TRAIN ROBOT TO CLIMB STAIRS: DETECT THE STAIRCASE

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Project Proposal Report

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DECLARATION

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

Name	Student ID	Signature
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The above candidate is carrying out research for the undergraduate Dissertation under my supervision.

Signature of the supervisor: Date:

ABSTRACT

Currently, robots are used for different work types, like the manufacturing industry, healthcare, and hotel industry. According to the current epidemic situation, the usage of robots was increased because of the need to reduce human interaction. As a result, they have to walk around the workplace, because of that, they may have to climb staircases. So that robot needs to identify staircases among the different objects in the environment. The identification of the stairs is the primary purpose of this study. Clear vision is the main characteristic of doing something fast, safe, and smooth. Therefore, the robot needs to learn using some data set of staircases. That data set will be taken from different angles and types. By understanding that data set, the robot will get an idea about staircases. That like a child is learning to walk. First, want to know what the objects are, then walk. The identified images from the image sensors will get as input. The technology stack that is used for image analyzing is a computer vision-related method in deep learning. Other than that, while climbing the stairs robot needs to identify whether the staircase is over or not. Here introduces a new concept: get the number of steps required to climb before climbing the stairs. It is related to how humans identify things by seeing and making decisions.

Keywords: robot, staircase, machine learning, computer vision

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

According to technology development, people use that to make their more effortless and comfortable their lives. As a result of that, different types of robots, designs are coming out. Those robots specialized in tasks. Such as cleaning, helping older adults, build vehicles, rescue tasks, etc. So, some types of robots need to walk through the surroundings to do their work. Because of that, they have to detect obstacles, staircases, vehicles, tables, chairs, etc. [1]. For example, in a rescue task in a building with many floors, the robot needs to climb staircases. So that, staircase detection holds a significant part. The detection and climbing process can handle automatically or with the help of human actions with remote control. But in human interaction, sometimes there will be a radio connection error or insufficient visual information [2]. Therefore, the automated system is very efficient and safe. The primary purpose of this study is staircases identification with a highly accurate rate and do it fast. It will help to climb stairs.

1.1. Background and literature survey

When talking about staircase detection, many researchers have done it in different ways. This system can develop by using a vision-based approach like a human. The human also sees objects through the eyes, that images converted to a neuron signal. That signal sends to the vision area in the human brain. Then the brain can process that signal and give the vision, not only that it can detect the objects based on the previous information.

As mentioned above human have eyes to see things likewise robot has many sensors, ultrasonic sensors, gyroscope sensors, tactile sensors, cameras, etc. Those sensors help get vision and other information of environments, like sound, touch, temperature, and pressure. In previous works, there are three main approaches to detect staircases. Those are sensor-based, vision-based, hybrid systems [1], [3], as shown in figure 1.

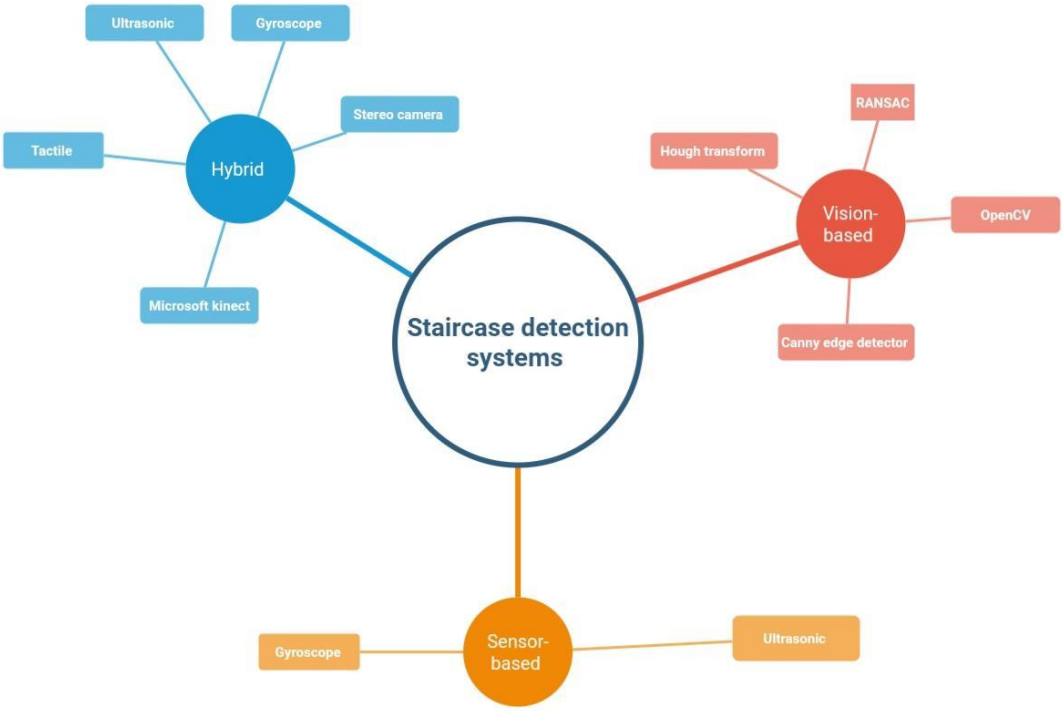


Figure 1 Types of staircase Detection System

a) Sensor-based systems

Department of Mechanical Engineering, K.N. Toosi University of Technology, Tehran, has done research using a Fuzzy Controller for autonomous staircase detection [2]. Laser range finders (LRF) have been used. There are two types of LRFs. Those are vertical (VLRF) and horizontal (HLRF). To identify the staircase using the input array from VLRF is processed. The following characters are considered when determining the stairs,

1. The gap between consecutive vertical lines should be between 25 cm to 35 cm.
2. The length of vertical should be between 12 cm to 25 cm.
3. If the system could find at least one pair above, then move to the next step.
4. Using HLRF should be able to see a line of at least 150 cm in a range of 45 to 135 degrees.

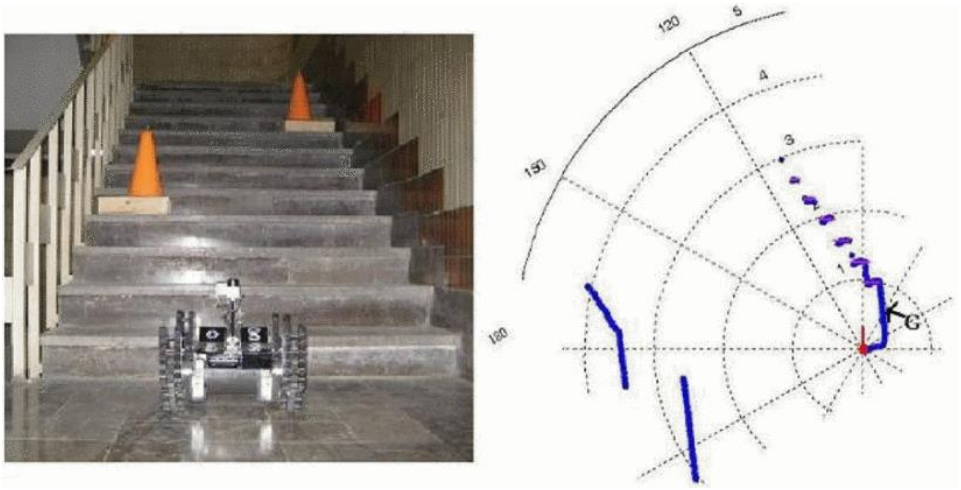


Figure 2 Sample scan of an up staircase.[2]

All the above characteristics are satisfied; the algorithm identified it found a staircase. Figure 2 shows a sample scan of an up-going staircase on the left and the right. According to their experiments, the system performed as expected without any error.

Engineering School of the University of Sfax implements a staircase detection system with one ultrasonic sensor [4]. The purpose of using that sensor is to perform under low light situations. That approach is used to detect and identify ascending staircase and descending staircase. The implemented model is SVM. That can be applied for classification purposes, which is supervised learning. By using that model, they have achieved a 72.41% accuracy rate.

b) Vision-based systems

A real-time staircase detection system was developed by the Institute for Robotics and Intelligent Systems University of Southern California [5]. They have collected 210 images containing 3 to 4 steps of a staircase. To avoid different environmental issues, they have used images with different situations scenes. Those images are preprocessed in different disorders and transformations and make 5250 positive 40×40 pixels images and 7000 negative images which do not contain stairs as they told the implemented system based on AdaBoost. Two new parts were added to that system. Ground plan estimation and Temporal consistency are the newly introduced parts. After the system

takes an image, first do a candidate detection, then do ground plan estimation and temporal consistency. Finally, output the results based on those predictions. When considering their results, false-positive reduces from 1400 to 501, 65% approximately because of the newly introduced two systems.

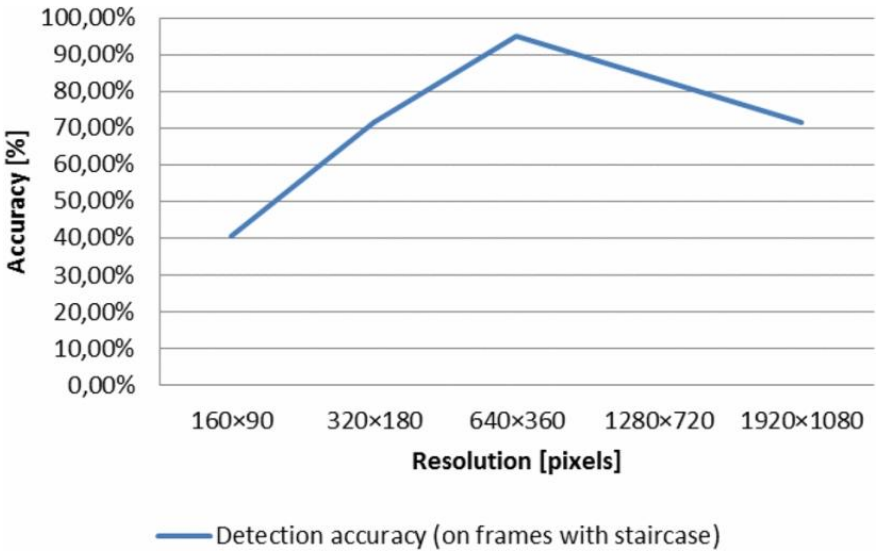


Figure 4 – This shows detection accuracy without staircase [5]

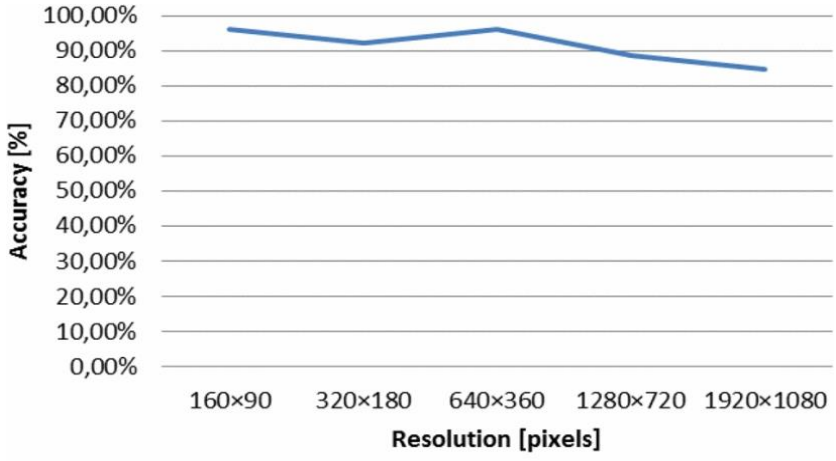


Figure 3 – This shows detection accuracy with staircase [5]

In [6] has researched how the resolution of images causes the accuracy of staircase detection. Staircase detection is happened by analyzing binary image row and column structure. They show that higher resolution images do not gain better accuracy. But the higher resolution is suitable when the staircase on a more considerable distance from the camera. An otherwise low resolution like 160 x 90 is not ideal. As Irena Galic has said: 640 x 360 is the ideal resolution for staircase detection. But it takes 2 to 5

seconds for processing. Another solution can use 320 x 180 for this purpose with a four-times reduction of processing time. Figures 3&4 show how the accuracy change with the resolution.

Wei Lu [7] says there are two types for detecting the stairs. Those are by the shape of a stair and by the specific color on the stair. But the shape base system was not accurate because the distance between robot and stair could not get accurately. The detection by color means white rectangle paper is pasted on the stair as in figure 5. That implemented system detects the color of white paper as a step. So that this system can get the number of steps to need to climb before starting the climbing process, but this needs human interaction and fails under different light conditions because the color of the paper can change according to the light situation.

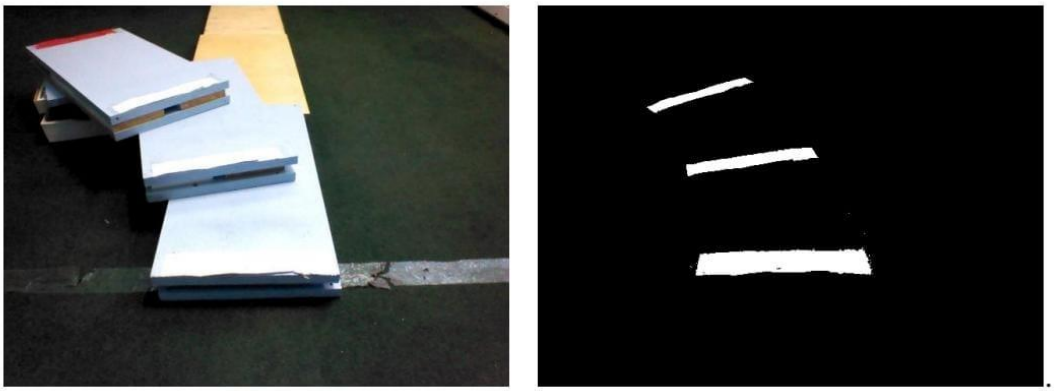


Figure 5 – Detecting stairs by color[7]

c) Hybrid systems

Department of Computer Science and Engineering, Khulna University of Engineering & Technology has developed a hybrid system [3]. In their system introduced two systems, and the collected data was processed by raspberry pi unit. Those systems are ultrasonic sensor-based systems and camera-based systems. The used data set contained 510 images taken from the camera of a cell phone and Google. Before using them to train the model, they preprocessed those images to 720X960 size and labeled them as “upstairs” and “downstairs” classes. “LabelImg” is used for the label images.

The prediction model is based on the Faster-RCNN model of neural network. That system failed to identify upstairs and downstairs correctly when the contrast of images is too high or low. However, in normal light situations, the accuracy rate is 95%.

Other than that Department of Computer Science, University of Freiburg, Germany, had extended Nao humanoid robot with a laser range finder [8]. That laser named as Hokuyo URG-04LX. It is mounted in the head and can get 240 degrees view. They have used 2D laser data from the LRF, inertial measurement unit (IMU) data, and the joint encoders data for localization while walking and climbing stairs. They detect the edges of the staircase by using the images taken by Nao's lower camera and edge prediction done by the lasers. Using that data, the model estimates the 6D robot pose. Then the given 3D environment uses to predict the edges of the image. To detect horizontal edges, they have used probabilistic Hough transform and Canny edge detection. As they said, their robot successfully climbed 97% (86 out of 89) of the stairs with the help of the implemented system.

1.2. Research gap

According to the literature review above, identify stairs is a much-needed implementation because some approaches have not been considered in some areas well. As shown in table 1, there is a comparison between existing research have done previously and the proposed system.

Table 1 Comparisons between past research papers and proposed system

Research	Detect staircase while moving	Support for low light situation	Identify the number of steps
Autonomous staircase detection and stair climbing for a tracked mobile robot using fuzzy controller [9]	Yes	No	No
Autonomous climbing of spiral staircases with humanoids [8]	No	No	No
Staircase Detection to Guide Visually Impaired People: A Hybrid Approach [3]	Yes	No	No
Design And Implementation of Autonomous Stair Climbing with NAO Humanoid Robot [7]	No	No	Yes (with human help)
Real-time Object Detection with Deep Learning for Robot Vision on Mixed Reality Device [10]	Yes	No	No
Autonomous RGBD-based Industrial Staircase Localization from Tracked Robots [11]	Yes	No	No

Stair's recognition using stereo vision-based algorithm in NAO robot [12]	Yes	No	No
Proposed system	Yes	Yes	Yes

1.3. Research problem

According to the Statista Research Department, on June 16, 2021, the global sales volume of industrials robots tripled in the past decade. As said in the literature review, there are many approaches but have many problems when detecting the objects. So that the increase of robot usage, they need a good staircase detection system. Otherwise, it cannot climb the staircase when required.

The staircase detection system should be very accurate because that is the main part of the climb stair. For that below requirements should address in the proposed approach to achieve a reasonable success rate.

- How to detect staircases accurately?
- How to identify environment light situations?
- How to balance the brightness of the image in different light situations?
- How to get a count of steps need to climb in a staircase?
- How to predict in a minimum of time?
- How to optimize the models for real-time detection?
- How to collect a data set to train the models?

2. OBJECTIVES

2.1. Main objectives

In this research, the main objective of the individual component is to develop a staircase detection system for the robot and get the number of steps required to climb before climbing the stairs.

2.2. Specific objectives

For implementing the staircase detection system, as mentioned in the background, there are three main approaches. Below show what the objectives need when using all of the approaches.

- Collect data
    - To train the model, we need to create a dataset. Target is to collect staircase images by considering the below characteristics,
        - Color
        - Number of steps
        - Light conditions
        - Material
- Preprocessing of the data set
    - Before use data to train the model need to do necessary preprocessing steps.
    - Under the methodology, this preprocessing section is described further.
- Create staircase structure.
    - The implementation and training robot happens in a simulation environment.
    - For the training need to create a staircase structure in the simulator.
- Integrate sensors into the system.
    - Real-time data is taken from the sensors because of that need to integrate that into the system.
    - The collected data need to save inside of the robot's storage.
- Create a model to identify staircase features (described in the methodology).
- Create a model to identify the number of steps (described in the methodology).

3. METHODOLOGY

Background and Literature survey was done in staircase detection area to find out what are similar implementations have done by the researchers worldwide. As mentioned in the research gap, there are some parts that have not been addressed yet, and some features have further improvements. So, the following requirements were identified

- The proposed model should be able to identify environment light situations.
- The proposed model should be able to balance the brightness of the image in different light situations.
- The proposed model should be able to get the count of steps need to climb in a staircase.
- The prediction should do in a minimum of time.
- Optimize the models to real-time detection.

3.1. System overview

The following figure 6 shows the high-level architecture of the individual component.

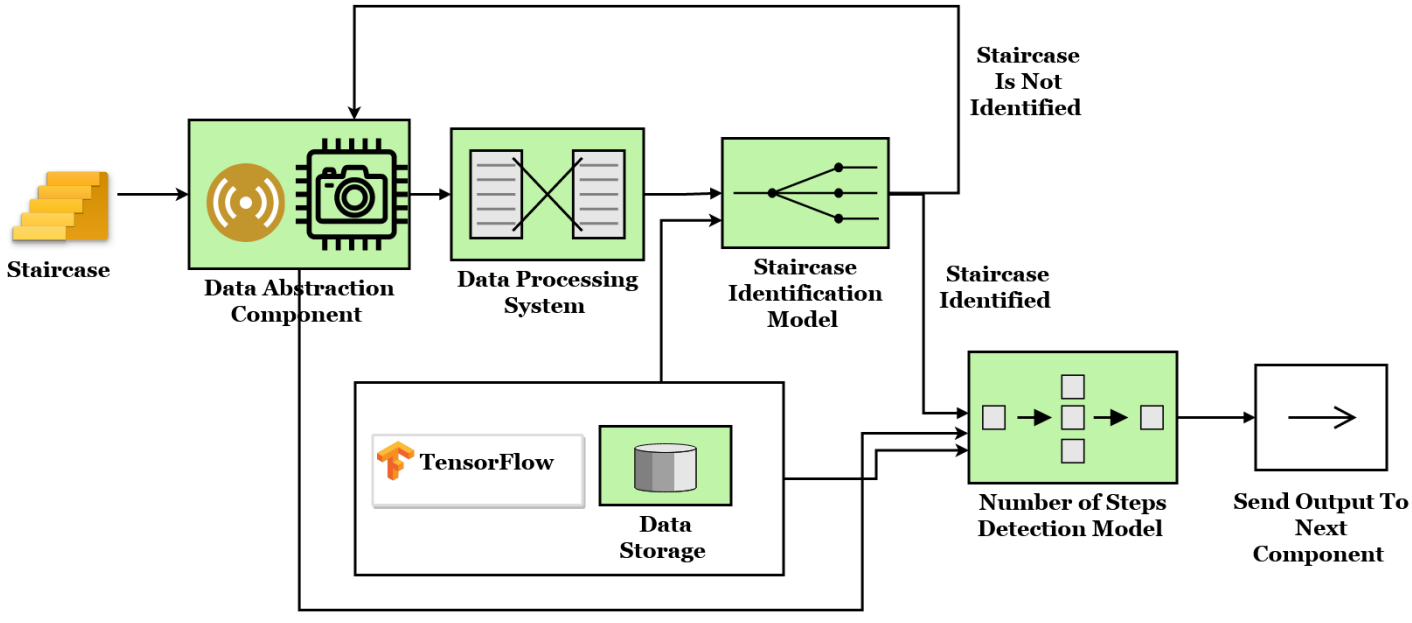


Figure 6 High-level architecture of the individual component

Robot Operating System (ROS) is one of the robot development tools in the industry. That provides libraries and tools to help software developers create robot applications. It has hardware abstraction, device drivers, libraries, and more. ROS is licensed under an open-source BSD license. According to the ROS community, they recommend Linux distribution. So, ROS Melodic distribution is installed in Ubuntu 18.04 LTS. After that, for the simulation purpose, we need a simulator. Here able to use Gazebo simulation. It can download from the official gazebo site. Other than that, need OpenCV and TensorFlow for the image processing.

The camera and sensors use to get input data. After getting the data do a preprocess task to remove unwanted things and optimizations. Then that image use by the staircase detection model. It checks whether there is a stair or not. If the system could find a stair, it transfers to the step detection model. It detects the count of steps. Then pass steps count, and stair found message to the next component.

3.2. Data preprocessing and analyzation

All the images need to preprocessing according to following

- Images resolution should be 640x360 pixel range.
    - According to [6], the resolution does not cause to the accuracy rate.
- Need to increase or decrease brightness level of the images according to the environment light situation.
    - Some low and high contrast levels image identification does not happen correctly so that need to balance it before prediction.

3.3. Model implementation

- Create a model to identify staircase features.
    - All of the stairs have some similar features like continuous vertical lines and distance between each line reduce when considering bottom to up.
    - The model should be able to consider on features of stairs.
- Create a model to identify the number of steps.
    - As said in above, one vertical line represents a step.
    - This model could count each line to get the count of steps.

3.4. Project requirements

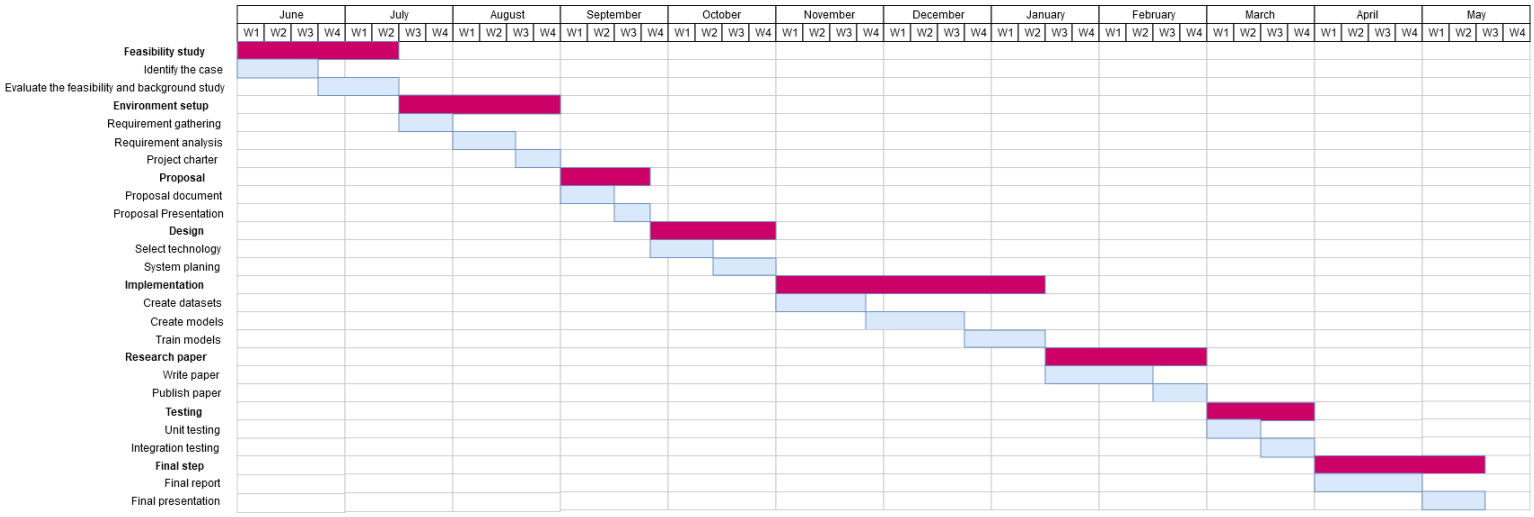
3.4.1. Functional requirements

- Capture images
- Detect staircases
- Get sensors-based data
- Detect number of steps in a staircase
- Sent results to other components

3.4.2. Non-Functional requirements

- Speed
- Accuracy
- Lightweight
- Maintainability

3.5. Gant chart



4. BUDGET

Table 2 Budget details

Component	Amount (USD)	Amount (LKR)
Frameworks and libraries	Free (0$)	0 LKR
Internet Package	30$	6000 LKR
Total	30$	6000 LKR

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