts of accuracy.	* Dent Reality has launched its SDK but the application is currently unavailable on the app store and play store.	[11]

			* Uses AI to find the route through space.	* The system can handle the issues faced by large-scale AR.		
12.	**Blind Square**	Indoor Navigation using AR for blind and visually impaired users.	* IOS application * Uses Foursquare and OpenStreetMap for determining location. * Many algorithms used to determine what information is most useful to the user like popular cafes, restrooms, libraries etc.	* It helps blind and visually impaired users to navigate independently using mobile screens.	* For those users who have a severe hearing loss or are deaf, will find this application difficult to use. * $39.99 may appear to be expensive for some users. * It is not possible to record routes using BlindSquare.	[12]

2.1.4 Problem Identified

Finding a location inside a large building is quite challenging and time consuming. Imagine having real-time information on various aspects such as whether a specific area within the university is occupied or not and all that on your Smartphone screen. Finding the shortest path is really important for the one to reach a place on time. One can find the optimal path from source to destination location using NaviGuide Indoor Navigation System and hence can reach there within reasonable time. Most of the Indoor Navigation Systems are highly expensive as they use beacon technology whereas NaviGuide uses QR code technology for location finding which is cheap.

2.1.5 Survey of Tools and Technologies Used

The proliferation of mobile devices and the growing demand for location aware systems that filter information based on current device location have led to an increase in research and product development in this field. However, most efforts have focused on the usability aspect of the problem and have failed to develop innovative techniques that address the essential challenge of this problem: the positioning technique itself. With NaviGuide we aim to solve the existing problems in indoor positioning by making use of advanced tools and techniques. The following tools and techniques have been used for the system design:

- **Augmented Reality:** It is used in order to make 3D virtual arrows on the mobile screen which will direct the user from source to destination location. The main aim of Augmented Reality is to create an application such that the user cannot see the difference between the real world and the virtual augmentation of it.
- **Unity:** Unity is a cross-platform game engine along with a built-in IDE developed by Unity Technologies. Unity is used in the making of the NaviGuide Indoor Navigation System by writing different scripts.
- **ARCore:** ARCore is developed by google which is a software development kit that allows AR applications to be built for android smartphones.
- **Visual studio:** Visual studio is an Integrated Development Environment (IDE) tool from Microsoft. It is the default C# script editor for unity and it is preinstalled in the Unity Download Assistant, as well as in the Unity Hub installation tool.
- **Vuforia:** It is a software platform for creating Augmented Reality applications. Vuforia adds advanced computer vision functionality to any Augmented Reality application which allows it to interact with spaces in the real world.
- **Android:** Android is a mobile operating system for touchscreen mobile devices such as smartphones.

2.1.6 Summary

There is no such application like NaviGuide exists till now that provides users such easy functional operations, the user has to just scan the nearby QR code and then the user can choose the destination where he wants to go and then NaviGuide will guide him through the shortest path. Other functionality of NaviGuide is that the current precise location of the user can be known by referring to the map. NaviGuide differs from the work that has been done before as no system till now has been embedded with similar features of making learning simple , hassle free and convenient for the potential users.

2.2 SOFTWARE REQUIREMENT SPECIFICATION

2.2.1 Introduction

An efficient indoor navigation system could be implemented at various places to help the users reach their destination without facing much difficulty. We aim to develop NaviGuide, an indoor navigation system using Augmented Reality**.**

2.2.1.1 Purpose

The purpose of this capstone project is to create an indoor navigation system which would be able to guide the user with a great deal of accuracy. This would make their visit to a new enclosed building very smooth, saving them the effort while finding their desired destination. The indoor navigation system, Naviguide aims to provide the most optimal path to the user from their current location to their destination and guide them using 3D arrows. Navigation with the help of 3D virtual arrows shall make it very easy for the user to use the application and reach their destination.

2.2.1.2 Intended Audience and Reading Suggestions

This document is intended to be used by developers, project managers, marketing staff, users, testing officials and documentation writers. Developers may review the document to learn about NaviGuide and to understand the requirements, produce their expected end product and review the project’s capabilities. This formal document also specifies all user requirements and acts as a confirmation between the user and the developer regarding the user requirements and their expectations. Marketing staff may use this document in order to get accustomed to the various product features in order to effectively advertise the product. Testing Officials can use this document as a base for the project evaluation and may use it to give useful feedback to the developers. The testing becomes methodically more organized as finding bugs becomes easier while referring to the requirements document. The hardware developers can focus on the functional requirements through this document.

This document has been organized in an increasing order of specificity. Readers interested in a brief overview of NaviGuide may focus primarily on Chapter 1 of the document, which provides a brief description of every aspect of the project as a whole. These readers may also be interested in Chapter 5 which provides an overview of the project and the future work plan of NaviGuide.

Readers who wish to explore the features of NaviGuide in detail may proceed with the reading of Chapter 2, which expands upon the information laid out in the project overview. Chapter 3 offers further implementation details of the project.

2.2.1.3 Project Scope

Keeping in mind the limited time frame, we aim to implement the proposed indoor navigation system on a short scale for the Lecture Theatres and Labs building in Thapar Institute of Engineering and Technology. This can further be extended for the entire campus. But given the current scenario of lockdown, we have used a dummy map instead, in order to check the working of our application. Also, the proposed indoor navigation system shall be designed to work on Android smartphones only. Since ARCore is supported by Android smartphones running Android 7.0 and later, our application shall be supported by these devices.

2.2.2 Overall Description

This section discusses the overall description for the project. It includes products perspective which talks about the main idea of the project, along with product features which aims to capture all important features of the final application.

2.2.2.1 Product Perspective

Our capstone project is an attempt to design and develop an indoor navigation system that is both accurate and economical. The application would calculate the shortest path to the user's destination and render the path in augmented reality via arrows that direct the user to his/her destination.

2.2.2.2 Product Features

NaviGuide Indoor Navigation System can be used in Universities, shopping malls, airports, warehouses, resorts, theme parks, etc. Some of the features of NaviGuide Indoor Navigation Systems are as follows:

- **Smartphone Technology:** NaviGuide Indoor Navigation System is built for Smartphones as the number of people using smartphones is growing rapidly. Any mobile-based application is more easily adopted by the people than an application which is on a computer.
- **Real-time Mapping:** Real-time mapping is one of the best feature as one can effortlessly reach their destination location within a stipulated time. Imagine having real-time information on various aspects such as whether a specific area within the university is occupied or not and all that on your Smartphone screen. This will save us a lot of time.
- **Indoor Location Tracking:** NaviGuide Indoor Navigation System identifies the exact location of a person within the university by scanning the QR code.
- **Optimal Path Finding:** One can find optimal path from source to destination location using NaviGuide Indoor Navigation System and hence can reach there within reasonable time.
- **Location Based Services:** The spread of Smartphones are undoubtedly one of the most amazing developments in information technologies in the past few years. Within the several applications of Smartphone, location-based services are the most important ones as they primarily function via indoor location tracking.

2.2.3 External Interface Requirements

This section discusses the external interface requirements for the proposed system. It encompasses a description of user interfaces, hardware interfaces, as well as software interfaces of the application.

2.2.3.1 User Interfaces

User interfaces are the ways the users can interact with the designed system. A system may have both hardware and software interface. It consists of all the components with which the user can interact, including the various display screens, mouse, keyboard as well as the desktop appearance. The major part of the UI in NaviGuide is the Android application. It consists of a screen to scan the R code. Once the QR code is scanned, the UI consists of a drop down menu from which the user can select his/her destination, a camera view of the surroundings as well as the map layout displaying the shortest route to the destination.

2.2.3.2 Hardware Interfaces

Since the NaviGuide Indoor Navigation System mobile application does not have any designated hardware, hence it does not have any direct hardware interfaces.

2.2.3.3 Software Interfaces

Following are the softwares used for the NaviGuide Indoor Navigation System as shown in Table 4:

Table 4: Software used and their description

S. No.	Software used	Description
1.	Operating System	We have chosen the Android operating system for its best support and user-friendliness.
2.	Unity	Unity is a cross-platform game engine along with a built-in IDE.
3.	C#	To implement the project, C# language is chosen for its interactive support.

2.2.4 Other Non-functional Requirements

This section discusses various other non-functional requirements for the proposed system. It includes the performance requirements, the safety requirements along with the safety requirements of the final application.

2.2.4.1 Performance Requirements

Performance requirements for the proposed system are as follows.

- **Precision:** Precision is a very important performance parameter for indoor navigation systems. The proposed system shall be able to detect the precise location of the user so as to guide the user from the start to the destination with accuracy.
- **Finding the most optimal path:** The proposed system shall use path finding algorithms such that the user is navigated to the destination following the most optimal path.
- **Reliability:** The proposed system shall be reliable in the sense that the system shall be able to assist the user correctly. The probability of finding the correct user location by the system shall be high.
- **Cost:** We need to consider the cost of the system as it is very important in order to practically implement the system.

  i) Hardware cost of the system is negligible as the system does not have any designated hardware.

  ii) Software cost shall be optimised according to the application.

  iii) Installation cost would depend on the area where the proposed indoor navigation system shall be implemented.
- **Speed:** Speed is critical to indoor navigation systems. The proposed system shall be able to mark the position of the user and suggest the shortest possible path with an optimised speed.

2.2.4.2 Safety Requirements

Safety requirements for the proposed system are as follows:

- The application should be made to scan only the visual markers that are specific to NaviGuide.
- The application should be made to run only on the specified operating system (Android operating system).
- The application must be provided with proper network service and WiFi facilities so as to operate smoothly.

2.2.4.3 Security Requirements

Security requirements for the proposed system are as follows.

- The application should be designed in such a manner that the user's personal location is accessible to anyone except the user.
- The database storing locations of identified virtual markers should be accessible to the owner or developers only.
- The access to modify or update the database must be provided to the owner or developer of the application.
- The application must ask for permission before accessing a user's location or other special services.

2.3 Cost Analysis

Since this is a software project, the only cost involved would be for hosting the NaviGuide application on the Play Store, which would cost around Rs 2000.

2.4 Risk Analysis

- The functionality of the application may get hampered due to an unstable internet connection.
- The accuracy of the application may get hampered in case a lot of people try to use the application simultaneously.

- Since only a certain number of QR code sheets can be put up, the user may have to walk a while to reach the nearest QR code.

CHAPTER 3: METHODOLOGY ADOPTED

3.1 Investigative Technique

NaviGuide Indoor Navigation System falls under the Experimental technique. After doing a detailed investigation on the techniques available for implementation of indoor navigation systems and going through many research papers written on the subject of indoor navigation systems, we have come up with the proposed system. The proposed system aims to help the user by guiding them to their destination by finding an optimal path from the start to the final location. The system shall display the path in map view as well as in augmented reality view using 3D virtual markers. Thus the user shall be able to reach their destination, without wasting their time and effort. This would be specifically helpful for instances when the user is visiting the place for the first time, thus avoiding confusion and hustle. The proposed system is built keeping in mind the following objectives:

- To generate self contained visual markers with cloud linkage.
- Positioning: To find the current precise location of the user via device shaking.
- Routing: To redirect the optimal path to destination through voice.
- Rendering: To generate 3D virtual images.

The map used for navigation is built using SLAM technology. To start the navigation process, the user needs to scan the QR code, which would help the system to identify the user's current location. After scanning the QR code, the user needs to choose the destination, according to which the system shall generate the most optimal path from user's current location to this chosen destination. The system shall use an optimal path finding algorithm for the same. The final step is the generation of 3D arrows to guide the user along the way using Augmented Reality. The Android based application NaviGuide shall use ARcore to accomplish this task.

3.2 Proposed Solution

The proposed system, NaviGuide, aims to provide an economical solution to the problem of indoor navigation without compromising on the accuracy of the application.

The application opens up in camera view to enable the user to scan QR codes. Sheets of paper would be pasted at regular intervals throughout the building displaying QR codes for scanning. The user can start the application by scanning the nearest QR code.

Once the application is started, the device detects the user position through positioning. On scanning the QR code marker, the user can select his/her destination from a drop down menu available. As soon as a destination is selected, the system uses unity's navmesh technology to find the shortest path from the source to the destination. This path is displayed to the user on a map of the building in the application.

This path is now rendered in an augmented environment and the user is guided to his/her destination by arrow pointers rendered in the augmented environment. Arcore's SLAM technology is used for the purpose of rendering the path generated in an augmented environment.

3.3 Work Breakdown Structure

The Work Breakdown structure of the application is shown in Figure 3.

A work breakdown structure is a deliverable oriented hierarchical diagram that depicts the objectives/ project deliverables in an organized manner achievable by a team.

The first objective 'To generate self contained visual markers' has further been divided into 3 sub sections, which includes generation of QR codes that would act as visual markers for our indoor positioning system, developing a QR code scanner in the android application and unit testing.

The second objective 'Finding current precise location of user' includes creating the building map, adding location information with each visual marker, enabling the device to fetch user's current location inorder to generate a path from user's current location to destination and ensuring that the pointer accurately fools the user as he/she moves in real time.

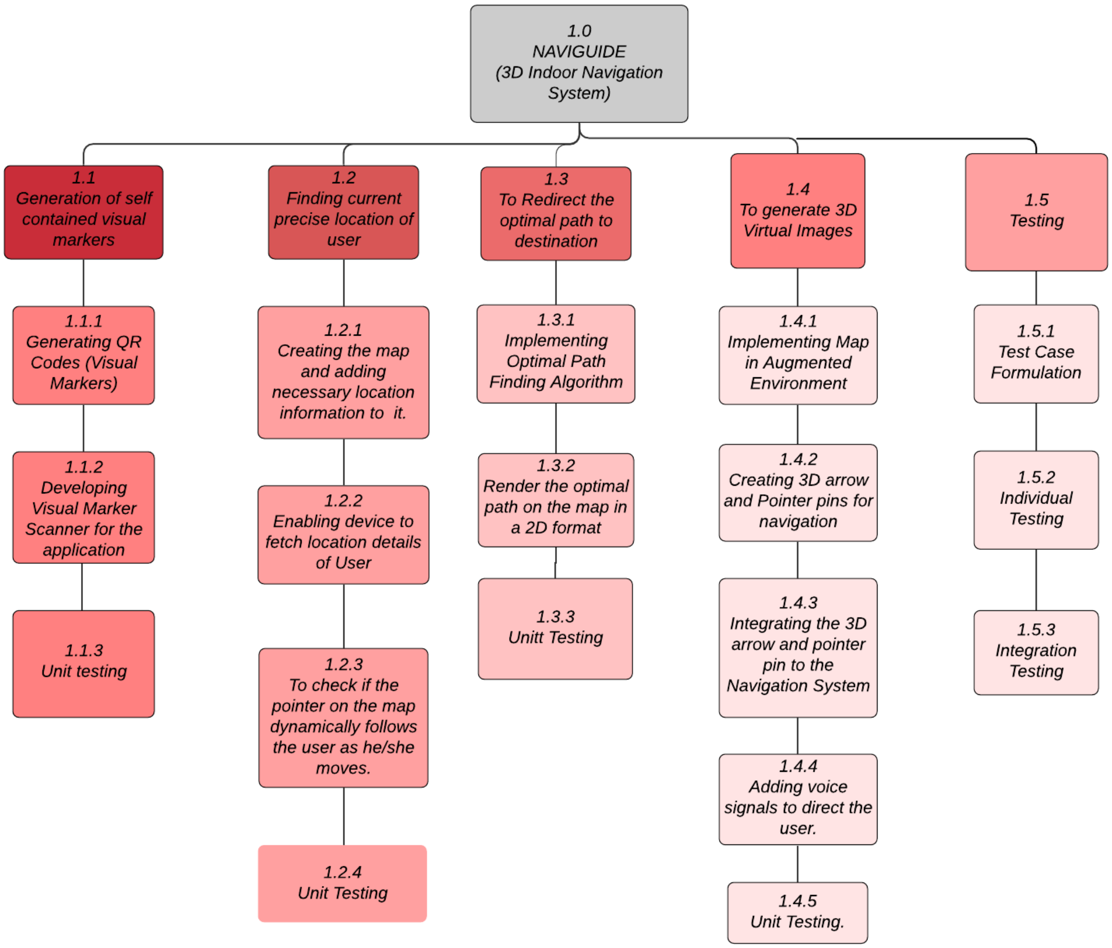


Figure 3: Work breakdown structure of NaviGuide

The third objective 'To redirect the user via an optimal path' includes implementing an optimal path finding algorithm from the current location of the user to the final destination selected by him/her.

The fourth objective 'To generate 3D virtual images' includes implementing the indoor positioning system in an augmented environment which will guide the user by means of 3 dimensional pointers and voice commands.

Each of the objectives consists of a unit testing that helps identify and resolve errors in a timely manner.

The final objective includes generation of test cases and final testing of our application in order to match the predefined objectives and customers satisfaction.

3.4 Tools and Technology

Following tools and technologies are required for making NaviGuide Indoor Navigation System:

- **Android:** Android is a mobile operating system based on the modified versions of linux kernel and other open source softwares developed to be used for touchscreen mobile devices such as smartphones etc.

- **ARCore:** ARCore is a platform by google that is used to build augmented reality applications by making use of its ability to sense the environment and interact with it.

- **Augmented Reality:** It is a technology that is used to create systems such that the user is unable to find differences between the real world and the virtual environment created by it. In our application we will be making use of augmented reality to create 3D pointers which can guide users through the augmented environment to the chosen final destination.

- **Git:** Git is an open-source tool used by developers to collaborate with each other for the development of a project. It is also used to store and manage changes made on the set of files over time.

- **Navmesh:** Navmesh is a class in Unity that is usually used for pathfindings or walkability tests. Such classes are used to compute optimal paths between objects in a large space.

- **Unity:** Unity is a cross-platform game engine along with a built-in IDE that is used to create 2 dimensional, 3 dimensional, virtual and augmented reality games. Since our project aims to implement the navigation system in an augmented environment we will be making use of Unity software.

- **Visual studio:** Visual studio is a tool by Microsoft that is being used as a default C# script editor for unity that comes preinstalled in the Unity Download Assistant, as well as in the Unity Hub installation tool.

- **Vuforia:** Vuforia is a software platform for creating Augmented Reality applications. Additional functionalities such as computer vision can be added to these applications in order to make them interact with spaces, recognize objects in the real world.

CHAPTER 4: DESIGN SPECIFICATIONS

4.1 System Architecture

The system architecture of NaviGuide can be depicted by the means of the following diagrams as shown in Figure 4 and 5:

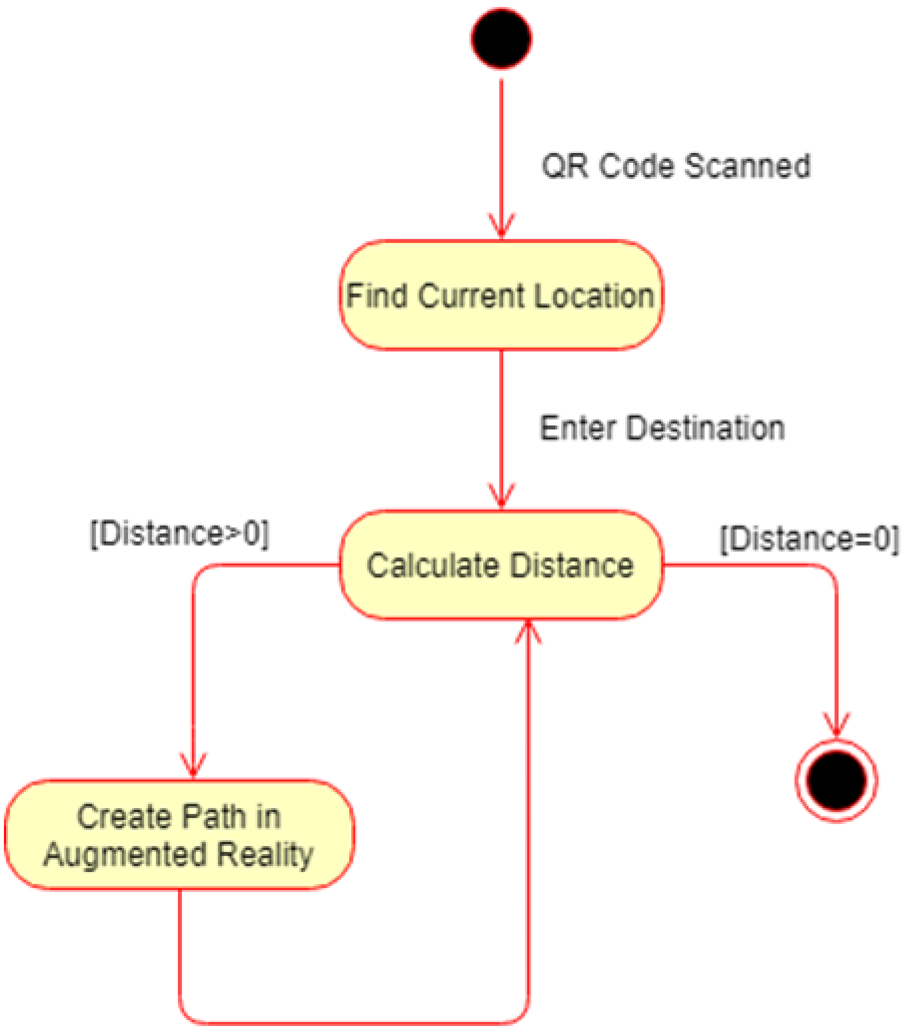


Figure 4: State chart diagram composed of a finite number of states to describe the behaviour of the system.

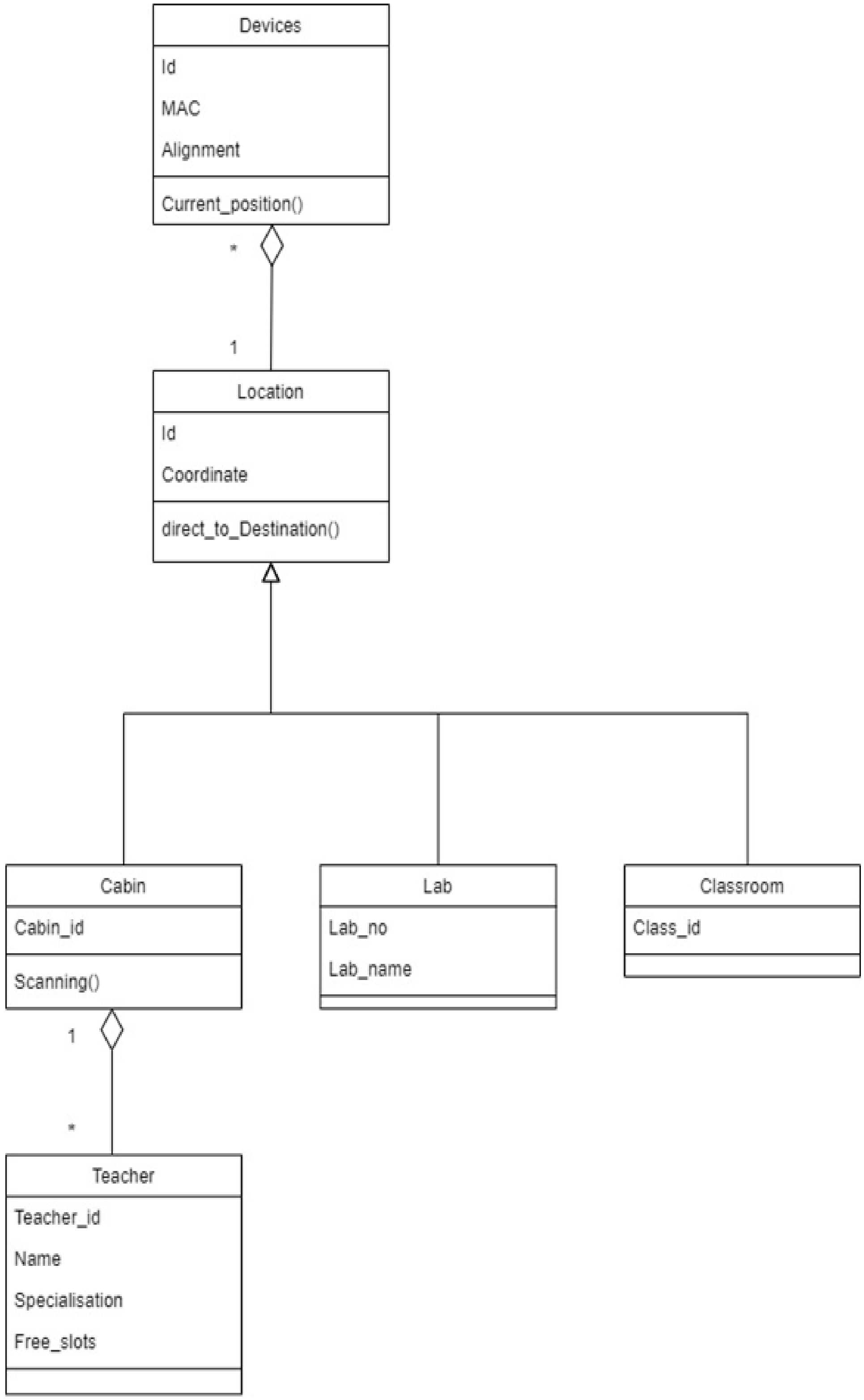


Figure 5: Class diagram showing the system classes, their attributes, operations and the relationship among them.

4.2 Design Level Diagrams

These include Component Design, Interface Design and Data Design Diagrams.

4.2.1 Component Design

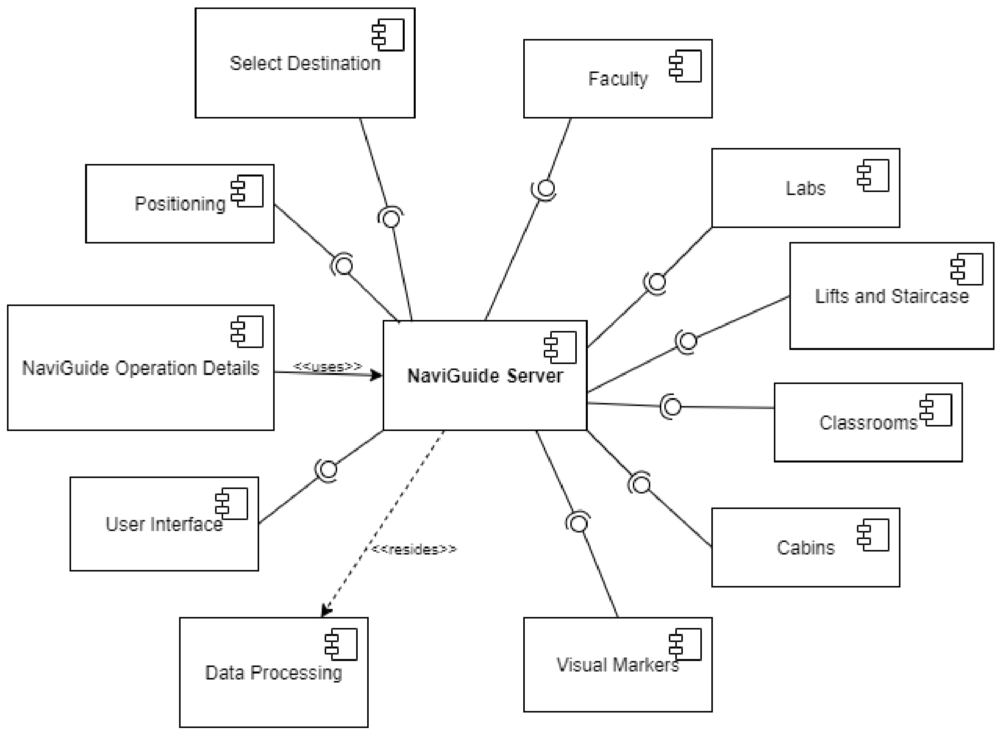


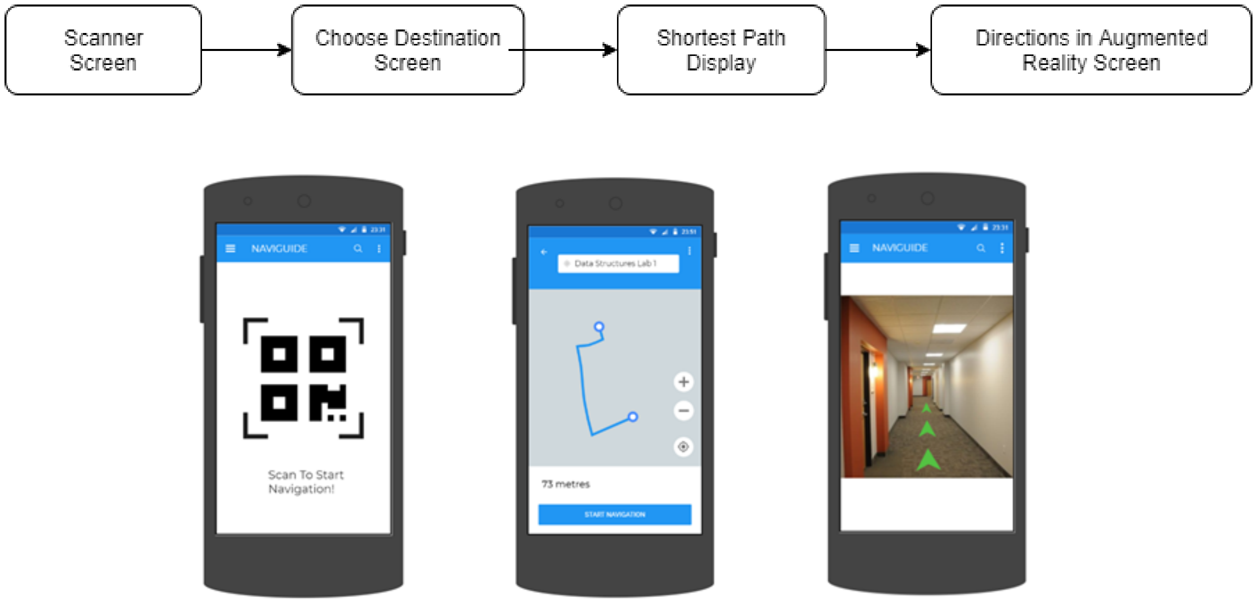
Figure 6: Component Design for NaviGuide

A component diagram is also called UML component diagram. It describes the wiring of the physical components and organization in a system. Component diagrams are usually made to get model implementation details and to cross-check that every aspect of the system's required functions are covered by planned development or not.

Figure 6 shows the component diagram for the NaviGuide system. There are 12 components namely Positioning, Select Destination, Faculty, Labs, Lifts and Staircase, Classrooms, Cabins, Visual Markers, Data Processing, User Interface, NaviGuide operation details, NaviGuide Server. NaviGuide Server acts as providing interface for Positioning, Select Destination, User

Interface and acts as requiring interface for Faculty, Labs, Lifts and Staircase, Classrooms, Cabins, Visual Markers. There is a dependency between NaviGuide Server and Data Processing.

4.2.2 Interface Design



(a) Scanning Visual Markers (b) Finding Optimal Path (c) 3D Arrows Generation

Figure 7: Interface Design for NaviGuide

The user interface design is the front end view of the application visible to the user. It is the software interface design that would be used to interact with the system.

Figure 7 shows a flowchart of events that would occur once the user starts the navigation process. The first step is to scan the QR code. This would help the system to identify the current location of the user. The next step is to choose the destination from the options provided. The system finds the optimal path from the current location to the destination and displays it to the user. The system further guides the user with the help of augmented reality virtual arrows. The prototype of the application showing the above mentioned steps is shown in Figure 7(a), 7(b) along with 7(c).

4.2.3 Data Design

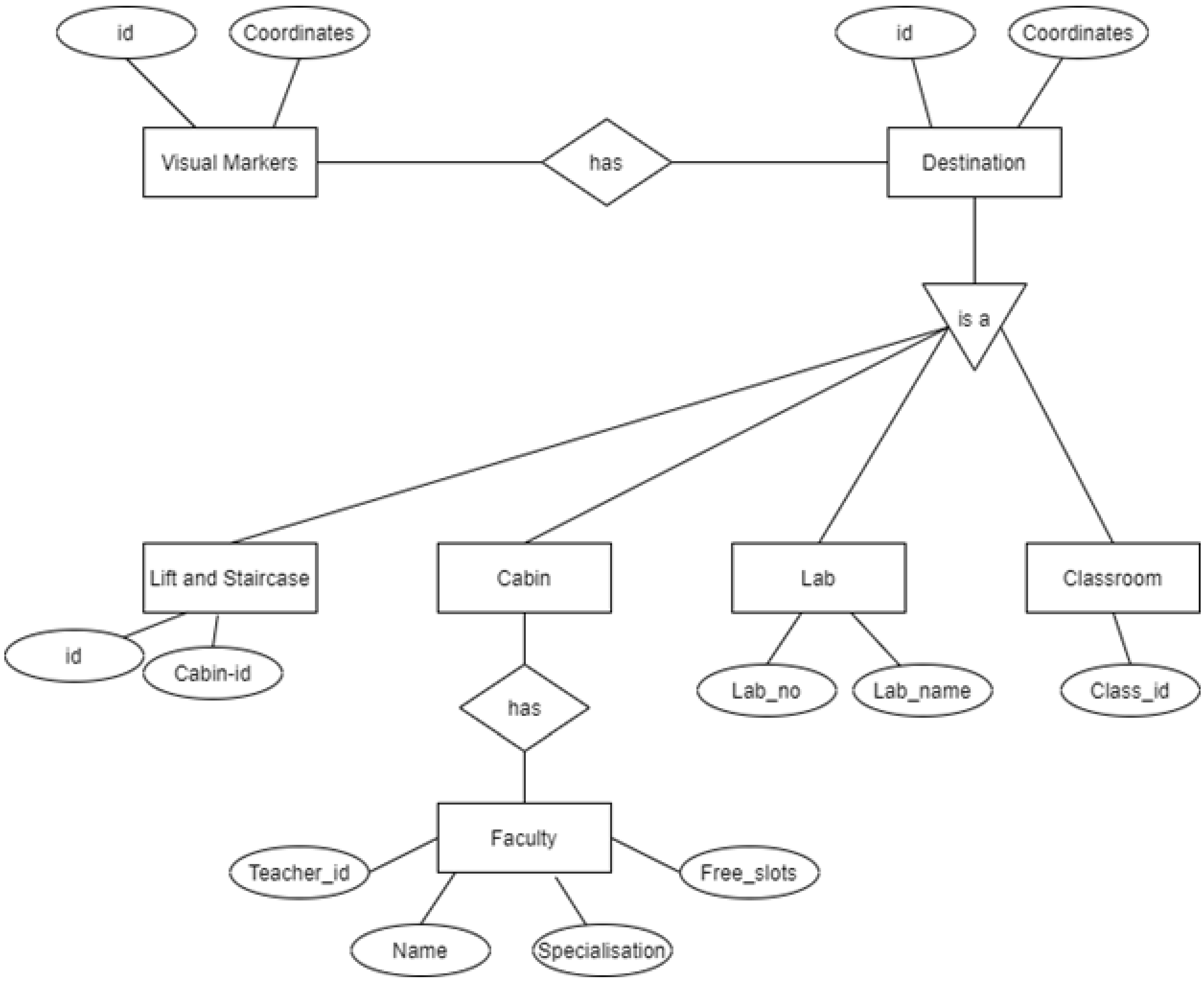


Figure 8: Data Design for NaviGuide

ER Diagram is an effective way to examine the Data Design for the system. An ER diagram is used to represent the relation between various entities.

Figure 8 shows the ER diagram for the NaviGuide system. The entity Visual Markers has many to many relationship with the entity named Destination. Destination entity has ‘is a’ relationship with four entities namely, Classroom, Lab, Cabin, and Lift and Staircase. These entities store data regarding the possible destinations available for the user. Finally, the Cabin entity is related to the Faculty entity with a one to many relationship. This relationship connects the faculty with their assigned cabins.

4.3 User Interface Diagrams

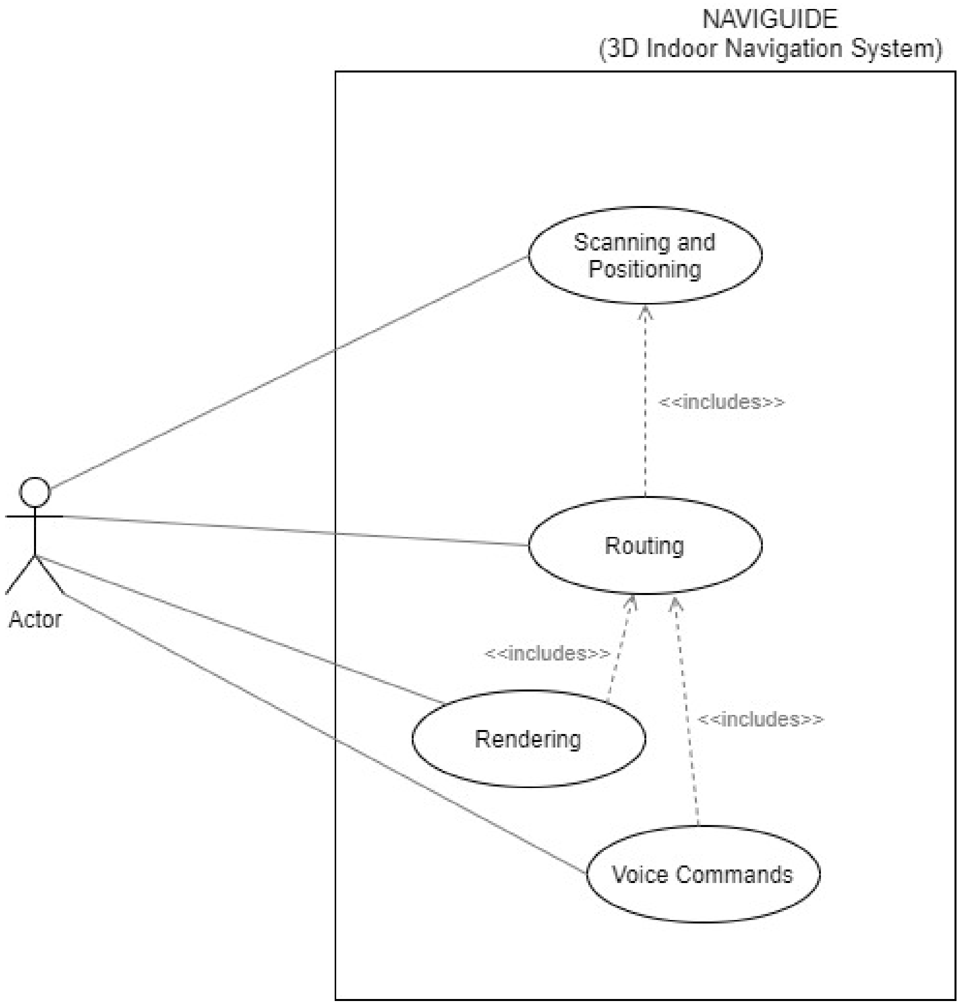


Figure 9: Use case diagram for NaviGuide

A use case diagram is a graphical depiction portraying the methodology used in system analysis and to organise, clarify and identify system requirements.

Figure 9 shows the use case diagram for NaviGuide. There is a single actor who is the user who scans the QR code. Routing and pathfinding requires the QR code to be scanned so that positioning can be started. Once the shortest path has been found, it can be rendered in an augmented environment and then the user will also be guided through voice commands.

CHAPTER 5:

IMPLEMENTATION AND EXPERIMENTAL RESULTS

5.1 Experimental Setup (or simulation)

The experimental setup consists of the following components -

1. **Game Engine:** Game engine comprises the development environment needed to create the software. It consists of unity game development software along with visual studio software.
2. **Location Database:** Location database comprises a database consisting of a list of destinations which the user can choose to go to along with the location coordinates of each with respect to the map of the building.
3. **User Interface:** This is the android application that the user can use to access a list of destinations in the building and the application determines the shortest path to the destination along with the directions to the same rendered in augmented reality.
4. **Augmented Reality Platform:** Augmented reality platform is needed to interact with the augmented environment and to render 3-D pointers which can direct the user to his/her chosen destination. Arcore has been used for this purpose for android devices.

5.2 Experimental Analysis

This section gives us detailed analysis of the data to be used in the project and it also describes various performance parameters that have been considered in the development of this project.

5.2.1 Data

For implementing this project in the real world, the project requires a map of the location as data for Indoor Navigation. Map is created in Unity for that we have made a plane and then place the image material onto the plane. Map is scaled in real life like if the distance between two objects is 2.45 meters so there must be 2.45 units between two objects in Unity. With a simple cube we can measure the same. Other than that, there is no need for any type of data to make this project operational.

5.2.2 Performance Parameters

The following performance parameters have been considered -

1. Internet Connectivity Speed - For viewing the user’s location in real time, it is crucial that the NaviGuide has good internet connectivity. Low Internet Speed will lead to delay in the process of positioning. Hence, a high Internet speed is required.

2. Current Location - For better results the system should get the current location of the user as accurate as possible. In NaviGuide the current location is known to the system by scanning the QR code by the user. If the system is unable to know the user's precise location due to some error then the path made by the system will be less accurate.

5.3 Working of the project

This section of the report discusses the implementation of the proposed project, in terms of its workflow and deployment.

5.3.1 Procedural Workflow

Figure 10 shows the sequence diagram for the system. It clearly depicts the workflow of the system. The user scans the a QR code using the scanner in the application. The system following this fetches the current location of the user from the location database. This current position is displayed to the user as a pointer on the map in the android application. Subsequently the user selects the destination he/she wishes to visit from a dropdown menu. The system takes this destination along with the current location to calculate the shortest distance between the two and hence displays an optimal path to the user as a line path rendered on the map. Along with this, 3D arrows are rendered in an augmented environment that the user can follow to reach the required destination along with voice commands. The system hence guides the user to the selected destination and once the user reaches the required location the 3-D arrows are replaced by a 3-D pin.

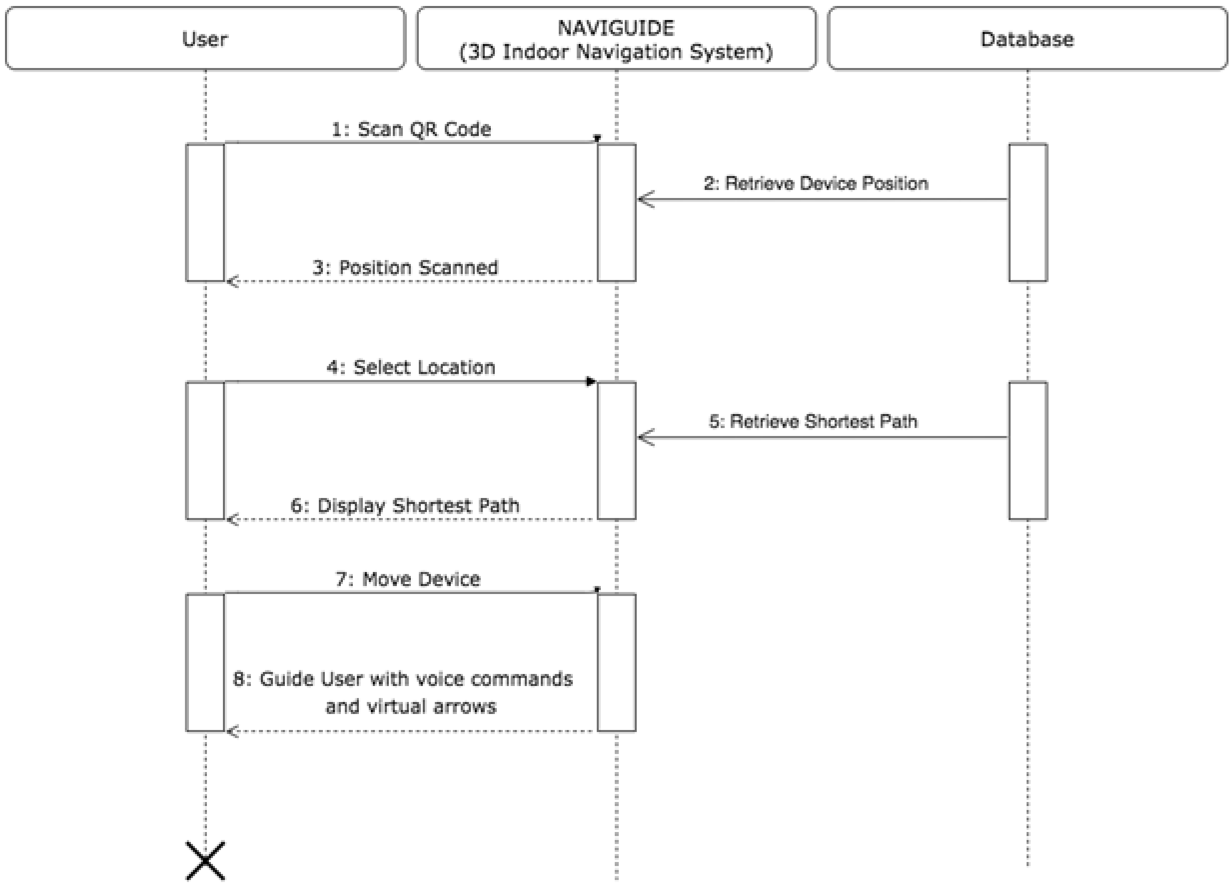


Figure 10: Sequence diagram for NaviGuide

5.3.2 Algorithmic Approaches Used

The following algorithmic approaches have been used in the development of NaviGuide: 3D Indoor Navigation System:

1. NAVMESH Algorithm

This algorithm is used to find the optimal path from the current location of the user to the chosen destination. Navmesh is a path finding algorithm that can be implemented in Unity. In order to implement this algorithm; we need to indicate the surfaces on the map as ‘walkable’ or ‘not walkable’ as shown in Fig 11. The GameObjects represent non-walkable surfaces.

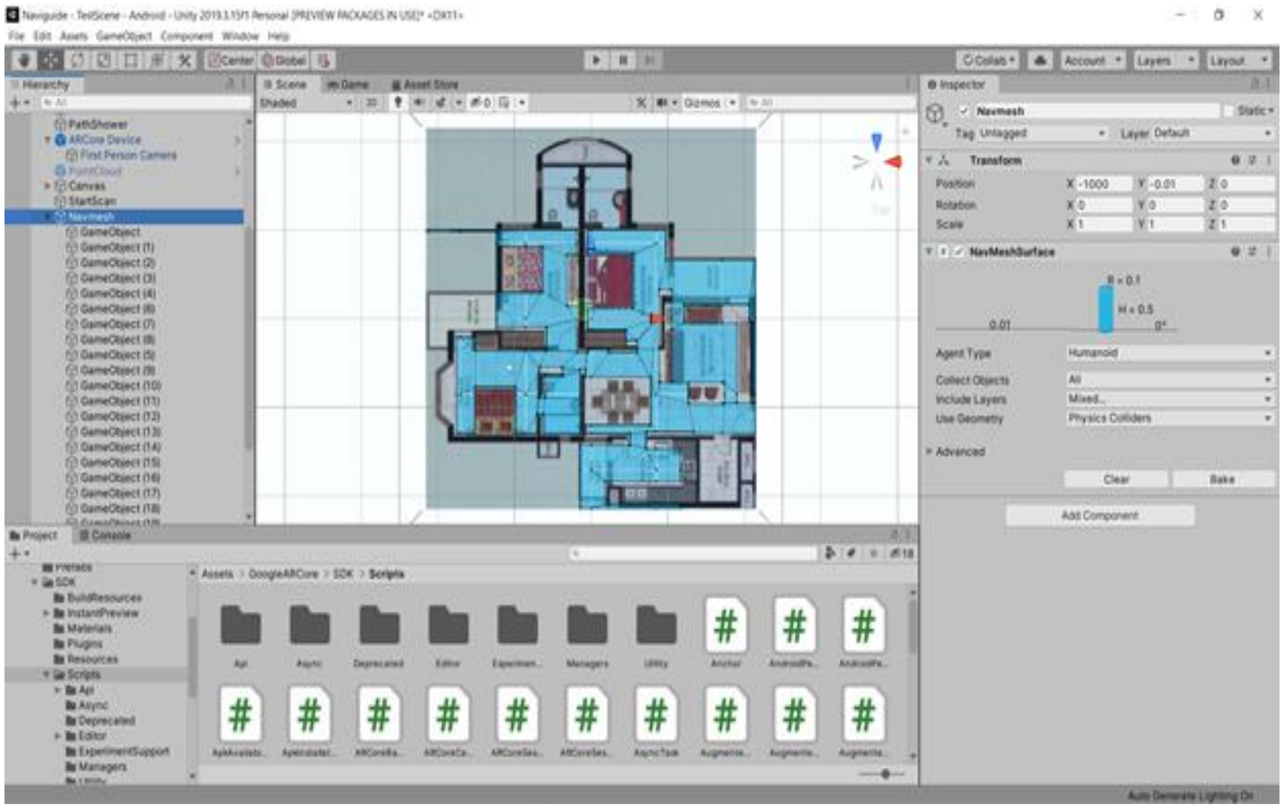


Figure 11: Unity window showing Navmesh implementation

The walkable surfaces are the ones where the user can move and the algorithm will use only these surfaces while finding the path. To make a specific surface non-walkable:

- Create an empty child object of Navmesh.
- In the Inspector window of this object, add the ‘NavMeshModifierVolume’ component.
- Move the object to the required surface and edit its volume to match the surface.
- Mark the area type as ‘Not Walkable’.
- Once this has been done for all the non walkable surfaces, bake the Navmesh.

The blue surfaces are walkable whereas the others have been marked non-walkable. Once this is done, the inbuilt functions in Unity help to find the shortest path from the starting position to the destination of the user and display it using Lime Renderer. For finding the optimal path, Unity uses A* algorithm. It is a very effective algorithm and uses heuristic function to find the shortest path.

2. SLAM Algorithm

For displaying the path using Augmented Reality, the device needs to know the 3D position of the user. In order to achieve this, SLAM (Simultaneous Localisation and Mapping) algorithm is used. The spatial relationship between various keypoints and the device's location is used to find the exact 3D position of the user, which thereafter is used to find the optimal path from start to the destination. SLAM algorithm identifies unique points and features using the camera of the device. Once the system gains information about the environment, it then starts building the map and locates the position of the device in the environment. This algorithm helps the device to understand the environment and movement of the user.

5.3.3 Project Deployment

A component diagram is also called UML component diagram. It describes the wiring of the physical components and organization in a system. Component diagrams are usually made to get model implementation details and to cross-check that every aspect of the system's required functions are covered by planned development or not.

Figure 12 shows the component diagram for the NaviGuide system. There are 12 components namely Positioning, Select Destination, Faculty, Labs, Lifts and Staircase, Classrooms, Cabins, Visual Markers, Data Processing, User Interface, NaviGuide operation details, NaviGuide Server. NaviGuide Server acts as providing interface for Positioning, Select Destination, User Interface and acts as requiring interface for Faculty, Labs, Lifts and Staircase, Classrooms, Cabins, Visual Markers. There is a dependency between NaviGuide Server and Data Processing.

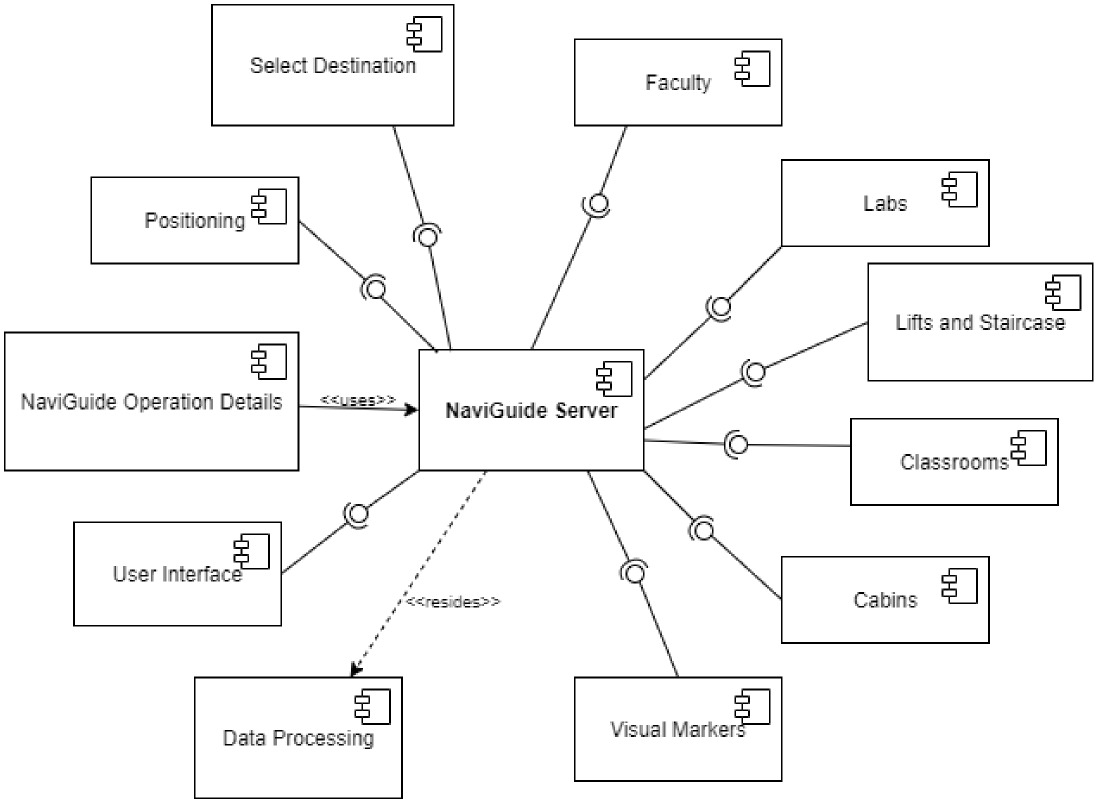


Figure 12: Component Design for NaviGuide

5.3.4 System Screenshots

This section shows the snapshots of working of NaviGuide.

Snapshot 1: Figure 13 shows the map of the building used in the implementation of NaviGuide.

Figure 13: Map of the Building

Snapshot 2: When the user opens the app NaviGuide, a screen appears which prompts the user to scan the QR code to start the navigation process, as shown in Figure 14 below. After scanning, the system detects the current precise location of the user.

Figure 14: Prompt to scan the QR code to start navigation

Snapshot 3: The sample QR code used for scanning is shown in Figure 15.

Figure 15: The QR code to be scanned by the user

Snapshot 4: Once the scanning is done, another screen appears, displaying the options to choose the desired destination. It also provides an option to switch to map view as shown in Figure 16.

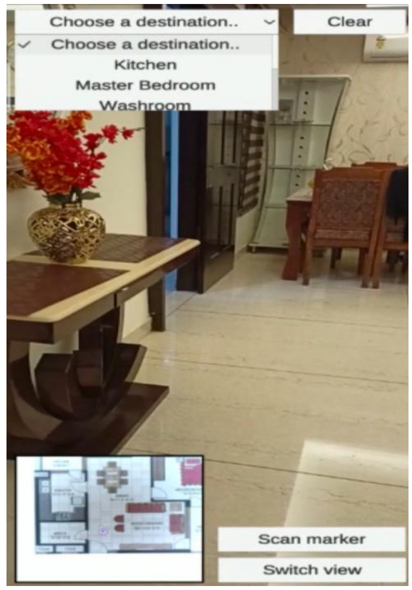


Figure 16: Screen for choosing the destination of the user

Snapshot 5: Once the user chooses the destination, the most optimal path is displayed to the user in map view as shown in Figure 17 below. The user can either view the navigation in map view or AR view.

Figure 17: Most optimal path from start to destination displayed in map view

Snapshot 6: Finally in figure 18 the system shows the shortest path from the user's current location to the chosen destination through 3D arrows and voice commands.

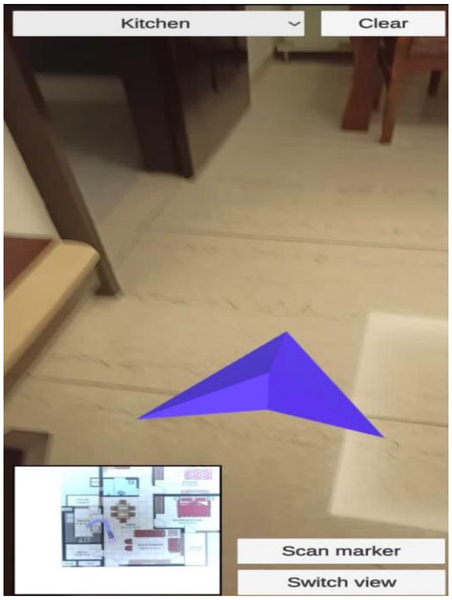


Figure 18: Displaying path through 3D arrows

Snapshot 7: When the user reaches the chosen destination system shows a 3D pin as shown in Figure 19.

Figure 19: Displaying 3D pin as user reaches destination

5.4 Testing Process

The test plan, strategy and results for “NaviGuide” have been discussed below. It includes the test plan, the features to be tested, the test strategy, the test techniques, test cases and the final test results.

5.4.1 Test Plan

This section of the document discusses the features to be tested, the testing strategy, and the testing techniques used.

5.4.2 Features to be tested

Table 5 shows the features to be tested:

Table 5: Features of NaviGuide to be tested

S. No.	Item Being Tested	Scenario Being Tested
1.	QR code scanner	The application is able to scan the QR code and load the subsequent window.
2.	View switch button	The view switch button is able to swiftly switch between the map view and the 3-D augmented reality view.
3.	Localisation	The pointer in the map view follows the user though the building accurately and precisely in real time as the user moves.
4.	Drop-down menu	The destination drop-down menu works swiftly and the user is able to select his/her required destination from the menu which is then sent to the system for path finding.
5.	Optimal path calculation	The system is accurately able to determine the shortest path between the current location of the user and the destination selected by the user.
6.	Line renderer path	The optimal path is accurately displayed to the user as a line rendered on the map in the system and updates in real time as the user moves.
7.	Routing	The system shows and renders the correct path from the exit to the master bedroom.
8.	Routing	The system shows and renders the correct path from the washroom to

		the balcony.
9.	Routing	The system shows and renders the correct path from the exit to the kitchen.
10.	Routing	The system shows and renders the correct path from the dining room to bedroom 1.
11.	Routing	The system shows and renders the correct path from bedroom 2 to the master bedroom.
12.	Routing	The system shows and renders the correct path from the kitchen to the balcony.
13.	Routing	The system shows and renders the correct path from the washroom to the exit.
14.	Voice Commands	The system directs the user to the chosen destination through voice commands (left, right, straight).
15.	3-D pointer generation	The application is able to generate 3-D arrows which guide the user to his/her destination in an augmented environment.
16.	3-D pointer deletion	The application deletes 3-D arrows when the user crosses them and generates a new one further directing the path to the user.
17.	3-D pin generation	The system generates a 3-D pin in an augmented environment when the user reaches his/her destination.
18.	Rescan button	The rescan button works properly and opens the QR code scanner window in case the user loses connectivity.

5.4.3 Test Strategy

We performed Unit testing of all the individual modules of the system, namely:

- Scanning and Positioning: This module deals with the scanning of the QR code to initiate the application and the use of ARCore to locate the device in real time.
- Routing: This module deals with finding the most optimal path from the start to the chosen destination and verifying correct working of Navmesh algorithm.
- Rendering: This module deals with guiding the user with the help of arrows rendered in 3D environment by the use of ARCore.

After the unit testing, we performed System Integration testing to verify the working of all the modules in coordination with each other. The next step was to evaluate our system in terms of user experience, reliability and scalability and delay.

- **User Experience:** To check if the interface of NaviGuide is very user-friendly and easy to follow.
- **Reliability:** To check if the system can find the optimal path in all kinds of scenarios and guide the user to the desired destination.
- **Scalability:** To determine the ease with which the system can be extended to a larger area.
- **Delay:** To check if the system works spontaneously without causing any delay.

5.4.4 Test Techniques

Mentioned below are the techniques used for the testing of this project:

1. Unit Testing: This type of testing is done to test the functionality of a single module or a single piece of code, typically in a disconnected environment.

2. System Integration Testing: This type of testing is done to test the coordination between different software modules, i.e., to make sure that they work together correctly, portraying desired behaviour, and maintaining data integrity.

3. Beta/Acceptance Testing: This type of testing is done in a live environment. It is done to test and evaluate the system from a user point-of-view, to make sure that the desired business functionality is satisfied.

5.4.5 Test Cases

This section of the report lists the different test cases for different testing environments, along with the steps to take in order to perform the tests. Table 6 lists the test cases for unit testing in a local environment. It illustrates each test case with the steps to be taken to perform it and the output expected corresponding to each test case.

Table 6: List of different test cases for different testing environments

S. No	Test Case	Steps	Expected Output
1.	QR code scanning	1. Open the android application. 2. Give permission to the application to access the device camera. 3. Scan the nearest QR code using the scanner in the application.	The scanner should be able to scan the QR code, begin the synchronisation of ARCore and display the drop down menu.
2.	View switching	1. Scan the QR code. 2. Click on the switch view button. 3. Repeat at least 5 times.	The view should swiftly change between map view and the augmented reality view on clicking the button.
3.	Localisation	1. Switch to the map view using the switch view button. 2. check if the pointer in the map accurately matches your current location. 3. Move around and check if the pointer on the map follows you.	The pointer on the map should accurately determine the current location of the user and should accurately and precisely update its position in real time as the user moves through the building.
4.	Drop-down menu	1. Scan the QR code. 2. click on the drop down menu. 3. Click on any of the available destinations.	The drop-down menu should display all the available destinations and when the user selects one, the routing process for that destination should begin.
5.	Optimal path routing	1. Choose one of the available destinations from the drop-down menu. 2. Check if a 2-D path is rendered on the map from the current location to the destination.	A path should be rendered on the map from the current location of the user to the destination and it should be the shortest and the most optimal out of all the available paths.
6.	Line renderer	1. Choose a destination from the drop-down menu. 2. Check if a path is rendered on the map from the current location to the selected	A path should be rendered on the map from the current location of the user to the selected destination, which should update and decrease in length as the user moves on this

		destination.	optimal path.
7.	3-D pointer generation	1. Select a destination from the drop down menu. 2. Check if a 3-D arrow is generated in the direction of the destination.	The user should be directed from his/her current location to the selected destination by the means of a 3-D arrow. Once the user crosses an arrow, a new arrow should be generated and the previous one should be deleted.
8.	3-D pin generation	1. Select a destination from the drop-down menu. 2. Move to the selected destination. 3. Check if a 3-D pin is generated at the destination.	Once the user reaches his/her selected destination, a 3-D pin should be generated indicating that the user has reached the final destination.
9.	Rescan button	1. Wait for the device to lose connectivity (or disable wifi on the device). 2. Click on the rescan button.	Clicking the rescan button should open the QR scanning window to restart arcore navigation.
10.	Voice Commands	1. Select a destination from the dropdown menu. 2. Check if the system gives a voice command for left, right and straight; when the arrow points to the left, right and straight directions respectively.	The voice commands should give appropriate directions.

5.4.6 Test Results

Table 7 lists the results for the unit test cases describes in the previous section:

Table 7: Results of unit test cases performed

S. No	Test Case	Expected Output	Actual Output	Verdict
1.	QR code scanning	The scanner should be able to scan the QR code, begin the synchronisation of ARCore and display the drop down menu.	As expected	Pass

2.	View switching	The view should swiftly change between map view and the augmented reality view on clicking the button.	As expected	Pass
3.	Localisation	The pointer on the map should accurately determine the current location of the user and should accurately and precisely update its position in real time as the user moves through the building.	As expected	Pass
4.	Drop-down menu	The drop-down menu should display all the available destinations and when the user selects one, the routing process for that destination should begin.	As expected	Pass
5.	Optimal path routing	A path should be rendered on the map from the current location of the user to the destination and it should be the shortest and the most optimal out of all the available paths.	As expected	Pass
6.	Line renderer	A path should be rendered on the map from the current location of the user to the selected destination, which should update and decrease in length as the user moves on this optimal path.	As expected	Pass
7.	3-D pointer generation	The user should be directed from his/her current location to the selected destination by the means of a 3-D arrow. Once the user crosses an arrow, a new arrow should be generated and the previous one should be deleted.	As expected	Pass
8.	3-D pin generation	Once the user reaches his/her selected destination, a 3-D pin should be generated indicating that the user has reached the final destination.	As expected	Pass
9.	Rescan button	Clicking the rescan button should	As expected	Pass

		open the QR scanning window to restart arcore navigation.		
10.	Voice Commands	The voice commands should give appropriate directions.	As expected	Pass

5.5 Results and Discussions

As a result, an Indoor Navigation System has been established. The System successfully scans the QR code and then asks the user to select the destination and after that successfully calculates the shortest distance to the destination from the user's current location and then finally directs the user to the destination through 3D arrows using ARCore and when the user reaches the destination system shows a pin. The main objective of the project was to ensure that the user reaches the destination location from shortest distance with no delay, which is fulfilled through this project.

5.6 Inferences Drawn

The following inferences have been drawn through this project:

1. The above mentioned testing techniques prove that our proposed system NaviGuide provides sufficiently accurate results. The system successfully locates the user within a small margin of error and tracks the user's motion throughout the building.
2. We have been able to successfully use cost efficient techniques in our navigation system such as using printed visual markers in the form of QR codes instead of expensive beacons.
3. The optimal path finding algorithm used for our application, Navmesh has proven to produce the shortest walkable distance to the destination.
4. SLAM (Simultaneous Localization and Mapping) technology has been able to successfully gather visual data from the surrounding physical environment and feed that into the system in order to produce correct directions.

5.7 Validation of Objectives

Table 8 shows the status of the objectives of the project. It describes whether each of the four objectives were achieved or not.

Table 8: Status of Objectives

S. No.	Objective	Status
1.	To generate self-contained visual markers with cloud linkage.	Successful
2.	Positioning: To find the current precise location of the user via device shaking.	Successful
3.	Routing: To redirect the optimal path to destination through voice.	Successful
4.	Rendering: To generate 3D virtual images.	Successful

CHAPTER 6: CONCLUSIONS AND FUTURE SCOPE

6.1 Conclusions

As supported by our work, we conclude that our proposed system NaviGuide, a 3D Indoor Navigation System has been implemented in an efficient manner in comparison to the existing systems. The technologies such as Augmented Reality, Unity, AR core, Visual Studio and Android platform have helped us design a system in which the user firstly scans the nearby self generated marker (QR code) to get a 2 dimensional view of the nearby location, after which the user gets to choose from the available destinations. On choosing any of the desired destinations, the user is shown an optimal path directing the user to this destination, the path of which is calculated with the help of NavMesh technology. The user then shifts to the 3 dimensional view in which the he/she is guided through this optimal path with the help of 3 dimensional arrow markers thus leading him/her to the final destination. Thus, NaviGuide finds an optimal path in real time to the required destination in a user friendly manner.

6.2 Environmental/ Economic/ Social Benefits

NaviGuide has the following environmental, economic and social benefits:

- Since users would now be able to navigate inside buildings via an app in their smartphones, organisations would not have to spend money on printing and displaying maps of the layout of the building to guide the users.
- Paper would no longer be wasted on printing maps and displaying information outside cabins as these would be replaced by the application.
- Money would no longer have to be spent on hiring guides inside buildings and monuments.
- Most of the other navigating softwares require beacons or other expensive technologies to function. NaviGuide can operate without any such technology.

6.3 Reflections

During the course of this project, we learned the following:

1. We gathered domain knowledge about the various techniques that can be used to implement an indoor navigation system.
2. We learned how to use tools and softwares such as unity and ARCore.
3. We learned about algorithms such as Navmesh, SLAM, etc and studied their workings.
4. We learned how to collaborate as a team for faster development. We learned how individual team members could work on separate modules in parallel, on separate branches, and later merge the code bases into a single branch, using version control systems like Git.

6.4 Future Work

NaviGuide is supported by Android devices running on Android 8 and later. We will try to find some alternative technology such that it is available for previous versions as well. Also an application for the IOS users can be developed as a future prospect. We can consider taking input as a video feed so that any new features can be recognized more accurately and improve the field of view. As a future prospect, NaviGuide can be implemented on more complex buildings such that it is able to distinguish between various floors. More research on technologies that can be used shall help us to improve upon the accuracy and reliability of our proposed system.

CHAPTER 7: PROJECT METRICS

7.1 Challenges Faced

Following are some of the challenges faced by the team:

- **ARCore Compatible Devices:** ARCore is a platform for developers needing Augmented Reality assistance in the android apps. Not all android devices are compatible with ARCore. Only devices with Android 7+ are compatible with ARCore. Due to this NaviGuide works only on devices with Android 7+.
- **Indoor Mapping:** Creating an indoor map of a building is not as easy as making a map of the outdoor environment as we do not have GPS signals indoor. Generating map was a big challenge for our team as it must be accurate otherwise NaviGuide will not be able to find the shortest path to destination.
- **ARCore:** We have used ARCore for rendering 3D arrows to show the path to the user in real-time. It was a relatively new concept for our team. Incorporating it in the project efficiently was quite a challenge.
- **Designing the Mobile Interface:** Designing interface for the android application was also one of the challenges which were faced by our team. It was difficult to show large amount of information on the small screens of mobile devices. The UI had to be designed in such a way that the information shown on a screen should be complete, so the user wouldn’t miss out on important information, and it should be organized so that the user would not be overwhelmed by a large amount of information shown in a small place.

7.2 Relevant Subjects

Course subjects that are applied during the development of the system are as follows -

- **Augmented Reality:** Concepts of augmented reality shall be used to ease the navigation process in the application for the user by creating an interactive experience with the real world environment.
- **Data Structures:** Data structures shall facilitate the development of an appropriate

algorithm to find the optimal path from one location to the next.

- **Computer Networking:** Concepts of computer networking shall enable the application to use Wi-Fi signals to accurately determine the location of the user with respect to the surrounding environment.
- **Software Engineering:** The basic work plan to be followed for the development of the application is derived from the concepts of software engineering.
- **Database Management System:** Concepts of DBMS shall be used to store the details of all the locations inside the building, such that an optimal path can be generated from one location to the other.
- **Computer Programming:** Computer programming would facilitate the development of the application such that it can perform all the tasks required by it.

7.3 Interdisciplinary Knowledge Sharing

For the complete development of this project in-depth knowledge of various courses was required. All the members of the team are pursuing B.E. in computer engineering so we thought of dividing the learning task amongst the team members. Each member of the team learns a new technology or concept and shares it with other team members. All the team members were eager to learn new technologies that helped in the development of this project. Some of the concepts and technologies which were required to develop this project are briefly explained below:

- **Android:** Android is a mobile operating system based on the modified versions of linux kernel and other open source softwares developed to be used for touchscreen mobile devices such as smartphones etc.
- **ARCore:** ARCore is a platform by google that is used to build augmented reality applications by making use of its ability to sense the environment and interact with it.
- **Augmented Reality:** It is a technology that is used to create systems such that the user is unable to find differences between the real world and the virtual environment created by it. In our application we will be making use of augmented reality to create 3D pointers which can guide users through the augmented environment to the chosen final destination.
- **Git:** Git is an open-source tool used by developers to collaborate with each other for the

development of a project. It is also used to store and manage changes made on the set of files over time.

- **Navmesh:** Navmesh is a class in Unity that is usually used for pathfindings or walkability tests. Such classes are used to compute optimal paths between objects in a large space.
- **Unity:** Unity is a cross-platform game engine along with a built-in IDE that is used to create 2 dimensional, 3 dimensional, virtual and augmented reality games. Since our project aims to implement the navigation system in an augmented environment we will be making use of Unity software.
- **Visual studio:** Visual studio is a tool by Microsoft that is being used as a default C# script editor for unity that comes preinstalled in the Unity Download Assistant, as well as in the UnityHub installation tool.

7.4 Peer Assessment Matrix

The Peer Assessment Matrix for the team by each member of the team has been given in Table 9. Each member has been ranked from 1 (min) to 5 (max).

Table 9: Peer Assessment Matrix

		Evaluation of			
		Simran Kaur	Srishti	Harnoor Sandhu	Manvi Kaul
Evaluation by	Simran Kaur	5	5	5	5
	Srishti	5	5	5	5
	Harnoor Sandhu	5	5	5	5
	Manvi Kaul	5	5	5	5

7.5 Role Playing and Work Schedule

The responsibilities of each team member during the project have been discussed below:

- **Simran Kaur:** Research on existing systems, generation of Visual Markers, designing the User Interface, implementation of Optimal Path Finding Algorithm, testing and documentation.
- **Srishti:** Research on existing systems, generation of Visual Markers, designing the User Interface, implementation of Optimal Path Finding Algorithm, testing and documentation.
- **Harnoor Sandhu:** Research on existing systems, implementing the Map, localization, setting up ARCore, rendering the path in Augmented Environment and documentation.
- **Manvi Kaul:** Research on existing systems, implementing the Map, localization, setting up ARCore, rendering the path in Augmented Environment and documentation.

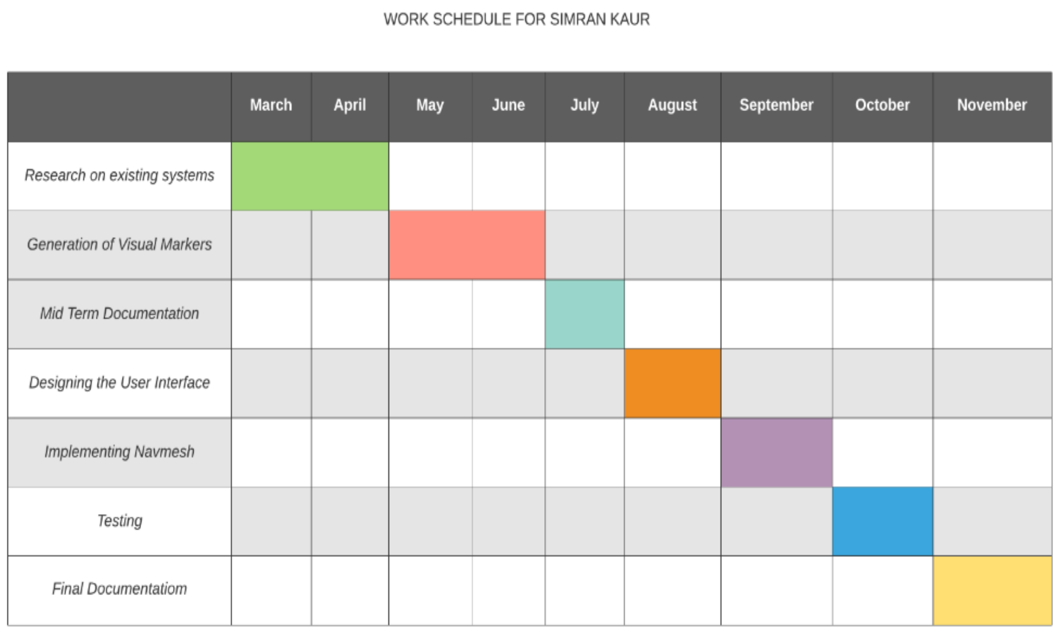


Figure 20: Gantt Chart for Simran Kaur

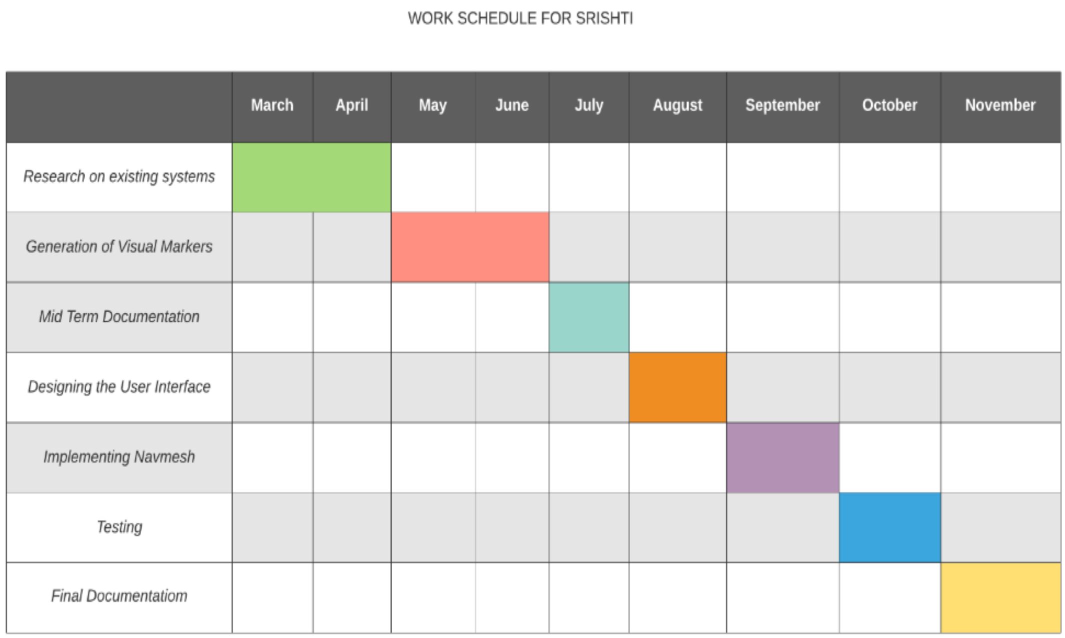


Figure 21: Gantt Chart for Srishti

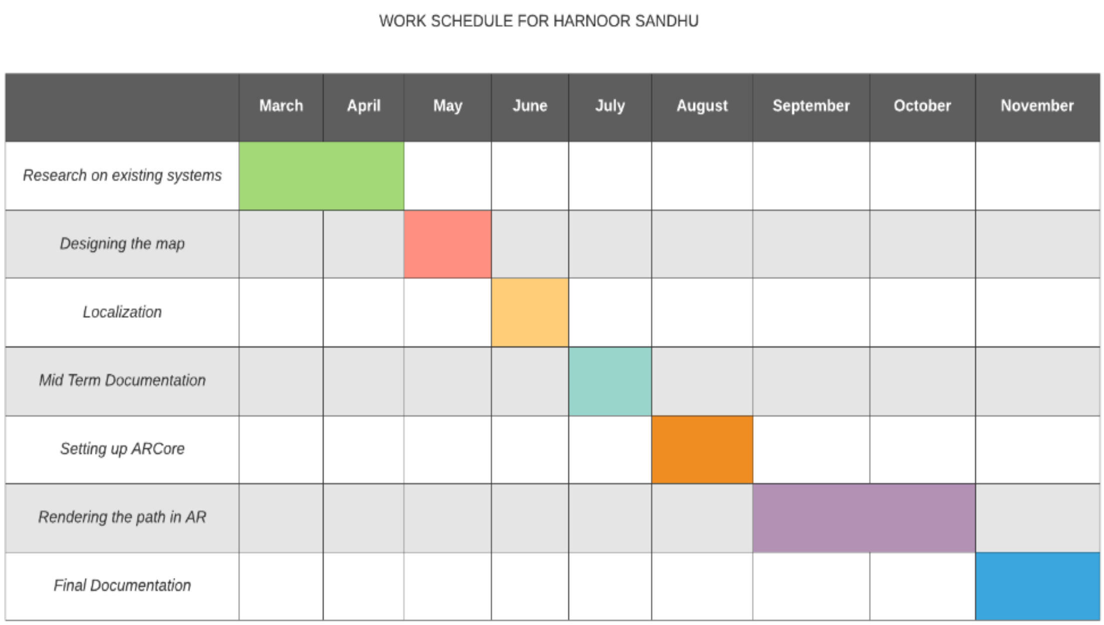


Figure 22: Gantt Chart for Harnoor Sandhu

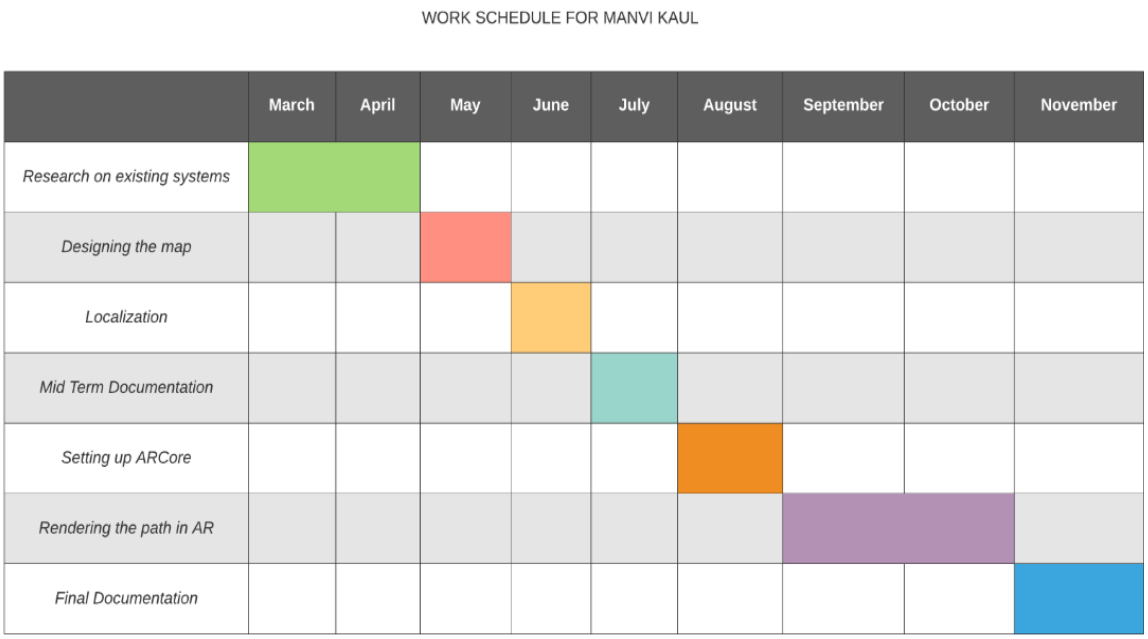


Figure 23: Gantt Chart for Manvi Kaul

7.6 Student Outcomes Description and Performance Indicators (A-K Mapping)

The student outcome mapping (A-K mapping) is shown in Table 10.

Table 10: Student-outcome mapping (A-K mapping)

S. No	Description	Outcome
A1	Applying mathematical concepts to obtain analytical and numerical solutions.	For finding the optimal path, Unity uses A* algorithm. It is an effective algorithm and uses heuristic function to find the shortest path between two locations.
A3	Applying engineering techniques for solving computing problems.	We designed a real-time Navigation System for real-time Navigation from users location to destination.
B1	Identify the constraints, assumptions and models for the problems.	Suitable time and cost constraints were set. Assumptions like good internet connectivity, were made to imitate real world conditions.
B2	Use appropriate methods, tools and techniques for data collection.	Collecting the current location of the user using ARCore SLAM technology to start the navigation process.
B3	Analyze and interpret results with respect to assumptions, constraints and theory.	Due to the time constraint the project is implemented on a small scale and the system accurately calculates the

		shortest path from the user's current location to all possible destination locations.
C1	Design software system to address desired needs in different problem domains.	We have designed a Navigation system which on extension, can be effectively put into use for Navigation in other places as well like Airports, Shopping Malls, University etc.
C2	Can understand scope and constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.	This system is technologically sound and very beneficial if implemented in a public place where paths can be confusing. Since users would now be able to navigate inside via an app in their mobile phone, organizations would not have to spend money on printing which will save paper and thus the environment.
D1	Fulfil assigned responsibility in multidisciplinary teams.	Divided the workload of development as well as documentation between team members. Each member completed the task assigned to them.
D2	Can play different roles as a team player.	Each member was assigned a different part of the project like Indoor mapping, positioning, routing, rendering, deployment and documentation.
E1	Identify engineering problems.	A vital factor while developing an Indoor Navigation System is to find the precise location of the user. This problem was efficiently solved using the SLAM technology.
F2	Able to evaluate the ethical dimensions of a problem.	We comprehended the sensitivity of the data that this system is collecting, and made efforts to make sure that the privacy of the users of the system is maintained.
G1	Produce a variety of documents such as laboratory or project reports using appropriate formats.	We completed and submitted all the required documents timely. All the documents were properly formatted, well written and without any errors.
G2	Deliver well-organized and effective oral presentation.	We presented our project in front of the panel in a commendable way. The presentation was divided equally among all the members, and each member knew their materials well. We were successful in expressing our idea to the panel members, and answering all their questions.
H1	Aware of environmental and societal impact of engineering solutions.	Since users would now be able to navigate inside via an app in their mobile phone, organizations would not have to spend money on printing which will save paper and thus

		the environment. Our system shall make finding a particular destination within a building much easier and time efficient for the user.
H2	Examine economic tradeoffs in computing systems.	Although some Navigation Systems use beacons for calculating a user's current location more accurately, we have used SLAM technology as it is more cost efficient.
I1	Able to explore and utilize resources to enhance self-learning.	We spend a lot of self-effort hours learning new technologies and design patterns, from official documentation, blog posts and articles, and websites such as StackOverflow
I2	Recognize the importance of life-long learning.	We reflected that when it comes to technology, learning is a life-long process. We must always stay up to date with the least technology in order to enhance our systems and deliver better products.
J3	Comprehend the importance of contemporary issues.	Focusing on contemporary issues is significant, as these issues are what inspire innovation, which leads to the development of better technology and products, thus improving the state of living.
K1	Write code in different programming languages.	This project is developed in Unity which uses C# language for writing scripts.
K2	Apply different data structures and algorithmic techniques.	To find the optimal path, A* algorithm has been used effectively.
K3	Use software tools necessary for computer engineering domain	We have used a wide range of software development tools for this project. There includes Unity, Visual Studio, ARCore, Android, Git, NavMesh.

7.7 Brief Analytical Assessment

This section discusses about the brief analytical assessment as per the given questions:

Q1. What sources of information did your team explore to arrive at the list of possible project problems?

Ans: To get some knowledge about the technical aspect of the domain we studied a good number of research papers and articles to gather what problems the current solutions have and how we can improve and build upon the research done by others.

Q2. What analytical, computational and/or experimental methods did your project team use to obtain solutions to the problems in the project?

Ans: We used Unity for the implementation of our project. ARCore is used for the 3D arrows for displaying the shortest path to the user. The shortest path is calculated by NavMesh in Unity which uses A* algorithm.

Q3. Did the project demand demonstration of knowledge of fundamentals, scientific and/or Engineering principles? If yes, how did you apply?

Ans: Yes, the project required knowledge of the fundamentals, scientific and engineering principles. The project required vast knowledge of the domain and requires the use of proper technology stack. Without the proper technology stack and efficient design patterns, the system would not be able to perform in real time.

Q4. How did your team share responsibility and communicate the information of schedule with others in the team to coordinate design and manufacturing dependencies?

Ans: Our team shared the responsibility of this project very well. All the team members were eager to learn new technologies and frameworks. The development of this project was divided among all the team members. Weekly meetings were organized so that team members could express their concerns and take advice from other team members. Weekly progress was also discussed in these meetings. Meetings with the project mentor were also organized and progress on the project was also shared with the mentor. Feedback from the mentor was noted and worked upon.

Q5. What resources did you use to learn new material not taught in the class for the course of this project?

Ans: The project required knowledge of the new frameworks and services. To learn new technologies and frameworks we used blog articles and online forums like StackOverflow, but most of the time, learning was done through the official documentation of a particular technology.

Q6. Does the project make you appreciate the need to solve problems in real life using engineering and could the project development make you proficient with software development tools and environments?

Ans: Indeed, the project made us appreciate the need to solve problems in real life. We are very optimistic about solving more real-world problems in the future. Developing this project made us capable enough to work on software development tools and environment. This project helped in getting started in development and taught us how to self-learn new technologies and use these technologies to our benefit.

APPENDIX A: REFERENCES

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APPENDIX B: PLAGIARISM REPORT

URKUND

Document Information

Analyzed document	NaviGuide.pdf (D90467112)
Submitted	12/22/2020 12:21:00 PM
Submitted by	Anika
Submitter email	anika@thapar.edu
Similarity	1%
Analysis address	anika.thapar@analysis.urkund.com

Sources included in the report

W	URL: https://www.letsnurture.com/how-much-would-it-cost-to-build-a-mobile-ar-wayfinding ... Fetched: 12/22/2020 12:22:00 PM	3
W	URL: https://www.researchgate.net/publication/229034096_Augmented_reality_based_indoor_ ... Fetched: 10/25/2019 4:45:27 PM	3
W	URL: https://www.researchgate.net/profile/Muna_Al-Razgan/publication/305805769_Ebsar_In ... Fetched: 12/10/2019 10:53:22 PM	2
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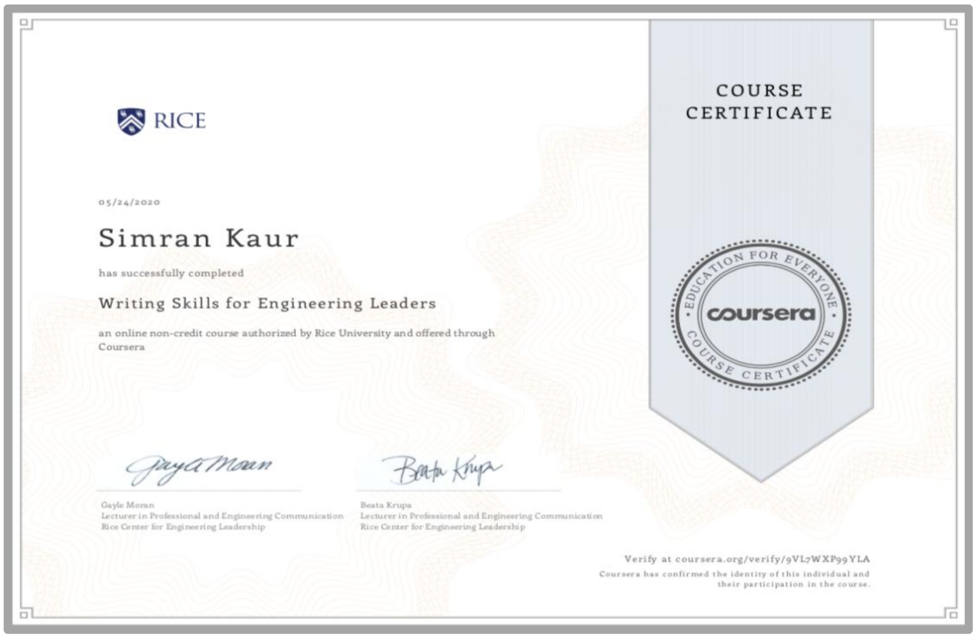
W	URL: https://core.ac.uk/download/pdf/148366578.pdf Fetched: 10/27/2019 1:20:39 AM	1

APPENDIX C: WRITING COURSE CERTIFICATES

The following are the certificates of completion of all the team members for the writing course offered by Coursera.



RICE

COURSE CERTIFICATE

05/24/2020

Simran Kaur

has successfully completed

Writing Skills for Engineering Leaders

an online non-credit course authorized by Rice University and offered through Coursera

Gayle Moran
Lecturer in Professional and Engineering Communication
Rice Center for Engineering Leadership

Beata Krupa
Lecturer in Professional and Engineering Communication
Rice Center for Engineering Leadership

Verify at coursera.org/verify/9VL7WXP99YLA
Coursera has confirmed the identity of this individual and their participation in the course.

RICE

COURSE CERTIFICATE

05/24/2020

Srishti

has successfully completed

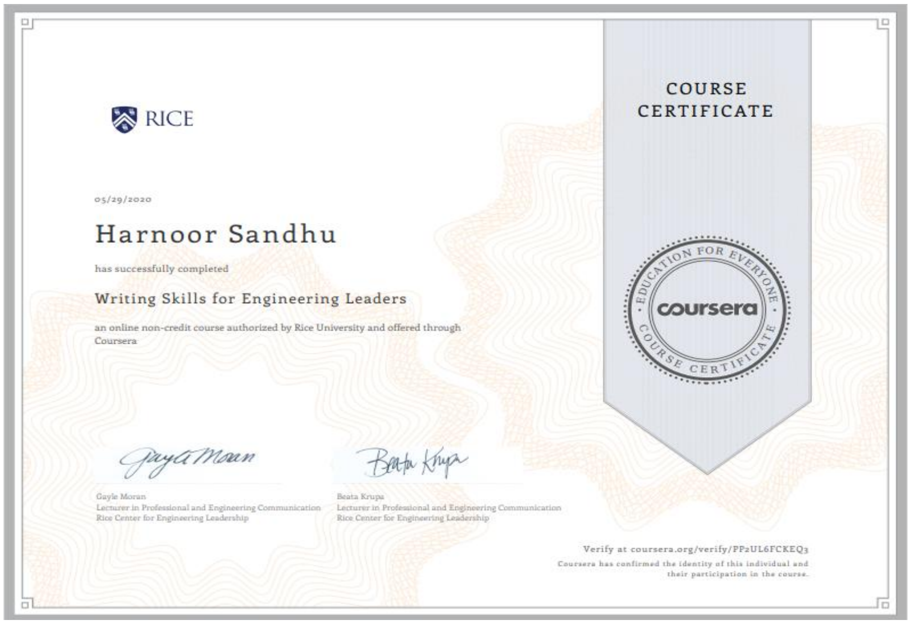
Writing Skills for Engineering Leaders

an online non-credit course authorized by Rice University and offered through Coursera

Gayle Moran
Lecturer in Professional and Engineering Communication
Rice Center for Engineering Leadership

Beata Krupa
Lecturer in Professional and Engineering Communication
Rice Center for Engineering Leadership

Verify at coursera.org/verify/38RNSWUX228F
Coursera has confirmed the identity of this individual and their participation in the course.


RICE

COURSE CERTIFICATE

05/29/2020

Harnoor Sandhu

has successfully completed

Writing Skills for Engineering Leaders

an online non-credit course authorized by Rice University and offered through Coursera

Gayle Moran
Lecturer in Professional and Engineering Communication
Rice Center for Engineering Leadership

Beata Krupa
Lecturer in Professional and Engineering Communication
Rice Center for Engineering Leadership

Verify at coursera.org/verify/PP2UL6FCKEQ3
Coursera has confirmed the identity of this individual and their participation in the course.


RICE

COURSE CERTIFICATE

05/28/2020

Manvi Kaul

has successfully completed

Writing Skills for Engineering Leaders

an online non-credit course authorized by Rice University and offered through Coursera

Gayle Moran
Lecturer in Professional and Engineering Communication
Rice Center for Engineering Leadership

Beata Krupa
Lecturer in Professional and Engineering Communication
Rice Center for Engineering Leadership

Verify at coursera.org/verify/U5UZ4XJQAY6R
Coursera has confirmed the identity of this individual and their participation in the course.