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**Indoor environments navigation assistant, guidance,
and localization system for visually impaired and
blind individuals**

**A Project Submitted in partial fulfilment of the requirements for the
Bachelor Degree in Computer Engineering**

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ABSTRACT

Visually impaired and blind individuals might face difficult challenges when navigating through indoor environments, especially if they were not familiar with them. Indoor environments can be very unpredictable and filled with obstacles, and they are rich of important visual information which only designed for eyes consumption. These difficulties rise the need of these individuals to assistants and guiders whether by asking strangers, or by taking companions. But these solutions will lead to decreasing the independence of these individuals. We are trying to offer a solution in this project, a wearable and easy to use system that guides and assists the users after determining their positions and scanning their surrounding environments using only a camera and smart phone.

The proposed system is an integration of three systems: Objects Detection, Localization, and Customizable Guidance System. These components rely on analyzing the images captured by a camera and extracting the important visual information from them. The Objects Detection System can detect the surrounding objects and describe them to the users if they asked to, and inform users about obstacles, and users can ask it to alarm them when they face an object with certain characteristics, such as a man wearing red T-Shirt. The localization system will use the camera to detect artificial landmarks to determine the user's location. And finally, the Customizable Guidance System reads to user custom information and instructions after entering specific areas.

- the result obtained

- the significance of the result or finding

KEYWORDS: Localization; Obstacles Avoidance; Objects Detection, Customization; Guidance; Pose; Calibration

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Glossary and List of Abbreviations

Glossary

Term 1 Definition of term 1.

Term 2 Definition of term 2.

List of Abbreviations

Abbr. Full form of the abbreviation.

Chapter 1

Introduction

1.1 Overview

Navigation in indoor areas presents considerable difficulties for those with visual impairments. Conventional GPS systems, while proficient in outside navigation, are inadequate for indoor environments due to diminished satellite signals and the intricate designs of spaces such as retail malls, hospitals, and educational institutions. Researchers have investigated alternate ways, including the use of artificial landmarks, to facilitate indoor navigation.

Artificial landmarks, including QR codes, offer a cost-effective and readily implementable alternative for localization and navigation in interior settings. These landmarks are identifiable by cameras or sensors, enabling visually challenged individuals to obtain audio or tactile feedback for navigational assistance. This project proposes a QR code-based navigation system to ensure precise localization and dependable obstacle detection for those with visual impairments. This project aim to develop a low-cost indoor navigation system that will combine accurate indoor localization, reliable obstacle detection, and customizable, for indoor environment using (... Tools and Software and QR code) to help with visual impairments.

1.2 Motivation

This project is motivated by the need to enhance the quality of life and autonomy for visually impaired individuals, especially in interior settings where conventional navigation aids such as GPS are inadequate. Visually impaired individuals encounter significant obstacles when navigating intricate indoor environments, which can restrict their mobility and independence. Existing options, such as guide dogs and human aid, although beneficial, may prove inadequate or unworkable in all situations. The motivation also is to develop a prototype solution utilising commonly accessible technology (such as QR codes and mobile devices) enhances the system's accessibility to a broader audience (Cost and Accessibility). This differs from expensive or complex systems that may require specialized hardware.

1.3 Problem Statement

Navigating indoor environments is challenging for visually impaired individuals, directly affecting their independence and daily activities. While some existing technologies have developed separate algorithms for indoor localization, they are often not integrated into a user-friendly device that individuals can easily use.

Moreover, many solutions rely on expensive sensors, increasing the overall cost of the device. Additionally, the majority of current aids do not provide a cohesive approach that combines accurate localization with obstacle detection, and they often lack context-specific, non-visual instructions tailored to the unique needs of visually impaired users. This highlights the urgent need for an affordable, integrated indoor navigation system that enhances mobility and independence in everyday settings.

1.4 Project Objectives

1.5 Project Outline

The remainder of this report is organised as follows: Chapter 2 provides the Background and the related works. Chapter 3 provides the project system design, and Chapter 4 covers the implementation. Chapter 5 provides the results obtained by the system, and Chapter 6 concludes the report.¹

¹Next Term. But we can mention it from now.

Chapter 2

Background

2.1 Introduction

The world isn't fair for the visually impaired, plenty of normal, everyday routes become hazardous without any way to see them, stairs, crowds, elevators, stores and plenty of stuff they're oblivious about existing unless someone guides one to them; even regular protrusions are tripping hazards and this is prevalent in most buildings where safety standards aren't enforced which accounts for most residential blocks in Saudi Arabia. There's also a rising concern of people with no family acquaintances or vacant assistants which gets more prevalent year by year thanks to the rise of the internet, which forms another big hurdle to the blind of today.

That's not to say that people didn't try to offer solutions to this; although it's apathetic compliance to authorities, there had been some effort to put Braille under hanged labels and on the ground (Figure 0.0 demonstrates an example of Braille)

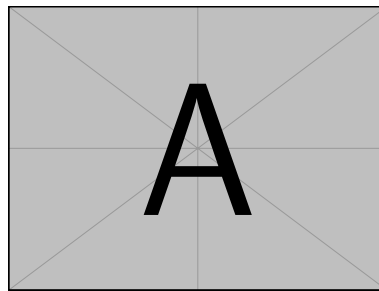


Figure 2.1: Braille

A conundrum arises though, how could a blind person tell where that hanged label or ground protrusion is, much less know how to read it?

You never know when you go blind, there's a good chance you would get it unexpectedly so you might not even know where to look to learn it if the previous paragraph also applies to said individual, in response to this, a much more respectable effort came in the form of tactile pavements, the blind shouldn't have to know anything about how to distinguish each tile, they just have to know it's presence, while they might still be able to miss it in certain cases, the authority of said place or building can just line them up in such a way that it becomes hard to miss since they also have the benefit of being generic tiles that only signal danger or caution, meaning one wouldn't have to make different tiles for each place, they just have to stick with one pattern, reducing cost of manufacturing and maintaining them significantly, below is a figure for an example tactile pavement.

Paragraphs above need citations to confirm their validity

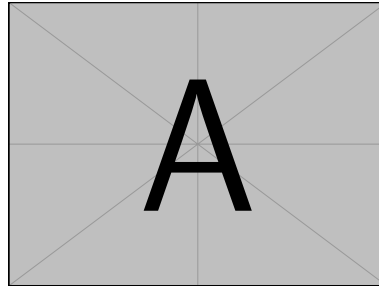


Figure 2.2: Example of a tactile pavement

A problem is still standing however, while they might signal potential danger or sudden elevations of ground or the edges of a track, they don't guide you anywhere so the blind is still hopelessly lost in the midst of a crowd and doesn't know which is where.

We've embarked on a project to change that, with the galactic rise of smartphones, odds are almost everyone is equipped with smartphones.

We aim to guide them with an inexpensive, easy to set up and maintain, and with cellular, you don't even have to have access to the internet to make it, which means higher odds that remote mosques and other such buildings to use it without any fear of cost or the presence of a maintainer.

2.2 Landmarks(Natural & Artificial)

Landmarks can be categorized as either natural or artificial. Natural landmarks are formed by nature, such as mountains, rocks, trees, or any other natural formations. While on the other hand, artificial landmarks are human-made structures such as traffic signs, statues, and QR codes. both categorizes can be used in various important fields in computer science. For example, computer vision algorithms leverage landmarks by detecting, identifying, and tracking them to determine the precise location of an object, create a 3D map of the surrounding environment, or to monitor the state of an object.

While both categorizes can be very useful, natural landmarks are much harder to recognize, very diversified and do not have uniform shapes, difficult to customize, and they do not encode data. All of these characteristics can be opposite in the artificial landmarks, which make them better in terms of control, precision, reliability, and adaptability. Also there are a lot of libraries that support encoding, detecting, decoding, and tracking artificial landmarks. There are also a wide variety of artificial markers such as QR, Arcuo, Topotag. More info on the other kinds of markers are present on reference [1].

2.3 QR code

Quick Response (QR) codes are a type of matrix barcode designed for efficient data encoding and rapid scanning. QR Codes first developed in 1994 by Denso Wave, to track automotive parts in manufacturing. but have since become widely used across various applications due to their versatility, simplicity, and capacity to store significant amounts of information compared to traditional barcodes.

2.3.1 QR Structure

QR Codes can be detected and decoded at various angles and distortion levels due to their unique structure. The code consists of black modules (squares) arranged on a white background in a grid pattern, allowing for rapid and error-resistant scanning. All QR Codes have standard structure as shown in Figure 2.3. This structure is made out of the following parts:

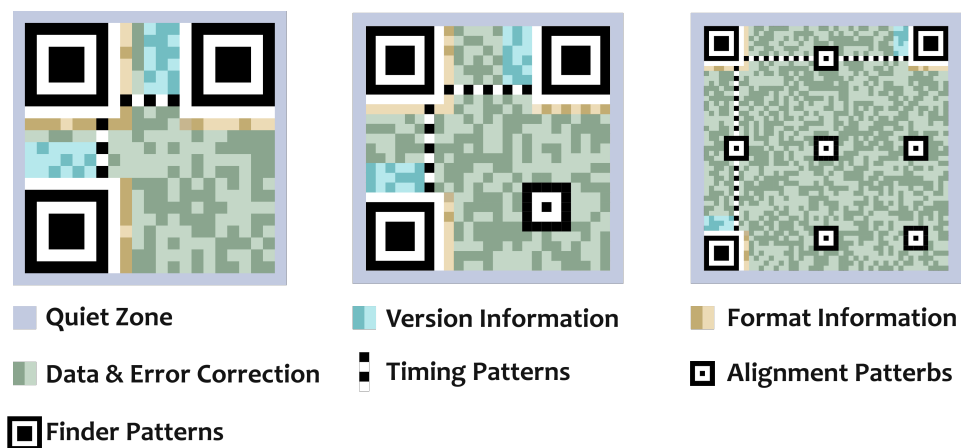


Figure 2.3: These are three QR Codes that store texts. The texts' lengths get larger going from the left to the right. Notice that the alignment pattern only appears at the bigger QR Codes, and there are multiple ones at the biggest QR Code.

- **Quiet Zone:** This is a white empty area surrounds the QR Code that helps distinguishing it from its surroundings.
- **Version Information:** QR Codes have different versions/sizes which specified by these two areas.
- **Format Information:** This part provides details about the error correction level and data mask pattern used.
- **Data & Error Correction:** This is where both encoded data & error correction are. data and error correction are stored together enabling the

QR code to recover and reconstruct the stored data, even if up to 30% of the code is damaged or obscured. Data have different types, such as text, URLs, or other.

- **Timing Patterns:** This part is essential for defining the grid's structure and assists the scanner in establishing the size and coordinate system of the code.
- **Alignment Patterns:** The Alignment Patterns help correct distortion and skewing of the QR code when viewed from different angles. It is especially crucial for larger QR codes that may be prone to bending or misalignment.
- **Finder Patterns:** These patterns assist the scanning device in rapidly locating and orienting the QR code, regardless of its rotation or angle.

See [8], for more information.

2.3.2 QR Code Versions and Types

QR codes come in 40 versions, each representing a different size and data capacity. Version 1 contains 21×21 modules, while Version 40 has 177×177 modules. As the version number increases, so does the data capacity and the complexity of the code, making it capable of storing more information or supporting higher levels of error correction [8].

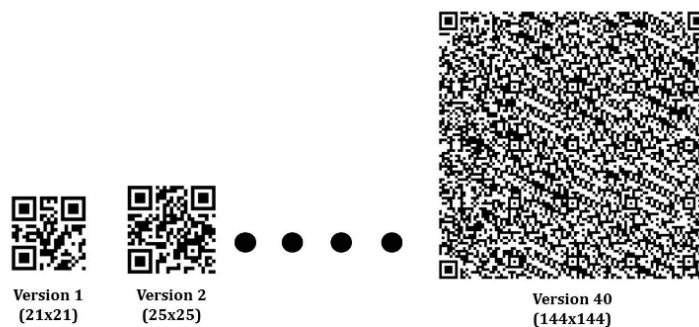


Figure 2.4: QR codes Versions (adapted from [8]).

There are also specialized QR code types designed for specific applications:

- **QR Code Model 1 and 2:** Model 1 is the original version of the QR code, developed in 1994 by Denso Wave. While model 2 is an improved version of model 1, and it is the one most commonly used today. These models are used for daily basis.

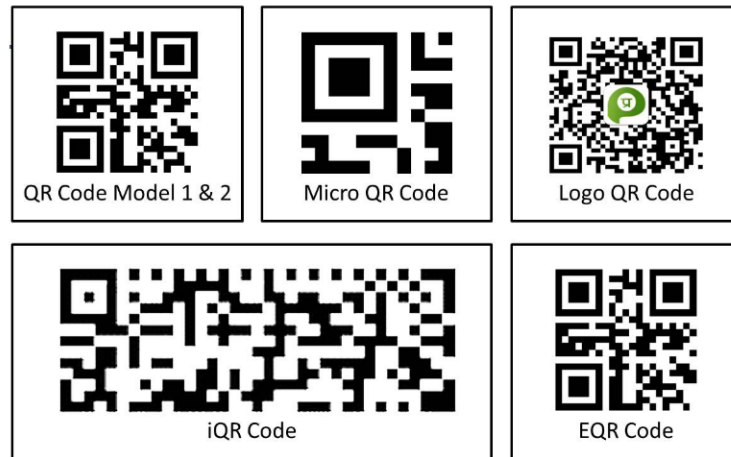


Figure 2.5: QR code types (adapted from [8]).

- **Micro QR Code:** Designed to be smaller and simpler, it uses only one Finder Pattern, making it more compact than traditional QR codes. It is often used when space is limited [8].
- **Logo QR Code:** Allows logos or images to be embedded within the QR code, enhancing the code's visual appeal for marketing or branding purposes [8].
- **iQR Code:** A flexible matrix-type QR code capable of being printed in various sizes and configurations, from small, high-capacity codes to large codes. It can store more data than standard QR codes and can be inverted or turned into dot patterns for direct part marking [8].
- **Encrypted QR Code:** Uses encryption techniques to secure the information encoded within, making it suitable for applications requiring data confidentiality [8].

2.3.3 QR Code Encoding

The encoding process for a QR code involves converting data into a matrix of black and white modules. First, the input data is analyzed to determine the appropriate encoding mode, such as numeric, alphanumeric, byte, or Kanji. The data is then transformed into binary code, and error correction is added using Reed-Solomon algorithms, ensuring that the code can still be scanned if partially damaged [8].

Popular online tools for generating QR codes include:

- **Online Tools:** These free online tools offer simple and fast solutions for both generating and decoding QR codes. QRickit allows users to decode

QR codes from uploaded images, while GOQR.me provides various output formats, such as PNG, SVG, and EPS, making it versatile for different use cases [10][11].

For generating QR codes programmatically, popular libraries include:

- **Python - PyQRCode:** A Python library that simplifies QR code creation, allowing output in SVG, PNG, and other formats [12].
- **Java - ZXing (Zebra Crossing):** An open-source library widely used for encoding QR codes in Java and Android applications [13].
- **iOS - Core Image:** iOS provides native QR code generation capabilities via the ‘CIQRCodeGenerator’ filter in the Core Image framework [14].

2.3.4 QR Code Decoding

Decoding a QR code starts by scanning the Finder Patterns, which allow the scanner to properly align the code. Next, the Format Information is read to apply the correct error correction and mask pattern. Once decoded, the binary data is translated back into the original format (e.g., text, URL) [8].

Common online tools for decoding QR codes include:

- **Online Tools:** These tools offer versatile QR code decoding solutions across platforms. ZXing is an open-source decoder integrated into Android and web applications, QRickit provides online QR code decoding from uploaded images, and Google Lens allows users to scan and decode QR codes directly via smartphone cameras [13, 17].

For decoding programmatically, useful libraries include:

- **Python - Segno:** A versatile Python library for generating and reading both QR and Micro QR codes [15].
- **Java - ZXing:** Provides decoding functionality along with encoding, and is widely used for mobile and web apps [13].
- **iOS - AVFoundation:** iOS provides native support for scanning QR codes using the ‘AVCaptureMetadataOutput’ class in the AVFoundation framework [16].

2.3.5 QR Code Setup

2.4 Indoor Localization

Indoor localization refers to the process of determining the precise position and orientation of an object or person within indoor environments, where traditional GPS signals are often unreliable. This technology is essential for a wide range of applications, such as navigation within large buildings, asset tracking in warehouses, and other useful and important applications.

Various technologies are employed for indoor localization, each with its own cons and pros. Wi-Fi, Bluetooth, RFID, and Ultra-Wideband (UWB) are some of the most common methods. While some systems rely on expensive and complex hardware like sensors and Inertial Measurement Units (IMUs), others use more cost-effective solutions such as Bluetooth beacons, and pose estimation using QR codes. The choice of technology often depends on the specific needs of the application, balancing factors such as accuracy, cost, and ease of implementation. For more information, see reference [9].

As indoor localization continues to evolve, new techniques and innovative approaches are emerging, including the use of QR codes for precise positioning and tracking.

2.4.1 Indoor Localization with QR Codes

Indoor localization using QR codes is a method to determine a user's pose. The system works by strategically placing QR codes around the space—on floors, walls, ceilings, or even hanging panels. Each QR code encodes specific positional information, allowing users to understand their location relative to these codes once they are detected.

The divided environment method The environment in this method is divided into several pieces (a piece might be a square, triangle, hexagon, and any other shape, depending on the need), each piece has its own QR Code inside of it encoding its position, whether it is put on the floor, ceiling, wall, or even in a hanging panel. See [3] where they used a similar method.

For better illustration, let us assume that we have a room of 4 meters in width and height, and it is divided into 16 squares with equal sizes so each square has an area of 1m^2 . If we customized a hat for example, that embeds a camera in its top, the user's position will get determined while navigating in the room wearing the hat.

Although this solution is very computationally cheap, it comes with its own downsides. For instance, the position values are always discrete. So if we needed a continuous and precise position we should not use this method. But actually, this method could be very useful depending on its use, see Appendix A for more details.

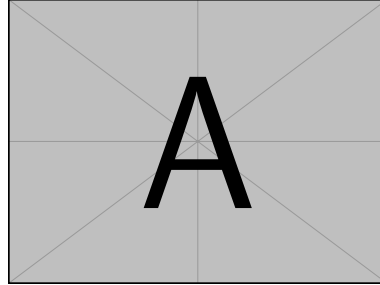


Figure 2.6: Grid Patter Illustration

Pose Estimation with QR codes Another approach of indoor localization involves calculating the relative position and orientation (pose) of the QR code in relation to the camera. After detecting a QR code, the camera determines its position and orientation relative to itself, and by combining this information with the known global position of the QR code, the system can estimate the user's precise, continuous position within the space.

Although this method offers significantly higher positional accuracy, it requires more computational resources, as it involves additional steps such as camera calibration to determine intrinsic parameters. This added complexity makes it more resource-intensive compared to divided environment method, but it delivers continuous localization with greater precision. Thus this method is suitable if continuous and precise values are needed. See [4] where they used a similar method.

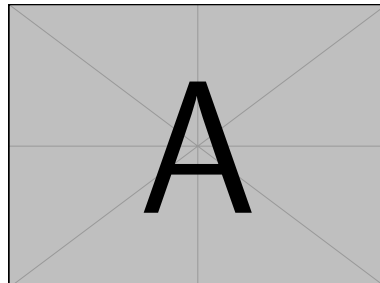


Figure 2.7: Grid Patter Illustration

In a well-designed setup, the system's effectiveness remains high, irrespective of the QR codes' locations. By tailoring the placement and setup of QR codes to

suit the environment, the system can deliver robust indoor localization, whether it prioritizes simplicity or precision.

2.5 Objects Detection

2.6 Customizable Guidance

2.7 Related Work

In the area of localization research, artificial landmarks have been used widely due to their difficulty detecting and building a system upon natural landmarks. However, artificial landmarks, specifically QR codes, have gained notable attention due to their ease of making and implementation, low cost, and the amount of information that can be encoded on them.

In the solution proposed by [3], an approach for indoor mobile robot localization using QR codes arranged in a grid pattern on the ceiling is presented. The robot is equipped with an industrial camera mounted on top, facing upward to detect these QR codes. The camera captures images of the QR codes, and a recognition algorithm processes the position and orientation of the QR codes within the image. By utilizing the coordinates of each QR code and camera calibration data, the robot can accurately determine its position. This setup allows for real-time, precise localization of the robot, which is crucial for effective navigation in structured indoor environments.

The paper [5] introduces a vision-based indoor positioning system that makes use of QR codes and a smartphone camera to accurately determine a user's location indoors. The system positions QR codes at specific locations, which are then identified by the camera. The two-dimensional coordinates of the QR codes are converted into three-dimensional spatial coordinates using camera calibration. By forming a quadrangle from reference symbols on the QR codes, the system calculates the center of gravity to determine the user's position and direction. Experiments have shown an average error of less than 1 meter.

With high accuracy, the paper [6] proposes a cost-effective localization method for indoor mobile robots using QR codes as artificial landmarks. The QR codes are strategically placed on the ceiling, and a smartphone mounted on the robot detects these codes to determine the robot's position and heading direction. The QR code positions are pre-stored in a database, allowing the robot to calculate its real-world coordinates by processing the image data from the smartphone camera. The accuracy of the system has been confirmed, indicating that the

method can produce localization errors ranging from 3.2 cm to 6.55 cm.

We should mention as a conclusion of this section how our solution will differ from them whether by accuracy, multiple tech integration, targeted audience, real world validation method, etc.

Chapter 3

System Design

3.1 System Design

The system design chapter presents the overall architecture and key components.

Chapter 4

Results and Discussion

4.1 Results

This chapter presents the results obtained from the system.

| Scenario | Expected Result | Actual Result |
|------------|-----------------|---------------|
| Scenario 1 | Success | Success |
| Scenario 2 | Failure | Success |

Table 4.1: Results of Various Scenarios

Table 4.1 shows the results obtained during testing in various scenarios.

Chapter 5

Conclusion and Future Work

5.1 Conclusion and Future Work

The project concludes by summarizing the findings and suggesting future work.

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Appendix A

A.1 The divided environment method

The idea of dividing an environment into smaller pieces is widely used in some industries in different ways and purposes. One of these industries is the video game industry. A huge amount of video games divide the game world into a chunk of squares, triangles, hexagons, and other shapes depending on the game's need and performance. But the difference here is that they do not use this technique for localization since the positions for all the objects in the games are known and stored at the RAMs already. They use the technique to categorize the pieces such as walkable ground, water, lava, rocks, and so on. Then these pieces are used along with their categories to find a proper path between two points. Different path finding algorithms can be used, but the most popular and simple one is A* algorithm. See this [4] incredible youtube tutorial made by Sebastian Lague, that explain an implementation of the A* algorithm and how it can be optimized.