

**TRIBHUVAN UNIVERSITY  
INSTITUTE OF ENGINEERING**

**Khwopa College Of Engineering**  
Libali, Bhaktapur  
**Department of Computer Engineering**



**A FINAL REPORT ON  
IMAGE STEGANALYSIS USING ENSEMBLE CLASSIFIER**

*Submitted in partial fulfillment of the requirements for the degree*

**BACHELOR OF COMPUTER ENGINEERING**

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# Certificate of Approval

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We found the students to be hardworking, skilled, bona fide and ready to undertake any commercial and industrial work related to their field of study and hence we recommend the award of Bachelor of Computer Engineering degree.

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# Abstract

Steganography is a technique used to hide information, such as text, images, audio or videos, within another carrier file in a way that is not easily detectable by human senses. Digital images, constituting nearly two-thirds of online content are popular carriers for steganography. This can be exploited by malicious actors to hide harmful information. This hidden malware can damage data, steal information, or disrupt systems. To address this challenge, we propose an ensemble classifier model using bagging method implemented as a random forest. We will be using high dimensional features from CC-C300 model to train our ensemble classifier. This approach offers robustness, model diversity, and faster development compared to other machine learning methods. The proposed model will perform effectively on three different steganographic methods; nsF5, J-UNIWARD and UERD, that hide messages in JPEG images.

**Keywords:** Steganography, Steganalysis, Ensemble Classifiers, CC-C300, Machine Learning, Random forest, JPEG

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# List of Abbreviation

API	Application Programming Interface
bpnzAC	Bits Per Non-zero AC
CNN	Convolutional Neural Network
CUDA	Compute Unified Device Architecture
DC-DM	Distortion Compensated-Dither Modulation
DB	Database
DCT	Discrete Cosine Transform
DCTR	Discrete Cosine Transform Residuals
DOM	Document Object Model
FLD	Fisher Linear Discriminant
GBM	Gradient Boosting Machine
GIF	Graphics Interchange Format
GFR	Gabor Filter Residuals
GPU	Graphics Processing Unit
HUGO	Highly Undetectable SteGO
J-Uniward	JPEG UNiversal WAvelet Relative Distortion
JPEG	Joint Photography Experts Group
JSON	JavaScript Object Notation
K-NN	K-Nearest Neighbors
LSB	Least Significant Bit
ML	Machine Learning
PHARM	Phase Aware Projection Model
PNG	Portable Network Graphics
RAM	Random Access Memory
STC	Syndrome Trellis Coding
SVM	Support Vector Machine
SQL	Structured Query Language
UERD	Uniform sEmbedding Revisited Distortion
WPC	Wet Paper Codes
YCbCr	Luminance, Chrominance Blue, Chrominance Red

# Chapter 1

## Introduction

### 1.1 Background

Steganography is the skillful technique of secret communication, accomplished through embedding a piece of information into a carrier. In steganography, a “carrier” refers to the cover or host file that conceals the hidden message or information. The word steganography is derived from the Greek words “*stegos*” meaning “*cover*” and “*grafia*” meaning “*writing*” defining it as “*covered writing*” [1]. Misusing steganography for malicious purposes can have serious consequences. A recent trend involves exploiting various steganographic techniques to embedd malware in the carrier. Some real life example would be: Hiding malicious code within banner ads, tricking users into installing malicious app, embedding malicious executables and so on. Steganography can utilize various file formats, primarily classified into four categories: text, images, audio, and video. Among these file formats, images are widely used as cover object. Steganalysis is the process of detecting hidden information within digital media, uncovering hidden data that has been secretly embedded using steganographic techniques. The goal of steganalysis is to collect sufficient evidence about the presence of embedded message and to break the security of its carrier. Thus defeating the purpose of steganography. The importance of steganalytic techniques that can reliably detect the presence of hidden information in images is increasing. Steganalysis finds its use in computer forensics, cyber warfare, tracking the criminal activities over the internet and gathering evidence for investigations particularly in case of anti-social elements. [2]

#### Image Steganography

Image Steganography is a steganography method where the hidden information is embedded into a image as carrier file. Among the various available formats of images, JPEG format is widely used for steganography. The figure below shows the glimpse of how a JPEG image is compressed.

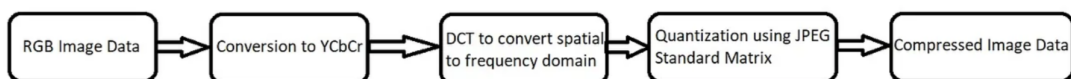


Figure 1.1: Steps used in implementation of Compression Algorithm

First the RGB color space is converted into YCbCr colorspace. After the YCbCr conversion, the image is partitioned into  $8 \times 8$  non-overlapping blocks. After that each pixel is transfered from range of 0 to 255 to -128 to 127. Finally, Each of these blocks is then subjected to a 2-D Discrete Cosine Transform (DCT). The DCT transforms the spatial data in the block into frequency data. After the DCT, the coefficients are

quantized, meaning they are divided by a factor determined by a quantization table. The quantization step is what actually removes information from the image, and it is this step that makes the JPEG compression process lossy.

$$C(u, v) = \alpha(u)\alpha(v) \sum_{x=0}^{N-1} \sum_{y=0}^{N-1} f(x, y) \cos\left[\frac{\pi(2x+1)u}{2N}\right] \cos\left[\frac{\pi(2y+1)v}{2N}\right] \quad (1.1)$$

for  $u, v = 0, 1, 2, \dots, N-1$  and  $f(x, y)$  is pixel position and  $\alpha(u), \alpha(v)$  as

$$\alpha(u) = \begin{cases} \sqrt{\frac{1}{N}} & \text{for } u = 0 \\ \sqrt{\frac{2}{N}} & \text{for } u \neq 0 \end{cases} \quad (1.2)$$

$$\alpha(v) = \begin{cases} \sqrt{\frac{1}{N}} & \text{for } v = 0 \\ \sqrt{\frac{2}{N}} & \text{for } v \neq 0 \end{cases} \quad (1.3)$$

Equation (1.1), (1.2), (1.3) are the formulas to calculate DCT coefficients,  $\alpha(u)$  and  $\alpha(v)$  respectively. [3]

Some popular techniques of image steganography are listed below:

### 1. DCT-LSB Method:

The DCT-LSB method conceals data in an image by dividing it into 8x8 blocks, transforming each block using Discrete Cosine Transform (DCT), and then replacing the least significant bit of DCT coefficients with hidden data. [4]

### 2. F5 and nsF5 Algorithms:

The F5 steganography algorithm operates by manipulating Discrete Cosine Transform (DCT) coefficients. F5 adjusts coefficients by adding 1 to those with a positive value and subtracting 1 from those with a negative value, leaving zero-valued coefficients unchanged. However, a drawback known as the “shrinkage” problem arises when coefficients with values of 1 or -1 become zero during embedding, reducing the algorithm’s capacity. [5]

To overcome the shrinkage problem, the nsF5 algorithm, an advanced version of F5, employs Wet Paper Codes (WPC). This technique designates certain coefficients as “non-modifiable”, preventing alterations after data embedding. This innovation addresses the shrinkage issue without sacrificing capacity. Even if new zeros are generated from coefficients with values of 1 or -1, the nsF5 algorithm records them, enhancing image quality and capacity compared to the common F5 method. [6]

### 3. UERD (Universal Embedding Reduced Distortion):

UERD (Universal Embedding Reduced Distortion) is a method that hides information in pictures so that it’s hard to notice. By strategically analyzing Discrete Cosine Transform (DCT) coefficients, UERD chooses those areas in the picture where changes won’t be obvious. UERD uses syndrome trellis coding (STC) to hide the message bits in the desired values. This further increases the security of the embedded data by making it harder to detect. [7]

#### 4. **J-UNIWARD Algorithm:**

The J-UNIWARD algorithm operates in both the spatial domain and the frequency domain. In the spatial domain, it uses the Least Significant Bit (LSB) steganography technique to hide data in the least significant bits of the pixel values. In the frequency domain, it uses the Discrete Cosine Transform (DCT) to transform the image into the frequency domain, where it hides data in the DCT coefficients. [8]

#### 5. **HUGO Algorithm:**

HUGO, which stands for Highly Undetectable steGO, is a steganography algorithm designed to hide information within images. It achieves this by analyzing complex patterns and structures in an image, determining optimal locations to hide data. [9] [10]

## 1.2 Motivation

The continuous evolution of steganographic techniques poses a critical challenge to digital privacy. With the increasing sophistication of methods used to embed information secretly, traditional steganalysis approaches are challenged by the need for improved accuracy and adaptability. Since two-thirds of the internet is composed of images, and they play a major role in digital communication. The use of advanced steganographic techniques in image endangers the user with malicious data hidden within it. So, creative approaches are required since secretly implanted malicious data are difficult for traditional steganalysis to identify. An example of such problem would be Witchetty espionage group (also known as LookingFrog) which is a chinese hacker group which has so far compromised the security of middle eastern governments and african countries by using the Windows logo as their point of entry.

## 1.3 Problem Statement

The continuous evolution of steganographic techniques poses a critical challenge to digital privacy. With the increasing sophistication of methods used to embed information secretly, traditional steganalysis approaches are challenged by the need for improved accuracy and adaptability. Since two-thirds of the internet is composed of images, and they play a major role in digital communication. The use of advanced steganographic techniques in image endangers the user with malicious data hidden within it. So, creative approaches are required since secretly implanted malicious data are difficult for traditional steganalysis to identify. An example of such problem would be Witchetty espionage group (also known as LookingFrog) which is a chinese hacker group which has so far compromised the security of middle eastern governments and african countries by using the Windows logo as their point of entry.

## **1.4 Objectives**

The main objectives of this project is to:

- To detect steganographically modified JPEG images using Ensemble Classifier, irrespective of the following algorithm used for steganography (nsf5,J-uniward,UERD).

## **1.5 Scope and application**

The major applications of this project are:

- Organizations can employ steganalysis to detect malicious activities such as data breach or covert communication channels used by cybercriminals.

# Chapter 2

## Literature Review

Some work has been done in image steganalysis. Various steganalysis tools use different approaches like feature extraction, shallow ML, and deep learning methods to detect steganographically altered images. This literature review seeks to portray the history, methodologies, implementation and applications of steganalysis.

Multiple research has been done to achieve excellent results in steganalysis. Krzysztof Szczypiorski et al. [11] used deep learning and ensemble classifiers to detect image steganography using different methods like DCTR and shallow machine learning classifiers. They found that performance depended heavily on the steganographic method used and on the density of the embedded hidden data. Detection of the content hidden with the nsF5 algorithm at the density 0.4 bpnzac was almost perfect while detection of data hidden using J-Uniward at 0.1 bpnzac was hardly possible. It is shown that steganalysis done using shallow ML is better in comparison to deep learning. This point is further proved by the fact that shallow ML consumes less resources and requires less time to be trained in comparison to deep ML and still provides accuracy similar or better than deep ML classifiers.

The paper [3] gives us a comprehensive overview of the Discrete Cosine Transform(DCT) and its application in digital image and video processing. The document discusses the properties of the DCT, including its decorrelation characteristics, energy compaction, and its ability to reduce entropy. It highlights the DCT's role in efficient coding and compression, particularly in the context of image and video standards such as JPEG and MPEG. Additionally, The document addresses the inverse DCT operation and its impact on visual distortion, providing examples of reconstructed images at different quantization levels.

George Berg et al. [12] proposed an ML approach to steganalysis. This paper shows the feasibility of using a machine learning and data mining (ML/DM) approach to automatically build a steganography attack. This paper used three common data mining and learning techniques: decision trees, error back-propagation, artificial neural networks and the naïve Bayes classifier, to identify messages hidden in compression-(JPEG) and content based (GIF) images.

MT Hogan et al. [13] evaluated the statistical limits by using probability density functions (pdfs). ML tests based on DC-DM are presented in this paper. To effectively uncover hidden information in images, we need a steganalysis tool with sharp pattern recognition skills. Sometimes, when we compare images that have been manipulated with certain tools to their original versions, we can spot a few noticeable visual irregularities – like odd pixels or changes in dimensions due to cropping or padding. If an image doesn't fit specific size criteria, it might get cropped or padded, and you'll see black spaces. Interestingly, most manipulated images don't give away obvious clues when compared to their originals. The simplest clue is a size increase between the manipulated and original images. Other signatures show up in how the colors are arranged in the image, such as a significant change in the number of colors or a gradual increase or decrease. Grayscale images follow a different pattern, increasing incrementally. Another strong indicator is an unusual number of black shades in a

grayscale image.

The paper [14] provides core concepts of this project such as ensemble classifier and importance of selection of features. A distinctive subject which it has touched upon is the concept of Curse of Dimensionality (CoD) which shows the relation of complexity and increase in resource usage for computation. It is highlighted how ensemble classifiers can counter this problem by using reduced dimension for training its base learners.

The paper [15] highlights several key studies in the field of steganalysis, which provides a solid foundation for understanding the current state of steganalysis. The document discusses the implementation of ensemble based steganographically altered image classifier using many base learners for classification. The proposed base learners are trained using FLD analysis due to its ability to increase diversity. The performance of the proposed model even though gets trained in very less time in comparison to usually used classification method of G-SVM can classify with similar or better accuracy. It is highlighted that a G-SVM classifier takes about 8 hours to be properly trained while an ensemble classifier takes only 20 minutes.

The paper [16] provides an in-depth insight into the use of an ensemble of classifiers for steganalysis, with a focus on machine learning. The ensemble-based steg analyzer uses feature vectors from multiple stegalyzers to create a decision algorithm that allows the combination of information from different steganalyzers. The resulting steganalyzer is also inherently suitable for multi-class classification scenarios. The paper presents a novel steganalysis decision framework using hierarchical classifiers, which addresses the limitations of existing steganalysis methods and provides a scalable and cost-effective approach to steganalysis. Ensemble classifiers are designed to overcome the limitations of individual classifiers by combining their outputs to achieve better performance. Steganalysis using ensemble classifiers is a powerful approach that utilizes the strength of multiple classifiers to help improve the detection of hidden information in images. It provides diverse steganographic techniques while also enhancing the overall accuracy. Ensemble classifiers are designed to overcome the limitations of individual classifiers by combining their outputs, thereby achieving better performance.

The paper [17] provide information on the pre features and their Cartesian calibrated and Non-cartesian calibrated form. The paper [18] and the paper [19] guides the outlook of our project to a better angle as it provides very crucial details on the section of feature extraction. They provide more insight on the pre features which can be utilized for better classification. These literature provided more insights on CC-PEv and CC-SHI which are different pre features used for steganalysis. "JPEG Image Steganalysis Utilizing both Intrablock and Interblock Correlations" provides more insight on the importance of considering relation between inter and intra block correlations during pre feature creation for better detection or classification.

This Paper [20] explains, IStego 100K is a large-scale steganalysis consisting of 208,104 images with a size of 1024\*1024 pixels. The training set consists of 200,000 images organized into 100,000 cover-setgo image pairs. The testing set comprises the remaining 8,104 images. Each image in the dataset has randomly assigned quality factors in the range of 75-95. Three well-known steganographic algorithms J-uniward, nsF5, and UERD [8] [6] [7] are randomly selected for embedding in the images. The embedding rate for each image is randomly set in the range of 0.1-0.4 bpac.

The relevant papers that we studied to grab knowledge about this project are given in the review matrix below:



S.N.	Name	Year	Authors	Dataset	Findings
1	Searching for hidden messages Automatic detection of steganography [12]	2003	George Berg, Ian Davidson, Ming-Yuan Duan, and Goutam Paul	BOSS	Images are commonly used to transmit hidden messages. Different strategies are used to hide messages in GIF and JPEG formats.
2	International Workshop on Information Hiding [20]	2005	Jessica Fridrich, Miroslav Goljan, and David Soukal	NA	matrix LT process,Block Minimal embedding,applications to steganography and data embedding
3	On steganographic embedding efficiency [7]	2007	Jessica Fridrich, Petr Lisonek, and David Soukal.	NA	Matrix embedding using linear codes (syndrome coding) is a general approach to improving embedding efficiency of steganographic schemes.
4	MI detection of steganography [13]	2005	Mark T Hogan, Neil J Hurley, Guenole CM Silvestre, Felix Balado, and Kevin M Whelan	BOSS	Non-blind steganalysis, Distortion-Compensated Dither Modulation
5	The discrete cosine transform (DCT): theory and application [3]	2003	Syed Ali Khayam.	NA	DCT, DCT applications, properties of DCT

S.N.	Name	Year	Author	Dataset	Findings
6	Steganalysis in high dimensions Fusing classifiers built on random subspaces [14]	2011	Jan Kodovsky and Jessica Fridrich.	BOSS	The paper proposes ensemble classifiers as an alternative to support vector machines. Experiments with steganographic algorithms nsF5 and HUGO demonstrate the usefulness of this approach.
7	Ensemble classifiers for steganalysis of digital media [15]	2012	Jan Kodovsky, Jessica Fridrich, and Vojtech Holub.	BOSS	Ensemble classifiers have improved detection accuracy for steganographic methods in JPEG images. The proposed framework allows for fast construction of steganography detectors.
8	Proceedings of the 11th ACM Workshop on Multimedia and Security [17]	2009	Jan Kodovsky and Jessica Fridrich.	NA	covert communication, Digital watermarking
9	Merging markov and dct features for multi-class jpeg steganalysis [19]	2007	Tomas Pevny and Jessica J. Fridrich	BOSS	The paper constructs a new multi-class JPEG steganalyzer with improved performance. The new feature set provides significantly more reliable results compared to previous work.

S.N.	Name	Year	Authors	Dataset	Findings
10	Detection of image steganography using deep learning and ensemble classifiers [11]	2022	Mikołaj Płachta, Marek Krzemien, Krzysztof Szczypiorski, and Artur Janicki	BOSS	Ensemble classifiers performed well in steganography detection. Deep learning algorithms achieved better results for UERD and nsF5 steganographic algorithms.
11	A markov process based approach to effective attacking jpeg steganography [18]	2007	Yun Q. Shi, Chunhua Chen, and Wen Chen.	BOSS	The proposed steganalyzer outperforms by a significant margin. The detection rates are higher while considering the introduced features.
12	A fast and accurate steganalysis using ensemble classifiers [16]	2013	Arezoo Torkaman and Reza Safabakhsh	BOSS	The proposed method achieved a lower error rate of 46% compared to the ensemble classifier. The training time of the proposed method was 88% lower than the ensemble classifier.
13	Istego100k Large-scale image steganalysis dataset [20]	2019	Zhongliang Yang, Ke Wang, Sai Ma, Yongfeng Huang, Xiangui Kang, and Xianfeng Zhao	IStego100K	The paper introduces a large-scale image steganalysis dataset called IStego100K. The performance of some steganalysis algorithms on IStego100K is tested.

Table 2.1: Review Matrix with Research Papers, authors and purpose

# Chapter 3

## Requirements Analysis

### 3.1 Software Requirements

Software requirements for the given project are as follows:

1. **Python:** Python is a versatile programming language commonly used for developing software applications. It can be used for various tasks in the system, such as backend development, data processing, and machine learning integration. Implementing interactive features on the system's web interface, and facilitating communication with the backend.
2. **GitHub:** GitHub is a web-based platform for version control using Git. It provides a collaborative environment for software development projects, allowing developers to host and share their code, track changes, manage workflows, and collaborate with others. GitHub offers features such as code repositories, issue tracking, project management tools, code review, and continuous integration.
3. **MATLAB:** MATLAB, short for "Matrix Laboratory," is a high-level programming language and interactive environment primarily used for numerical computation, visualization, and programming. It provides a wide range of built-in functions and toolboxes for various applications, including mathematics, signal processing, image processing, control systems, and machine learning.
4. **VS Code:** VS Code is a popular and widely used source code editor that offers a range of features and extensions to enhance the development experience. It supports multiple programming languages, including Python, JavaScript, and React, making it suitable for working with the different components of the system.
5. **LaTeX:** LaTeX is a typesetting system used for creating documents, particularly those that require complex mathematical equations or scientific notation. It is widely used in academic and technical fields for its ability to produce high-quality documents with consistent formatting. LaTeX uses markup language to format text, and it is highly customizable, allowing users to create templates and styles for their documents. It is also free and open-source, making it accessible to anyone who wants to use it.

### 3.2 Hardware Requirements

Hardware requirements for the given project are as follows:

1. Employed systems equipped with 16 GB RAM, 3.6 GHz processors, and NVIDIA GPUs for optimal performance.
2. Utilized a dedicated server having 64 GB RAM to enhance computational capabilities.

### 3.3 Functional Requirements

The functional requirements for the prepared project are as follows:

1. The Final model must be able to distinguish between cover and stego images.
2. The system must be able to process images in real-time.
3. The UI must be user-friendly and responsive.

### 3.4 Non-Functional Requirements

The non-functional requirements for the prepared project are as follows:

1. **Reliability:** The system must be reliable and consistent in its performance.
2. **Maintainability:** The system must be easy to maintain and update.
3. **performance:** The system must be able to process images quickly and efficiently.
4. **Accuracy:** The system must be able to accurately detect stego images.
5. **Compatibility:** The system must be compatible with different operating systems and devices.

# Chapter 4

## Feasibility study

### 4.1 Technical Feasibility

For the technical part, we obtained our project data from the IStego100K [20] dataset, which contained 200,000 images. These images had been modified using three different algorithms, which created diversity in the dataset used, improving the reliability of the system. We used free software to build the project, and for the training and testing, we used our own computers. Thus, we concluded that it was technically feasible.

### 4.2 Economical Feasibility

The only cost for the project is the computational power, covering processing and electricity. For development of the system, all the softwares used are free of cost and hardwares were available for us to train model.

### 4.3 Operational Feasibility

We had decided to use the Shallow ML approach, which allowed the model to be trained with less computational power in comparison to deep learning. For shallow machine learning, we planned to implement an ensemble classifier, and each of its models was trained using FLD to improve its effectiveness. Deep learning implemented the CNN approach, which required higher computational power to be trained. Thus, we decided to use a simpler machine learning approach that didn't need a lot of computational power, unlike the more complex deep learning method called Convolutional Neural Network (CNN). This way, the system was practical and didn't need a lot of resources, making it able to be effectively implemented in real-life applications, making it operationally feasible.

### 4.4 Schedule feasibility

The project was scheduled to be completed within in 6 months duration. Our project completed as scheduled in Gantt chart.

## 4.5 Gantt Chart

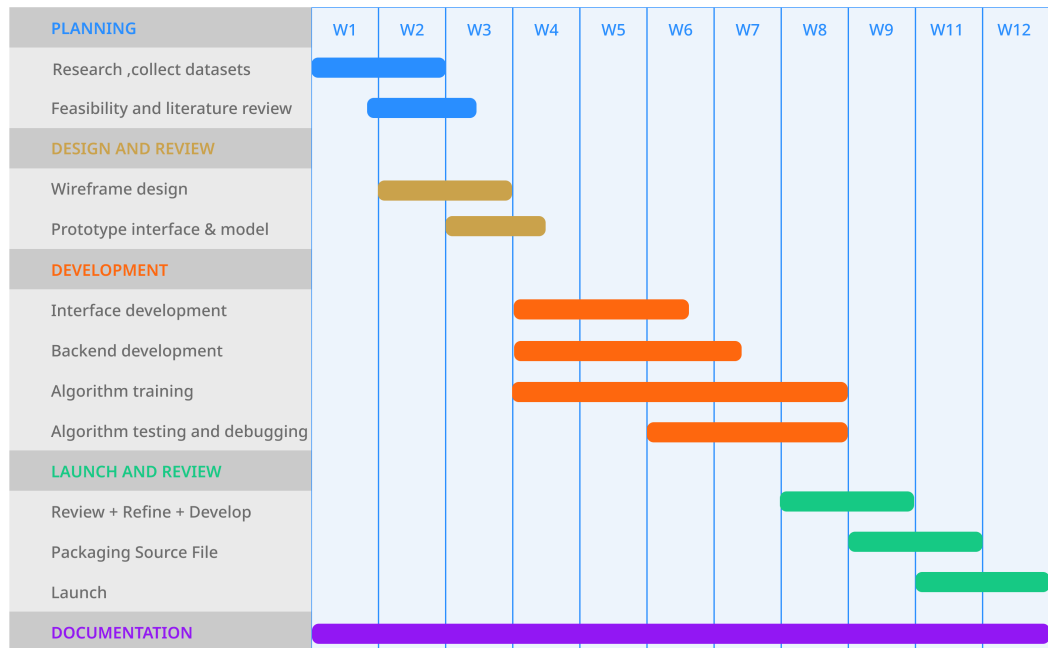


Figure 4.1: Gantt Chart

# Chapter 5

## System Design and Architecture

### 5.1 USE CASE DIAGRAM

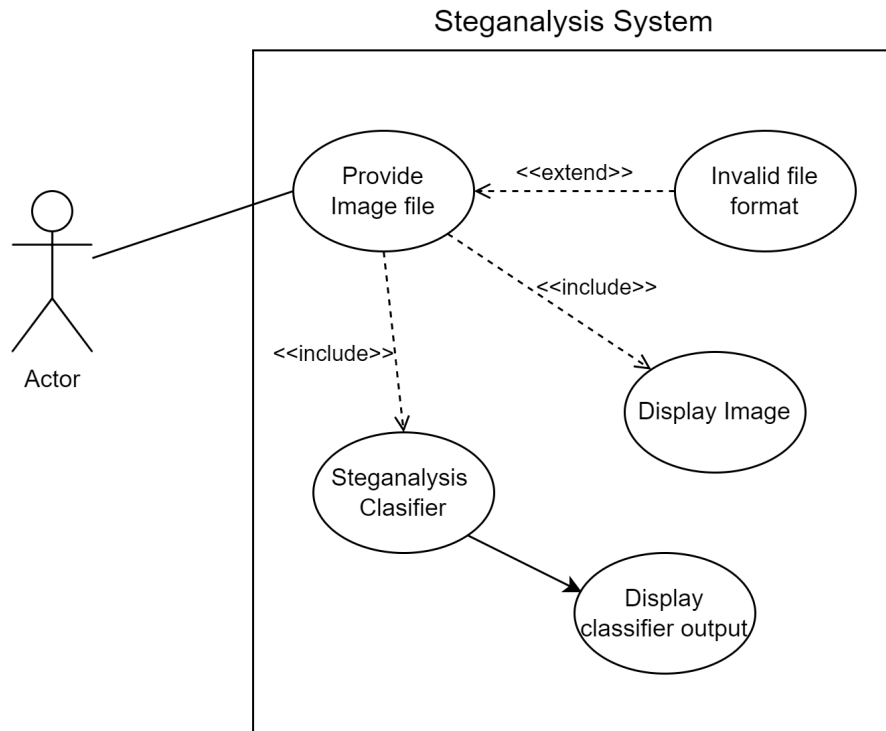


Figure 5.1: Use Case Diagram



## 5.2 SEQUENCE DIAGRAM

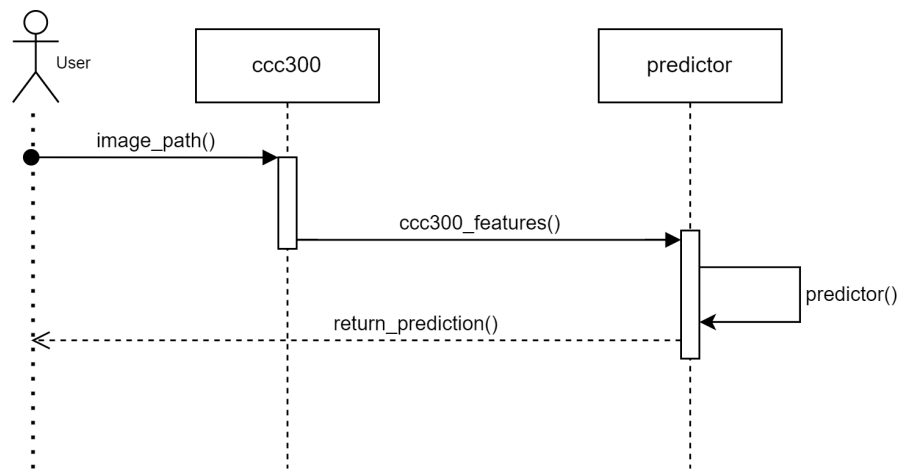


Figure 5.2: Sequence Diagram

## 5.3 SYSTEM BLOCK DIAGRAM

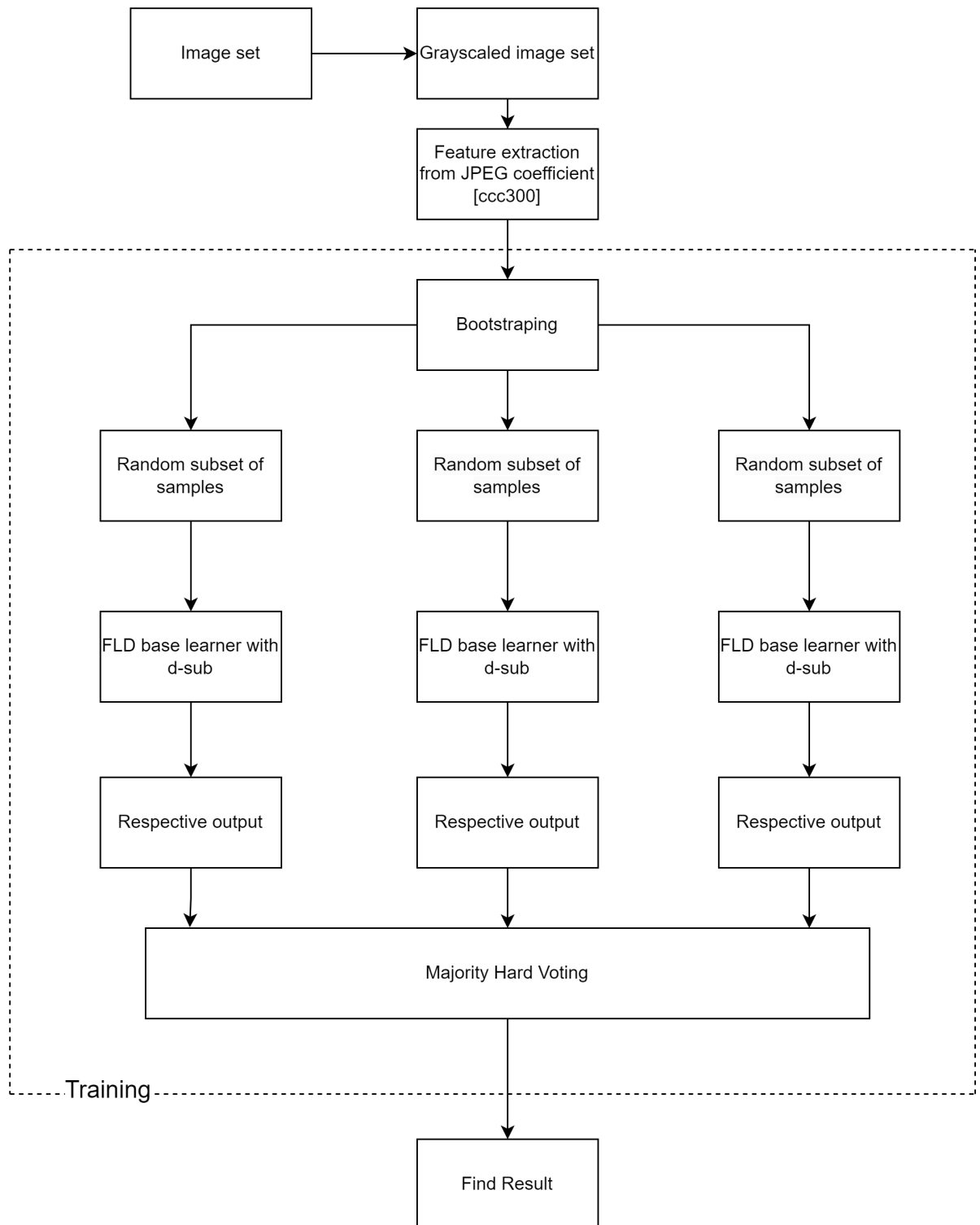


Figure 5.3: System Block Diagram

## 5.4 System Architecture

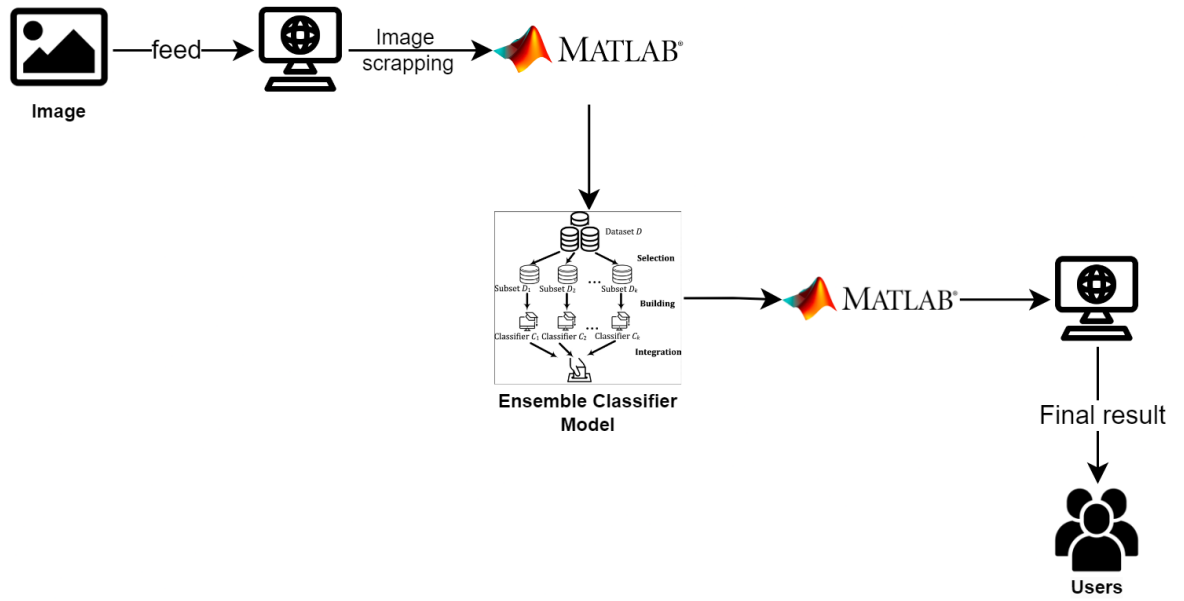


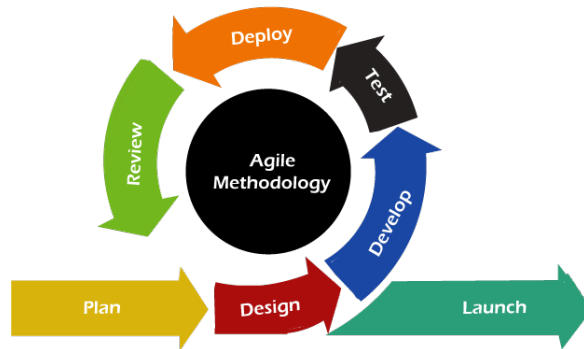
Figure 5.4: System Architecture

# Chapter 6

## Methodology

### 6.1 Software Development Approach

Agile is an iterative process-based approach to software development. In the Agile process model, work is broken down into more manageable, smaller iterations without requiring a lot of long-term planning. The requirements and scope of the project are determined early on, and the number, length, and scope of each iteration are preplanned. Each iteration is considered as a short time “frame” in the Agile process model, which lasts for a few weeks. In each iteration, teams move through the phases of the software development life cycle, which include planning, requirements analysis, design, coding, testing, and demonstration of a working product for client review. Agile places a significant value on flexibility, teamwork, and regular client feedback.



Source: <https://www.javatpoint.com/agile-vs-waterfall-model>

Figure 6.1: Agile Model

The main reason for which we choose this development process:

1. Very quick, flexible and efficient.
2. Risk minimization.
3. Projects are split into sprints for better management and productivity.
4. Through iterative testing and sprints, the final product contains less bugs.
5. Development period for applications is reduced.

### 6.2 Data Collection

We have collected dataset from the IStego100K dataset [7], a Large-scale open-source image steganalysis dataset. This dataset consists of a total of 200,000 images, serving as the primary resource for training and testing our model. Within the dataset, images are categorized into two main groups: “Stego” and “Cover,” each containing 100,000 images. The “Stego” subset contains images with hidden information added using three

different methods. As this dataset contains images with message hidden using more than one algorithm so we can call this universal dataset for steganalysis. In contrast, the “Cover” subset consists of images without any hidden information added; they are in their original, unaltered state.

The size of images in the data set is 1024\*1024 pixels in RGB format. Each image in the dataset has randomly assigned quality factors in the range of 75-95. Three well-known steganographic algorithms J-unward, nsF5, and UERD [8] [6] [7] are randomly selected for embedding in the images. The payload for each image is randomly set in the range of 0.1-0.4 bpac. [0.10 bpac means that for every coefficient in the DCT domain of the cover image, 0.10 bits of secret data are hidden on average.]

## 6.3 Feature extraction

### JPEG Coefficient Analysis

In the initial step, the JPEG coefficients for each  $8 \times 8$  block are computed, denoted as  $D(i, j)(k, l)$ , representing the  $(k, l)$  coefficient in the  $i, j$  block. Here,  $k, l = 0, 1, 2, \dots, 7$ ,  $i = 1, 2, 3, \dots, 8(M/8)$ , and  $j = 1, 2, 3, \dots, 8(N/8)$ , with  $M \times N$  as image dimensions. Subsequently, the coefficients undergo truncation to simplify complexity, ensuring the quantized DCT or JPEG coefficients are centered around 0.

The distribution of the differences between JPEG coefficients exhibits a Laplacian-like pattern, with most values close to zero. Truncation is applied to all available JPEG coefficients, expressed as  $D(i, j)(k, l) \leftarrow \text{trunc}_T(D(i, j)(k, l))$ , where  $\text{trunc}_T(x) = x$  for  $x \in [-T, T]$ .

$$P(\Delta i, \Delta j, k_1, l_1, k_2, l_2) = \left\{ \left[ D_{k_1 l_1}^{(i, j)}, D_{k_2 l_2}^{(i+\Delta i, j+\Delta j)} \right] \mid i = 1, \dots, N^{(i)}, j = 1, \dots, N^{(j)} \right\}$$

Following truncation, the values are processed to form pairs, and a co-occurrence matrix is computed based on the condition  $|\Delta(i)| + |\Delta(j)| + |k_1 - k_2| + |l_1 - l_2| > 0$ , ensuring distinct coefficients are utilized. Here,  $\Delta(i) = i_1 - i_2$  and  $\Delta(j) = j_1 - j_2$ . The resulting co-occurrence matrix is derived from the truncation process, generating a transition probability matrix with a dimensionality of  $(2T + 1) \times (2T + 1)$ . For instance, if  $T = 4$ , the co-occurrence matrix takes on a dimension of 81 for every pair of DCT modes denoted by  $(\Delta(i), \Delta(j), k_1, l_1, k_2, l_2)$ .

$$Cst = \frac{1}{N^{(i)} N^{(j)}} \sum_{i=1}^{N^{(i)}} \sum_{j=1}^{N^{(j)}} [a, b] \in P(\Delta i, \Delta j, k_1, l_1, k_2, l_2) \mid a = s, b = t$$

### Truncation

The co-occurrence matrix is calculated between each pair as depicted in img 2. The truncation process yields a transition probability matrix with a dimensionality of  $(2T + 1) \times (2T + 1)$ . When the threshold value ( $T$ ) is set to 1, considering elements within the range  $\{-1, 0, 1\}$ , it results in a transition probability matrix with a dimensionality of  $3 \times 3$ .

Let's denote the states as -1, 0, and 1, and assume a hypothetical transition probability matrix  $P$ :

$$P = \begin{bmatrix} p_{-1,-1} & p_{0,-1} & p_{1,-1} \\ p_{-1,0} & p_{0,0} & p_{1,0} \\ p_{-1,1} & p_{0,1} & p_{1,1} \end{bmatrix}$$

In this matrix:

-  $p_{-1,-1}$  represents the probability of transitioning from state -1 to state -1. -  $p_{-1,0}$  represents the probability of transitioning from state -1 to state 0. - Similarly, the other entries follow the same pattern for transitions between states 0 and 1.

The truncation value  $T$  is set to 4, resulting in a co-occurrence matrix of dimension 81 for every pair of DCT modes represented by  $(\triangle(i), \triangle(j), k_1, l_1, k_2, l_2)$ .

Initially, all possible DCT mode pairs are sorted based on their importance, and co-occurrences are then formed from the most important to the least important ones. As a measure of importance, mutual information (MI) is computed over a sufficiently large set of randomly selected DCT coefficient pairs from those two modes, using the `mutual_info_score(model, mode2)` where `model` and `mode2` are selected randomly.

## Feature Set Creation

The top  $N$  concatenated co-occurrence matrices, denoted as  $CN$ , yield a dimension of  $N \times 81$ . After Cartesian calibration, the dimensionality of what we denote as  $CC - CN$  doubles to  $2 \times N \times 81$ . Choosing  $N$  as 300, we have  $CC - C300$  with a dimensionality of  $2 \times 300 \times 81 = 48,600$  for each image, irrespective of image dimensionality.

For the concatenated matrix, let

$$C_1 = \begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \\ 7 & 8 & 9 \end{bmatrix}, \quad C_2 = \begin{bmatrix} 9 & 8 & 7 \\ 6 & 5 & 4 \\ 3 & 2 & 1 \end{bmatrix}, \quad C_3 = \begin{bmatrix} 0 & 1 & 0 \\ 1 & 1 & 1 \\ 0 & 1 & 0 \end{bmatrix}.$$

For  $CC - C2$ , the importance of each co-occurrence matrix is determined by mutual information (MI). If  $C_1$  and  $C_2$  are of highest importance, a new matrix is formed by concatenating  $C_1$  and  $C_2$ .

$$C = \begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \\ 7 & 8 & 9 \\ 9 & 8 & 7 \\ 6 & 5 & 4 \\ 3 & 2 & 1 \end{bmatrix},$$

where the dimension is  $2 \times 3 \times 3 = 18$ .

For mutual information (MI) to calculate the importance of co-occurrence, entropy and conditional entropy for each feature are calculated. The mutual information is then computed as the difference between entropy and conditional entropy for each feature, given by `mutual_info_score(mode1, mode2)`.

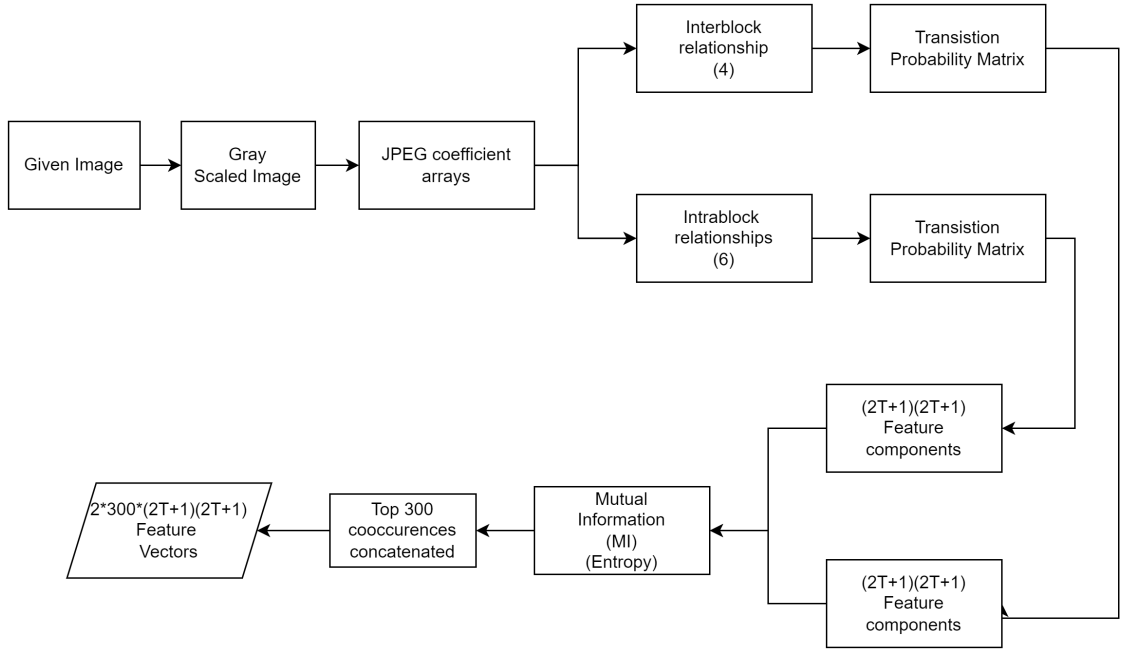


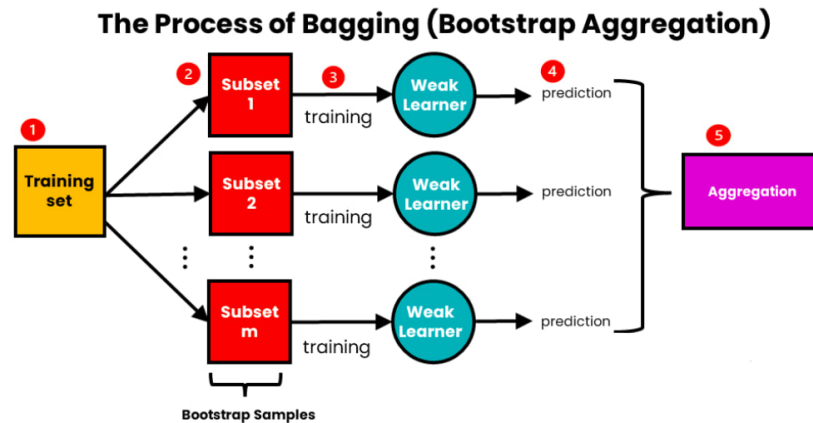
Figure 6.2: Feature Extraction Process

## 6.4 Ensemble Classifiers

Ensemble classifiers are machine learning techniques that combine multiple individual models, or “base learners,” to make predictions. The main idea behind the ensemble methodology is to weigh several individual classifiers, and combine them in order to obtain a classifier that outperforms every one of them. The key objective of the ensemble methods is to reduce bias and variance. High bias means the model is too simplistic and may not capture the underlying patterns in the data, leading to underfitting. Ensemble methods aim to reduce bias by combining multiple models, each capturing different aspects of the data. High variance means the model is overly complex and may capture noise or random fluctuations in the data, leading to overfitting. Ensemble methods aim to reduce variance by averaging the predictions of multiple models, smoothing out individual fluctuations and creating a more stable and reliable overall prediction.

Some of widely used ensemble methods are:

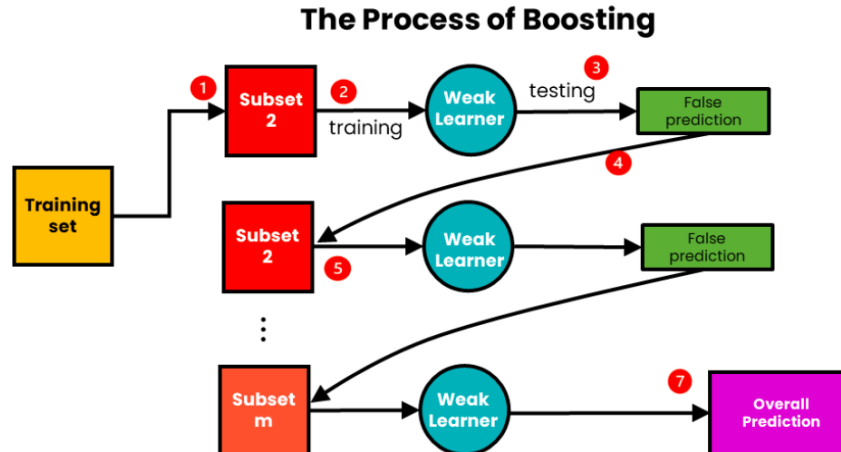
- **Bagging:** Bagging, or Bootstrap Aggregating, is an ensemble method that involves training multiple models on different subsets of the training data and combining their predictions. The subsets are created by sampling the training data with replacement, and each model is trained on a different subset. The final prediction is made by averaging the predictions of all the models. Bagging helps reduce variance by creating diverse models and averaging their predictions, leading to a more stable and reliable overall prediction.



Source: <https://www.analyticsvidhya.com/blog/2023/01/ensemble-learning-methods-bagging-boosting-and-stacking/>

Figure 6.3: Basic outline of Ensemble Classifier

- Boosting:** Boosting is an ensemble method that involves training multiple models sequentially, with each model learning from the mistakes of the previous models. The final prediction is made by combining the predictions of all the models. Boosting helps reduce bias by focusing on the mistakes made by the previous models and learning from them.

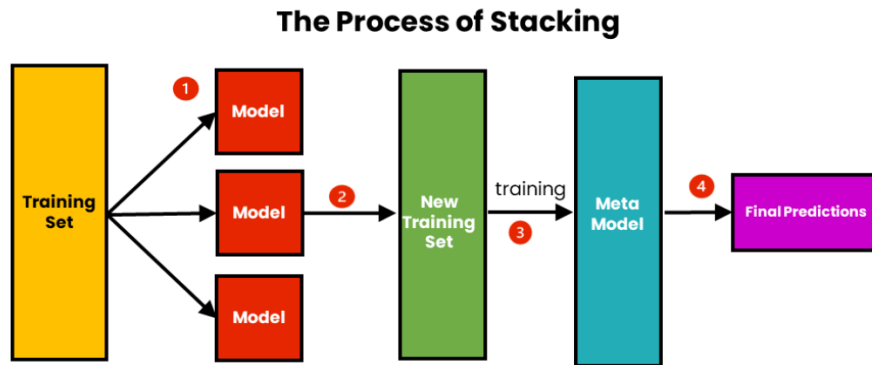


Source: <https://www.analyticsvidhya.com/blog/2023/01/ensemble-learning-methods-bagging-boosting-and-stacking/>

Figure 6.4: Basic outline of Boosting Classifier

- Stacking:** Stacking is an ensemble method that involves training multiple models and combining their predictions using another model, called a meta-learner. The meta-learner is trained on the predictions of the base models and learns to combine them into a final prediction.





Source: <https://www.analyticsvidhya.com/blog/2023/01/ensemble-learning-methods-bagging-boosting-and-stacking/>

Figure 6.5: Basic outline of Stacking Classifier

A standard ensemble approach used in classification tasks consists of the following fundamental components:

1. **Training set:** A labeled dataset is used for ensemble training. The instances of the dataset are described as attribute-value vectors. This set is crucial as it serves as the foundation for training the ensemble model, providing the necessary data points and their corresponding labels. In other words, it's the collection of data points used to train an ensemble learning algorithm. Each data point in the training set consists of two parts: the features (or attributes) and the label (or output). The features are the input variables used to predict the label, and the label is the output variable we want to predict.
2. **Base Inducer:** The inducer is an induction algorithm that obtains a training set and forms a classifier that represents the generalized relationship between the input attributes and the target attribute. Decision trees, Neural networks, Support Vector Machines(SVMs), k-Nearest Neighbors(k-NN), Random Forests, Gradient Boosting Machines(GBMs), AdaBoost etc. are different types of base learners that can be used in ensemble methods. The choice of base learner plays a vital role in the ensemble's performance and is often selected based on the nature of the problem and the characteristics of the data.
3. **Diversity Generator:** This component is responsible for generating the diverse classifiers. Diversity among the classifiers is crucial as it helps improve the ensemble's performance by ensuring that the individual models provide different perspectives on the data. Techniques such as bagging, boosting, and randomization can be used to generate diverse classifiers.
4. **Combiner:** The combiner is responsible for combining the classifications of the various classifiers. Some of the widely used combination methods are Weighting method, Majority voting, Performance weighting, Distribution summation, Bayesian combination, Dempster-Shafter, Voting, Naive bayes. The choice of combination method depends on the nature of the problem and the characteristics of the data. The combiner's role is to aggregate the predictions of the individual

models to produce the final ensemble prediction, which often leads to improved overall performance compared to using a single model. [21]

### 6.4.1 Algorithm

---

**Algorithm 1** Ensemble Classifier Algorithm [15]

---

```

1: for  $l = 1$  to  $L$  do
2:   Form a random subspace
3:    $D_l \subset \{1, \dots, d\}, |D_l| = d_{\text{sub}} < d$ 
4:   Form a bootstrap sample  $N_1^b, |N_1^b| = N^{\text{trn}}$  by uniform sampling with replacement
     from the set  $\{1, \dots, N^{\text{trn}}\}$ 
5:   Train a base learner  $B_l$  on features
6:    $X_l = \{x_m^{(D_l)}, \bar{x}_m^{(D_l)}\}_{m \in N_1^b}$ 
7:    $\rightarrow$  obtain eigenvector  $v_l$  and threshold  $T_l$ 
8: end for
9: for all  $y \in Y^{\text{tst}}$  do
10:  for  $l = 1$  to  $L$  do
11:    Make  $l^{\text{th}}$  decision:  $B_l(y^{D_l}) \triangleq \begin{cases} 1, & \text{when } v_l^T y^{(D_l)} > T_l \\ 0, & \text{otherwise} \end{cases}$ 
12:  end for
13: end for
14: Form the final decisions  $B(y)$  by majority voting:
15:  $B(y) = \begin{cases} 1, & \text{when } \sum_{l=1}^L B_l(y^{(D_l)}) > L/2 \\ 0, & \text{when } \sum_{l=1}^L B_l(y^{(D_l)}) < L/2 \end{cases}$ 
16: return  $B(y), y \in Y^{\text{tst}}$ 

```

---

In the provided algorithm:

$d$ : Represents the dimensionality of the feature space.

$d_{\text{sub}}$ : Represents the dimensionality of the feature subset.

$N^{\text{TRN}}$  and  $N^{\text{TST}}$ : Denote the number of training and testing examples, respectively.

$L$ : Represents the number of base learners.

$x_m, \bar{x}_m \in \mathbb{R}^d, m = 1, \dots, N^{\text{TRN}}$ : Refer to the cover and stego features computed from the training set.

$y_k, \bar{y}_k \in \mathbb{R}^d, k = 1, \dots, N^{\text{TST}}$ : Denote the cover and stego features computed from the testing set.

## 6.5 Model Training Approach

### **Ensemble Classifier Selection:**

The decision for selecting an ensemble classification approach is based on the problem at hand. The bagging approach appears ideal for this classification problem as it effectively addresses issues such as overfitting, prevalent during model training. One of the main focuses of our model is diversity, and bagging achieves this by creating diverse bootstrapped samples, enhancing the accuracy of the classification. Bagging also allows parallelization, significantly reducing training time compared to other models like boosted ensemble classifiers, L-SVM, or G-SVM. The simplicity and instability of bagging contribute to its advantages for ensemble classification.

### **Bootstrapping:**

Bootstrapping is simply the process of randomly dividing the dataset into various parts and feeding them to the number of base learners present inside the ensemble classifier for training. The datasets are divided into various smaller samples and then sent to the base learners for training. This division of datasets removes their dependency on each other, promoting parallelization and allowing the training of various models simultaneously..

### **Base Learner Training:**

The base learners are fed with the feature "dsub," a subset of "d" where "d" is the total number of features or dimensions of each data. The base learners are trained on Fisher's Linear Discriminant Analysis (FLD), which outputs binary classification. FLD is chosen for its diversity in revealing various errors, increasing the diversity of each base learner and resulting in a more accurate ensemble classifier.

### **Aggregation:**

The trained model can now successfully classify the input images as cover or steganographically modified images. The binary classifier typically classifies 1 as a steganographically modified image and 0 as a cover image. The chosen voting method is hard voting, which calculates the number of 0s and 1s and outputs the result dominated by the majority. The threshold is set at  $L/2$ .

### **Efficiency Considerations:**

The system prioritizes efficiency by embracing shallow machine learning techniques, specifically ensemble classifiers, instead of deep learning approaches. This strategic choice aligns with the computational efficiency goal, ensuring effective steganalysis without the computational demands associated with deep learning architectures. The intentional selection of CC-C300 as a feature further amplifies efficiency and bolsters the system's detection capabilities. This streamlined approach aims to strike a balance between accuracy and efficiency in steganalysis.

## 6.6 FLD as Base Learner

Fisher's Linear Discriminant (FLD), also known as Linear Discriminant Analysis (LDA), is a popular method used for dimensionality reduction and classification. It was introduced by Ronald A. Fisher in 1936 and is based on the idea of finding a linear combination of features that characterizes or separates two or more classes of objects or events. FLD is a supervised learning algorithm, meaning it requires labeled data to train the model. It is commonly used for classification tasks, where the goal is to predict the class label of a new data point based on its features. FLD works by finding the linear combination of features that maximizes the separation between the classes while minimizing the variation within each class. This linear combination is known as the discriminant function, and it is used to classify new data points. FLD is particularly effective when the number of features is larger than the number of samples. FLD is widely used in various fields, including pattern recognition, machine learning, and statistics, and it has been successfully applied to a wide range of classification problems. Modern steganographic methods typically require a high dimensional feature representation of images for accurate detection. FLD is well-suited for this task and is a widely used machine learning tool for steganalysis of digital media due to its efficiency when working with high dimensional feature sets. It is also known for its ability to handle multicollinearity, a common issue in high dimensional feature sets. [22]

### 6.6.1 FLD algorithm for Image steganalysis

**1. Input:**

- Training sets of cover and stego image features (matrices of size  $d \times N_{\text{trn}}$ )
- Number of base learners ( $L$ )
- Dimensionality of the feature space ( $d$ )
- Number of features selected for each base learner ( $d_{\text{sub}}$ )

**2. Calculate the means ( $\mu_c$  and  $\mu_s$ ) and covariance matrices ( $\Sigma_c$  and  $\Sigma_s$ ) of the cover and stego image features.**

**3. For each base learner:**

- a. Randomly select  $d_{\text{sub}}$ -dimensional subsets of the feature space.
- b. Calculate the weighting vector ( $w$ ) using the Fisher Linear Discriminant (FLD) criterion:
  - Calculate the means ( $\mu_c$  and  $\mu_s$ ) and covariance matrices ( $\Sigma_c$  and  $\Sigma_s$ ) for the selected features.
  - Calculate the weighting vector ( $w$ ) using the formula:  $w = (\Sigma_c + \Sigma_s)^{-1}(\mu_c - \mu_s)$

**4. Combine the decisions of all base learners:**

- a. For each test feature vector ( $f$ ):
  - Calculate the projections ( $v$ ) of the feature vector onto the weighting vectors of all base learners.
  - Combine the decisions of all base learners using a majority voting rule or other fusion method.

5. **Output:** The final classification decision for the test feature vector.

## 6.6.2 Mathematics

- **Class Mean:**

- Calculate the mean vectors for each class:

$$m_1 = \frac{1}{N_1} \sum_{i=1}^{N_1} x_i^{(1)}$$
$$m_2 = \frac{1}{N_2} \sum_{i=1}^{N_2} x_i^{(2)}$$

Where  $N_1$  and  $N_2$  are the number of samples in class  $C_1$  and  $C_2$  respectively, and  $x_i^{(1)}$  and  $x_i^{(2)}$  are feature vectors for individual samples.

- **Within-Class Scatter Matrix:**

- Calculate the within-class scatter matrix  $S_w$ :

$$S_w = \sum_{i=1}^{N_1} (x_i^{(1)} - m_1)(x_i^{(1)} - m_1)^T + \sum_{i=1}^{N_2} (x_i^{(2)} - m_2)(x_i^{(2)} - m_2)^T$$

- **Between-Class Scatter Matrix:**

- Calculate the between-class scatter matrix  $S_b$ :

$$S_b = (m_1 - m_2)(m_1 - m_2)^T$$

- **Fisher's Criterion:**

- Find the optimal weight vector  $W$  by maximizing the Fisher's criterion:

$$W = S_w^{-1}(m_1 - m_2)$$

Where  $S_w^{-1}$  is the inverse of the within-class scatter matrix.

- **Decision Rule:**

- The decision rule for classifying a new feature vector  $x$  is determined by:

if  $W^T x > \text{Threshold}$ , then classify as  $C_1$

if  $W^T x \leq \text{Threshold}$ , then classify as  $C_2$

# **Chapter 7**

## **Expected Outcomes**

The proposed system is expected to detect steganographically modified images using ensemble model. It is expected to be able to identify specificity of steganalysis using shallow Machine Learning.

# Appendix

## 1. HomePage



Figure A-1: Home Page

## 2. Image Upload Section

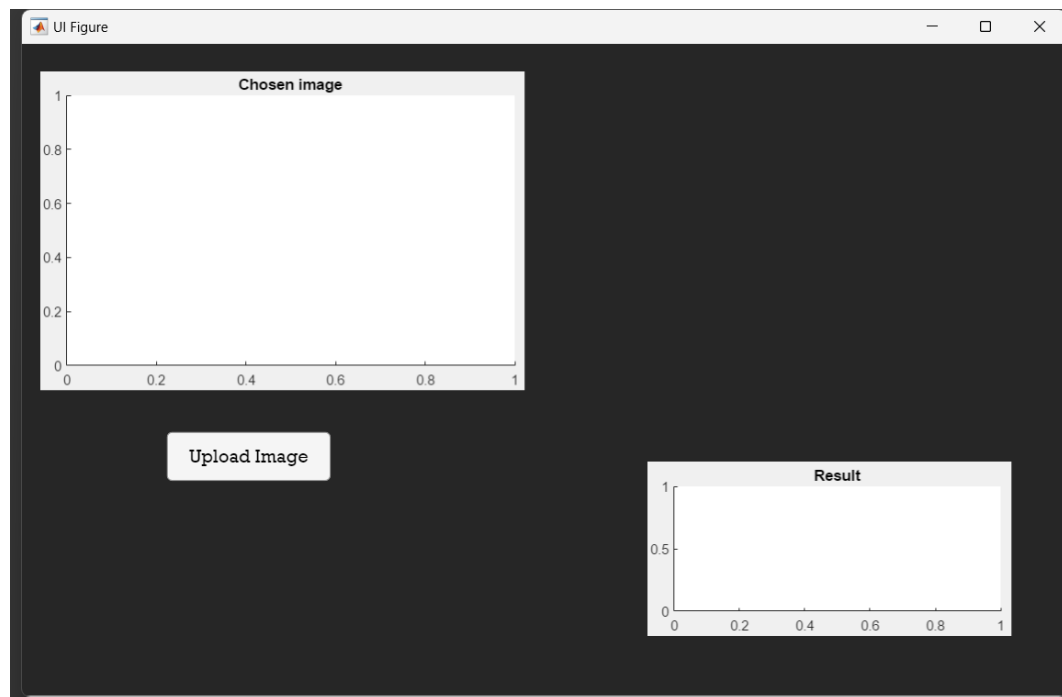


Figure A-2: Image Upload Section

## 3. Selection an Image

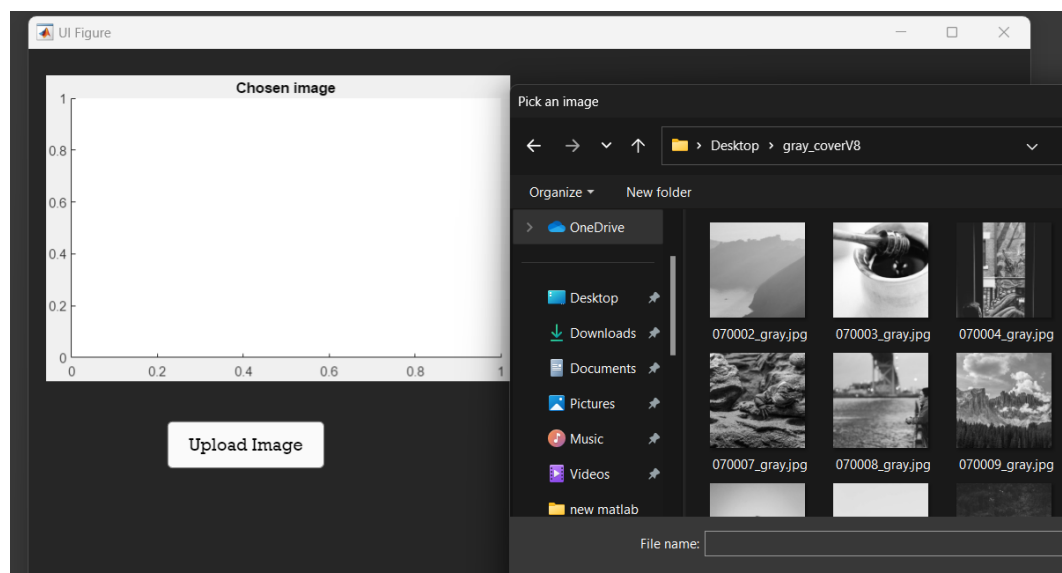


Figure A-3: Image Selection



## 4. Results

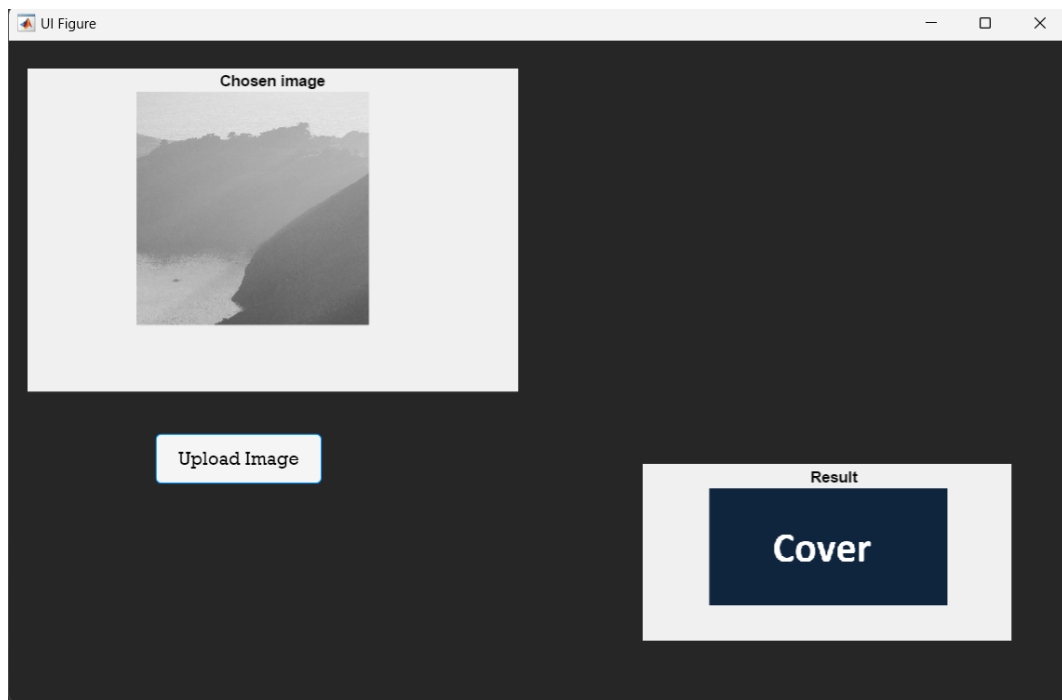


Figure A-4: Result

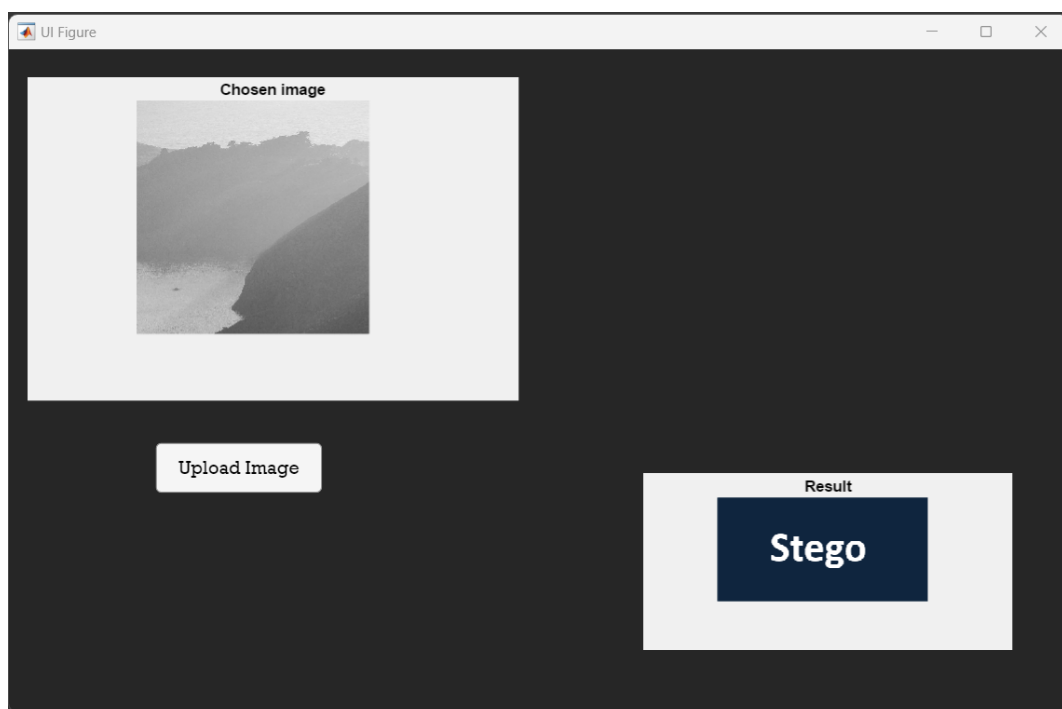


Figure A-5: Result

# Chapter 8

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