UNIVERSITY OF AMSTERDAM

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Research Project II

An Overview on Hiding and Detecting Stego-data in Video Streams

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Abstract

As steganography becomes more common today, new techniques to hide data in large amounts of data streams and new challenges come along every day. Video steganography is one of them. Steganalysis algorithms become then more important.

This paper has as goal to offer a critical review of the steganalysis techniques used today, mainly focusing on how they can be applied for (real-time) steganography detection on video streams. This paper also intends to give an overview on how these detection algorithms can be prevented.

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Glossary

DCT	Discrete Cosine Transform
DWT	Discrete Wavelet Transform
EOF	End of File
LSB	Least Significant Bit
MSB	Most Significant Bit
NFI	Nederlands Forensisch Instituut
PoV	Pairs of Values
PRNG	Pseudo Random Number Generator
QP	Quantization Parameter

Chapter 1

Introduction

The rapid increase of information sharing between people causes a variety of security problems. New security breaches are coming on a daily basis occurrence. One of the ways to offer security in information communication is by means of steganography. Steganography is the art and science of hiding one piece of data within another in such a way that the cover data is perceived not to have any embedded message for its unplanned recipients. Its purpose is to make communication undetectable. However, the increase in availability, sophistication and popularity of steganography programs also increases the potential opportunities for crime, being industrial espionage or criminal coordination among them. This is where steganalysis come up. Steganalysis is the mechanism of detecting information hidden using steganography. A steganographic system is hacked when it is understood that the file is carrying secret information.

There are three well-known cover medias: image, audio and video. Video steganography is emerging as a sub-field of digital steganography.

Research question

- ***Which methods are available for (real-time) steganalysis on a video-stream and how can these be prevented?***
  - Which are the steganography methods available for video-stream?
  - Which are the steganalysis methods available for video-stream?
  - How can steganography be prevented on a video-stream?

The approach to this subject was to analyze one of the available stego-tools, namely *OpenPuff* [8], to conclude if it is possible to do steganalysis on video-streams. Anti-forensics was also considered, i.e. the possibility of avoiding steganalysis. Moreover, *Defraser* [7] (a tool developed by the *NFI*) was also assessed to decide whether stego-videos created by *OpenPuff* can be identified by this tool.

Chapter 2

Background

In this section the meaning of steganography and steganalysis is explained. Also there is a review of the state of the art and previous work done.

2.1 What is Steganography?

Steganography is the art and science of hiding communication or, in other words, the technique of hiding information within a carrier where no one, except the intended recipient, have knowledge of the existence of hidden information. The word originates from the ancient Greek words *steganos* (covered) and *graphein* (writing), literally meaning 'covered writing' [5].

Figure 2.1 represents a usual steganographic system.

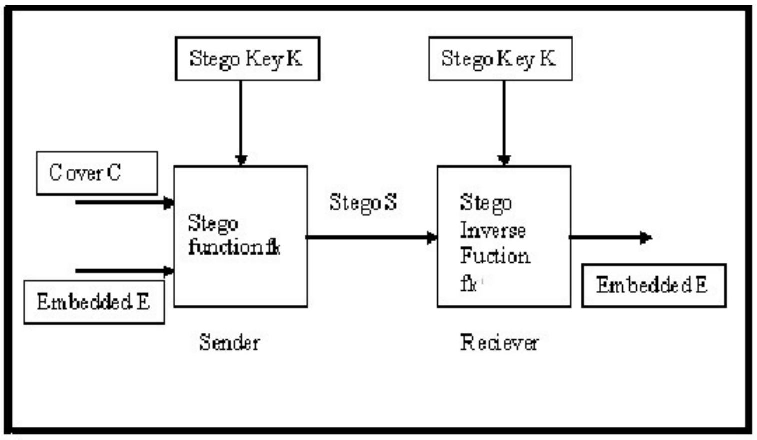


Figure 2.1: Usual steganographic system [1]

2.1.1 History

The earliest recordings of steganography come from the Greek historian Herodotus [5]. In his *Histories*, dated back to 440 BC, he recorded two different steganographic techniques used in Greece. The first stated that King Darius of Susa shaved the head of one of his prisoners and tattooed a secret message on his scalp. After the prisoner's hair grew back he was sent undetected. On the second story, Demaratus needed to send a warning to Sparta about a forthcoming attack to Greece. To do so he wrote the message on a wooden backing of a tablet before applying its wax surface. Also this message was sent undetectable.

During the XV century Johannes Trithemius, in his works *Polygraphiae* and *Steganographia*, wrote on steganographic techniques such as invisible inks, coding techniques for text or hidden messages in music.

More recently, during World War II steganography was also used to send hidden messages. Concepts such as null ciphers, image substitution or microdots were introduced during this time.

[1]Image source: https://bitsofbinary.wordpress.com/2011/10/18/an-introduction-to-lexical-steganography

2.1.2 Prisoners' Problem

This Prisoners' problem is commonly used as an example of the need of techniques for sending information in a cover way. This was introduced by Simmons in 1983 [11]. It tells the story of 2 prisoners working on an escape plan. Although they are allowed to communicate, their communications pass through the prison's warden which will attempt to find any hidden communication between them. The prisoners know that the warden will stop the communications if he discovers the secret channel.

The difficulty of the warden's task depends on the complexity of the steganographic algorithm as well as his prior knowledge.

Figure 2.2 represents the described problem, where Alice and Bob are the prisoners and Wendy the warden.

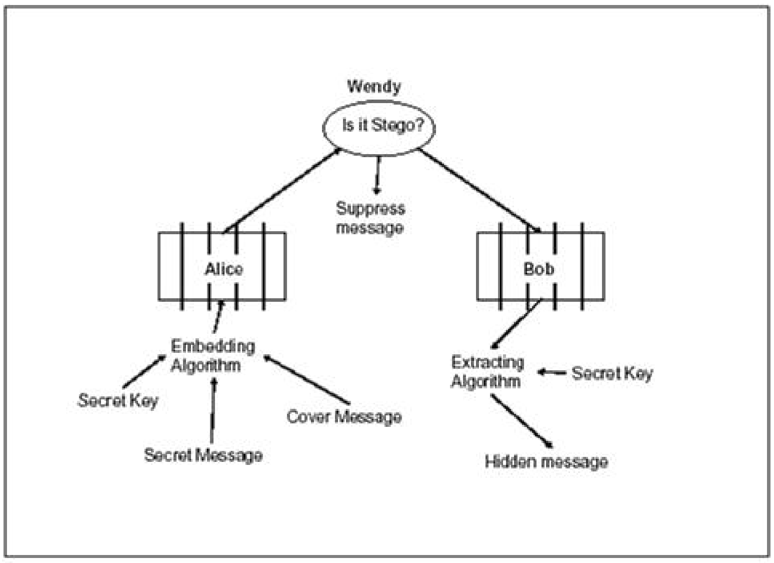


Figure 2.2: Prisoner's Problem approach [2]

2.1.3 Steganography vs Watermarking

Watermarking is similar to steganography, however there are some key differences. While on steganography the data embedded should be covert and undetectable, on watermarking it does not matter if the hidden information is easy to detect, the important factor any attempt to removing a watermark should result in significant degradation of the quality of the carrier file. Watermarking is commonly used to help trace the origin of files.

2.1.4 Steganography vs Cryptography

Steganography and cryptography are different. Cryptography is the study of the ways in which messages can be sent in a disguised form so that only the intended recipients can read the message. Steganography is often confused with cryptography since both are used to protect confidential information. The difference between the two is that cryptography scrambles a message so it cannot be understood, steganography hides the message so it cannot be seen.

2.2 What is Steganalysis?

The security of a steganographic system is defined by its strength to defeat detection. Steganalysis is the practice of detecting the presence of messages that have been hidden using steganography. Although it is not the goal of steganalysis, ideally the content of the hidden message is also determined.

[2]Image source: http://studentweb.niu.edu/9/ Z172699/Organisation.html

2.2.1 Types of Attacks

Steganalysis attacks can be active or passive. In the active attacks a steganalyst can manipulate the date while in the passive attack the steganalyst is only able to analyze the information without changing it.

The following are types of attacks used by steganalysts to detect steganography on files [10].

2.2.1.1 Stego Only Attack

The attacker has intercepted only the stego data and is able to analyze it. For example, only the stego-carrier (picture, video, etc) and hidden information are available.

2.2.1.2 Known Cover Attack

The attacker has intercepted the stego-file and knows which cover file was used to create this stego-file. This provides an advantage over the stego-only-attack for the attacker. For example, the original image and the image containing the hidden information are available and can be compared.

2.2.1.3 Known Message Attack

The attacker has intercepted the stego-file and knows both the cover file which was used to create the stego-file as well as the message that is embedded in this stego-file. Although the message is known, this attack might be very difficult to perform.

2.2.1.4 Chosen Stego Attack

The algorithm used as well as the stego-carrier are known. For example, the steganography tool, the image and hidden information are known.

2.2.1.5 Chosen Message Attack

The aim of this attack is to find patterns of the stego-object that can point to specific steganography tools or algorithms. To do so, the steganalyst generates stego-objects from some steganography tools or algorithms of a chosen message.

2.2.2 Visual Attacks

Visual attacks are the simplest form of attacking a steganographic system. This attack is based on the visual analysis of the image and if there are noticeable differences between the carrier and stego image, it is probable that the suspected image/video carries hide information. However, if an embedding is not detected by the observer, the bit planes of the image are then analyzed, beginning with the least significant plane.

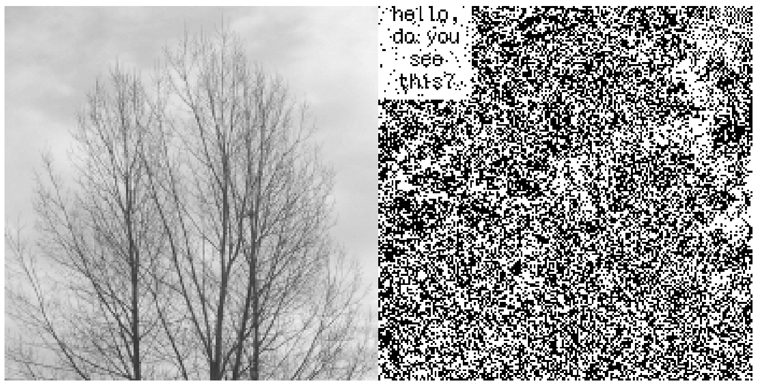


Figure 2.3: Visual attack example [3]

A successful visual attack shows also how the stego-system operates when embedding the hidden message. If the carrier is not known this attacks becomes very hard to perform.

[3]Image source: http://www.aaronmiller.in/thesis/

2.2.3 Structural Attacks

In a structural attack the steganalyst tries to find known properties of the algorithms used to hide the message. If they contain any properties of these algorithms they are analyzed further. Due to false positives, this attack is used to highlight images which show signs of possible embedded data. As in the visual attacks, the possibility for a structural attack to be successful depends a lot on if the carrier file is known or not.

2.2.4 Statistical Attacks

In statistical attacks an statistical analysis of the images is done using mathematical formulas. Depending on the results it can be determined if there is hidden information on the file or not.

Statistical attacks are much more effective than the visual or structural attacks.

2.2.4.1 Chi-Square Attack

The Chi-square attack, developed by Westfield and Pfitzmann [15], is a statistical test to measure if a given set of observed data and an expected set of data are similar or not. In this attack Pairs of Values (PoV) expected frequencies are compared to the observed frequencies of the file being analyzed, this gives the probability of hidden data. PoV are values where if the LSB is changed in one value they are transformed to another value and vice-versa. For example, if a pixel as the value 23 and a bit with value 1 is inserted into the LSB it will be changed to the value 24, the same way, if a bit with value 0 is inserted into the LSB of a pixel with value 24, it will be changed to the value 23.

This attack is successful even without knowing the carrier file, however it fails to determine the hidden data's size.

Chapter 3

Literature Study

There are various techniques for hiding data in a digital storage file. Although the aim of this project is video steganography, there are also steganography techniques applied to images and audio which are relevant to video file formats. Moreover, video can be divided into audio and image streams. In this chapter there is a discussion on audio and image techniques since it is important to understand them to be able to work with video steganography.

3.1 Steganographic Techniques

There are a collection of steganographic techniques that can be used to camouflage information in a file. The following described are examples of steganographic techniques.

3.1.1 Injection

This method is by far the simplest steganographic technique. Injection involves hiding the message in parts of a file that will be ignored by the application, such as comment tags, hidden form elements or End of File (EOF) markers, without affecting the integrity of the container file.

A drawback to this technique is that it generally makes the file larger than the original unmodified file.

3.1.2 Substitution

Substitution techniques identify areas of a file of least relevance and replace this data with the hidden information. This technique does not modify the size of the container file, therefore the steganographic capacity of the file is limited.

3.1.2.1 List Significant Bits Manipulation

The most common way to embed data in an image is to replace the least significant bits (LSB) [12].

In 8-bit images, each pixel is represented by 8 bits, such as shown on Figure 3.1.

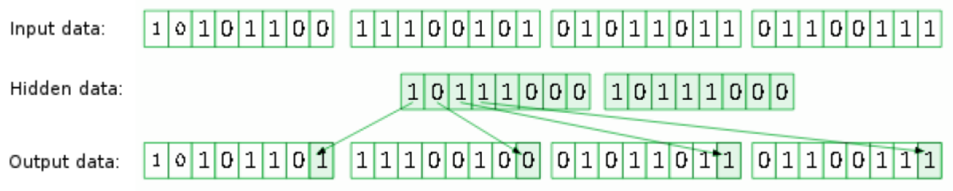


Figure 3.1: LSB using one least significant bit [3]

The most significant bits (MSB) are the ones to the left and the least significant bits are the ones to the right. While when changing the MSBs there is a noticeable impact on the color, changing the LSBs will not be noticeable to the human eye. Image formats commonly used in the LSB substitution are loss less and the data can be directly molded and recovered.

[3]Image source: http://lvee.org/uploads/abstract_file/file/111/2.png

One significant advantage of this method is that it is simple to implement. However, since the data is hidden in the LSBs, these methods are vulnerable to extraction and attacks such as compression or cropping.

LSB Sequential Insertion

In sequential insertion, as the name implies, the message is hidden in consecutive parts of the carrier file. This technique is easy to to detect and decode, since each change data bit from the message follows the next.

LSB Pseudo Random Insertion

In pseudo random insertion a pseudo random number generator (PRNG) is used to randomly hide the secret bits of the message into the LSB of the carrier file. In this technique a secret, known by both the sender and receiver, is used as a seed for a random number generator. This technique is difficult to be attacked both visually and statistically. It is also very hard to extract all the bits hidden within the message, since the data is hidden in a random way making it difficult to assure that the next LSB also contains hidden information.

3.1.3 Transform Domain

There are more complex ways of hiding secrets inside images, for instance the modification of discrete cosine transformations.

Transform domain techniques are generally used on compressed container files, such as JPEG or MPEG.

3.1.3.1 Discrete Cosine Transform

The Discrete Cosine Transform (DCT) algorithm works by using quantization, i.e. rounding the values (for example 3.872687 is 4) of the least important parts of the image in respect to the human visual capabilities. Although doing this to each and every value produces noticeable distortions in the image, the human eye under normal conditions does not detect high frequencies in images, therefore this allows DCT to make larger modifications to these frequencies with little noticeable image distortion. The algorithm works as follows: the image is split into smaller areas (8x8 squares) which will be transformed via DCT. A quantization on the frequencies is then applied. This is the stage where the secret message is injected. Finally the image is compressed, which will not have any impact on the integrity of the secret message.

Using this technique ensures that the hidden message is distributed in an even way through the whole image [6].

3.1.3.2 Discrete Wavelet Transform

Although DCT is quite useful for hiding data in a compressed image, it does not well at high compressed levels. This is where the discrete wavelet transform enters. The DWT technique makes it possible to rise the level of robustness of the information being hidden. It works by taking many wavelets to encode a whole image. This allows the image to be compressed highly by storing the high frequency separated from the low frequency details. The low frequency parts are then compressed, being also possible to use quantization for further compression.

Embedding secret information with DWT works pretty much the same way it works with DCT. The drawback of this method is that if the threshold is too high the stego-file will have detectable differences [6].

3.2 Video Steganography

Video steganography is growing as a research area, this to the fact that a video container file has diverse advantages not presented by other container formats. To change a video file is somewhat more difficult to detect by the human eye, as frames are visible on-screen for very brief periods of time. Moreover, video file containers are quite larger than audio or images files, hence reducing the problem of steganographic capacity. There are various types of video formats, among them AVI, WMV or MP4.

Since video files are an assortment of images and audio, the techniques used on these can also be applied to video files.

3.2.1 Spatial Domain

In the spatial domain the image is dealt as it is and the value of the pixels of the image change with respect to the scene (which can be a two- or three-dimensional scene, etc).

The techniques used in the spatial domain are based on direct manipulation of pixels in an image.

3.2.2 Frequency Domain

The frequency domain is a space in which each image value at a specif image position represents the amount that the intensity values in the image vary over a specific distance related to that same specif image position. In the frequency domain, changes in the image position correspond to changes in the spatial frequency or the rate at which image intensity values are changing in the spatial domain image.

As an example, imagine that there is the value 30 at the point that represents the frequency 0.1 (or 1 period every 10 pixels). This means that in the corresponding spatial domain image the intensity values vary from dark to light and back to dark over a distance of 10 pixels, and that the contrast between the lightest and darkest is 60 gray levels (2 times 30).

When secret messages are hidden in a video it is commonly classified into temporal domain and spatial domain. The advantage of the spacial domain based methods is that it is simple and easy to implement since the pixel values of the image are directly replaced with the hidden message. The transform domain techniques are more resistant to attacks on the stego-image due to the fact that the secret information is hidden in frequency domain, which makes it very difficult to extract the message [4].

Another advantage of using video files to hide information is that it adds more security against attacks since video files are relatively more complex than image or audio files.

3.3 Video Container Format

A video container is usually associated to the file format. In here it is contained the various components of a video, such as the stream of images or the sound. As an example, it is possible to have multiple soundtracks and/or subtitles included in a video file, as long as the container format allows it. Popular containers are OGG, Matroska, AVI or MPEG.

Figure 3.2 shows a typical structure for a video container. No specific format is represent since details might vary from format to format.

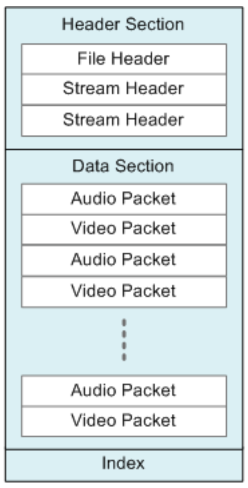


Figure 3.2: Typical structure of a video container [4]

[4]Image source: https://msdn.microsoft.com/en-us/library/windows/desktop/ee663601(v=vs.85).aspx

As can be seen in the figure, the video file structure is hierarchical, with the header information appearing at the beginning of the container. This is the typical structure of container formats (most of them). Also the data section contains crossed audio and video packets, which is a common structure in media containers.

3.4 Compression

Video compression regards reducing and removing redundant video data. Efficient compression techniques can significantly reduce the file size with no undesirable effects on the visual quality. Different video compression standards utilize different methods of reducing data, therefore results may differ in bit rate, quality and latency.

There are two types of compression, they are lossless compression and lossy compression.

Lossless Compression

This technique gives preference to the original image information, meaning that every single bit of data that was originally in the file remains after the file is uncompressed. This allows the original data to be perfectly reconstructed from the compressed data.

Lossy Compression

Lossy compression discards the points which are difficult to identify by the human eye. The resulting image is similar to the original image but not exactly the same. This technique reduces a file by permanently eliminating certain information, especially redundant information. When the file is uncompressed, only a part of the original information is still there (however it might not be noticed by the human eye).

Lossy compression is generally used for video and sound, where a certain amount of information loss will not be detected by most users.

3.4.1 MPEG Compression

MPEG compression is a lossy compression and, as almost all the lossy compression techniques, it exploits the fact that human senses do not distinguish small changes in high frequency information.

3 bytes are used in video to represent every single pixel. These are either separated in the usual RGB code (red, green and blue) or in luma and two chroma components, named YUV and YCbCr. MPEG also uses the DCT technique (see Section 3.1.3.1) to convert the spacial data into the frequency domain. This is done in 8x8 blocks of pixels. The upper left corner is called the DC value. DC stands for *direct current* and refers to the average brightness in the block. All the other values describe the variation around the DC value. They are called AC values, or *alternating current*. The DCT coefficients coming from the conversion are then quantized accordingly to their importance.

An MPEG file is a sequence of three kinds of frames: I-, B- and P-frames, as can be seen on Figure 3.3.

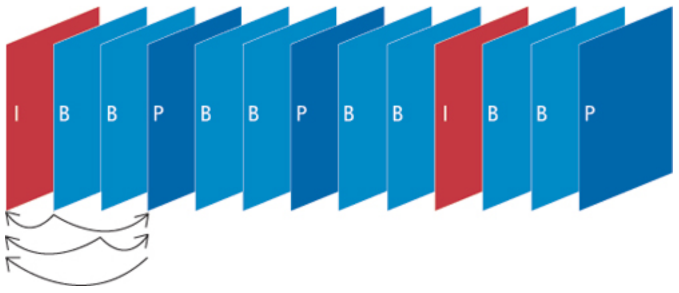


Figure 3.3: A typical sequence with I, B and P-frames [5]

[5]Image source: http://www.axis.com/products/video/about_networkvideo/compression.htm

I-frames

Intra-coded frames are video frames which can be reconstructed without any reference to any other frame. A video file will always start with an I-frame and will have successive I-frames added at regular intervals. The downside to an I-frame is that they are the largest in terms of size as the whole video frame is encoded every time. They are also entirely encoded using DCT values.

P-frames

Predictive-coded frames are video frames which are forwarded predicted from I-frames or P-frames, making it impossible to reconstruct them without the data from either I or P-frames. The downside to P-frames is that they are sensitive to transmission errors because of their dependency on earlier frames.

B-frames

Bidirectionally predictive-coded frames are both forwarded and backward predicted from the last I-frame or P-frame, i.e. they need two other frames to reconstruct them. Although using B-frames improves the prediction and the quality of decoded video it also increases the processing requirements and latency.

On steganography, the DCT values of these frame types may be changed by a limited amount when it is decoded.

3.4.2 H.264 Compression

H.264 compression introduces a new intra-prediction scheme for encoding I-frames. This technique can greatly reduce the bit size of an I-frame and, as I-frames are the largest of the video frames, this has a great impact on the overall size of the video file. H.264 achieves a smaller bit size for the frame while maintaining the quality by enabling the successive prediction of smaller blocks of pixels within each macro block in a frame.

H.264 compression works the following way: a block of residual samples is transformed using a 4x4 or 8x8 integer transform, an approximate form of the DCT. The transform outputs a set of coefficients, each of which is a weighting value for a standard basis pattern. When combined, the weighted basis patterns re-create the block of residual samples.

The output of the transform, a block of transform coefficients, is quantized, i.e. each coefficient is divided by an integer value. Quantization reduces the precision of the transform coefficients according to a quantization parameter (QP). Commonly, the result is a block in which most or all of the coefficients are zero. Setting QP to a high value means that more coefficients are set to zero, resulting in high compression at the expense of poor decoded image quality, oppositely, setting QP to a low value means that more non-zero coefficients remain after quantization, resulting in better decoded image quality but lower compression.

The H.264 baseline profile only uses I- and P-frames. Since B-frames are not used low latency can be achieved. [1]

Chapter 4

Analysis

To understand how steganography is applied on videos, one of the available stego-tools, namely *OpenPuff*, was analyzed.

4.1 OpenPuff

OpenPuff is a steganography tool created by Cosimo Oliboni. This tool lets the users to hide information in a wide range of carrier formats, among them videos, such as 3gp, Mp4 or Mpeg II. On top of this, the users can also hide data in more than a single carrier file, forming a carrier chain. For the hidden message to be retrieve, all the carrier files must be provided in the same order used to hide the information.

A successful steganographic system should take 2 important factors into consideration, embedding efficiency and embedding payload. If a steganographic scheme has a high embedding efficiency it means quality of stego data and less amount of the carrier file data changed [3]. As it is obvious, any kind of distortions will catch the attention of a steganalyst. Moreover, the security of a steganographic architecture is directly dependent on the embedding efficiency. [14]. A high embedding payload means that the capacity to hide secret information inside the carrier file is big.

As stated by Neils Provos in [9], a paper where *OpenPuff* is based on, steganalysis resistance and performance are incompatible trade-offs.

To make the system secure and to keep it with good performance **whitening** is used. This will provide higher data security and allows deniable steganography (which will be discussed on section 4.2). However it will require more carrier bits. i.e. the use of this technique requires larger files. On the other hand, to make the system secure and to make it steganalysis resistant **whitening** and **cryptography** are used. It will only assures higher data security with the drawback of marking the carriers more "suspicious", due to their random statistical response.

Therefore *OpenPuff* implements also 3 layers of hidden data obfuscation, being them cryptography, whitening and encoding. Figure 4.1 shows how *OpenPuff* steganographic architecture works.

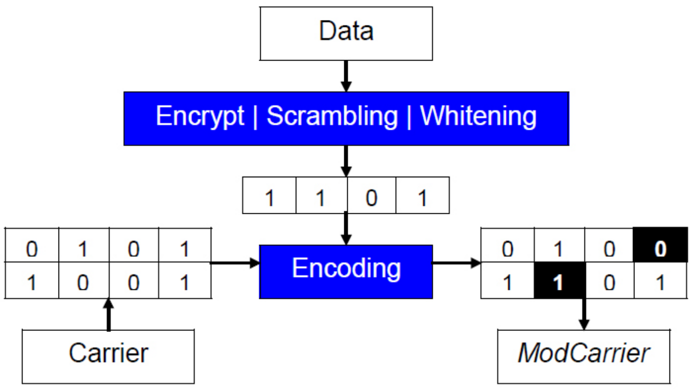


Figure 4.1: *OpenPuff* carrier bit encoding [6]

[6]Image source: https://en.wikipedia.org/wiki/File:OpenPuff_arch8.jpg

Before the data is carrier injected, it is encrypted and whitened, meaning that part of the hidden information will turn into a big block of pseudorandom suspicious data. Carrier injection will then encode it applying a a non linear covering function [2] which will take also original carrier bits as input.

This way, modified carriers will need less change and, since it will lower their random-like statistical response, it deceives various steganalysis tests [16].

4.1.1 OpenPuff Stego-analyzed

To understand and analyze *OpenPuff*, the approach followed was to create some stego-videos and perform known attacks (described on Section 2.2).

4.1.1.1 Visual Attack

The visual attack was performed by reproducing both the original and stego videos. Also, individual frames from the original and from the stego-file were compared and analyzed. Figures 4.2 and 4.3 show the same frames collected using *Defraser*. As can be seen both frames look identical.

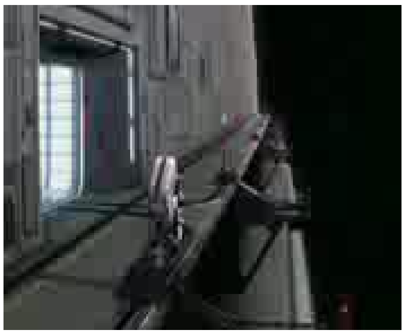


Figure 4.2: Original file frame

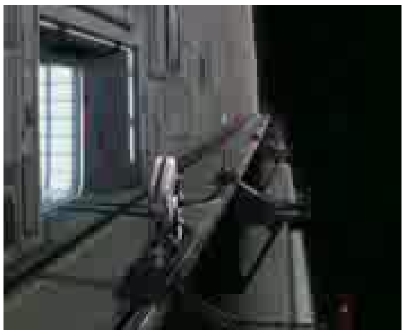


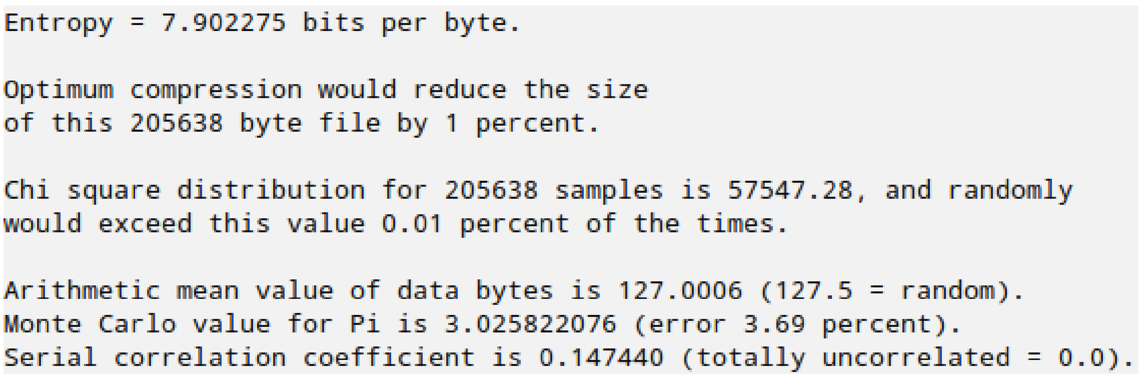
Figure 4.3: Stego-file frame

As expected no noticeable differences were found between both files neither while reproducing the videos nor analyzing the individual frames.

This was the only attack performed where *Defraser* was used. It cannot be determined whether *Defraser* is a valuable to tool to identify stego-videos, however the frames retrieved with this tool proved to be insufficient.

4.1.1.2 Statistical Attack

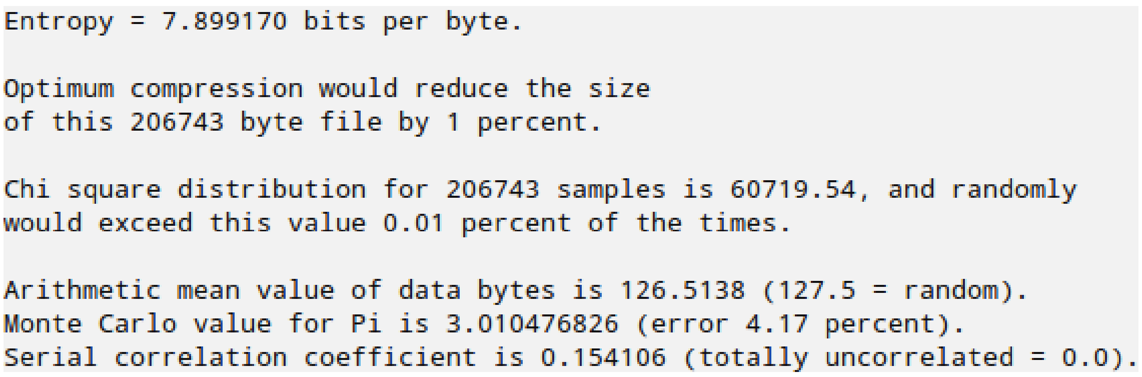
The statistical analysis of the stego-files created by *OpenPuff* was done with the program *ent* [13]. This tool does a collection of tests on the provided file, the output looks like represented on Figures 4.4 and 4.5.


```
Entropy = 7.902275 bits per byte.

Optimum compression would reduce the size
of this 205638 byte file by 1 percent.

Chi square distribution for 205638 samples is 57547.28, and randomly
would exceed this value 0.01 percent of the times.

Arithmetic mean value of data bytes is 127.0006 (127.5 = random).
Monte Carlo value for Pi is 3.025822076 (error 3.69 percent).
Serial correlation coefficient is 0.147440 (totally uncorrelated = 0.0).
```
Figure 4.4: ent command results of the original file



```
Entropy = 7.899170 bits per byte.

Optimum compression would reduce the size
of this 206743 byte file by 1 percent.

Chi square distribution for 206743 samples is 60719.54, and randomly
would exceed this value 0.01 percent of the times.

Arithmetic mean value of data bytes is 126.5138 (127.5 = random).
Monte Carlo value for Pi is 3.010476826 (error 4.17 percent).
Serial correlation coefficient is 0.154106 (totally uncorrelated = 0.0).
```

Figure 4.5: ent command results of the stego-file

The following explains the meaning of each of the values output by *ent*.

Entropy

The entropy value represents the information density of the contents of the file and it is expressed as the number of bits per character. The result shown on Figure 4.4 indicates that the file is extremely dense in information.

Therefore the compression of the files analyzed is not likely to reduce its size, since for both files it was output the value 1%.

Chi-square Test

This is the most common used test for the randomness of data and is extremely sensitive to errors in pseudo random sequence generators. It is calculated for the stream of bytes in the file and revealed as an absolute number and a percentage which indicates how frequently a truly random sequence would exceed the value calculated. This percentage is interpreted as the rate to which the sequence tested is suspected to be non-random. If the percentage is:

- **greater than 99% and less than 1%** - the sequence is almost surely not random;
- **between 99% and 95% or between 1% and 5%** - the sequence is considered suspect;
- **between 90% and 95% or between 5% and 10%** - the sequence is not sure to be suspect or not.

Although both files are very dense in information, as shown by the entropy value, is far from being random, as it is exposed by the chi-square test.

Arithmetic Mean

The arithmetic mean is the result of the sum of all the bytes in the file divided by the file length. A random data file shall return a value around 127.5.

Both values are close to a random data file.

Monte Carlo Value for Pi

The Monte Carlo Value for Pi is calculated by grouping each successive sequence of six bytes from the file in a 24 bit X and Y coordinate in a square. If the randomly-generated point distance is less than the radius of a circle inscribed within the square, the six bytes sequence is considered a hit. The percentage of hits is then used to calculate the value of Pi. If the sequence is close to random, the value will approach the correct value of Pi.

Although the values presented are not the correct value of Pi, they are not far from it.

Serial Correlation Coefficient

The serial correlation coefficient calculates how much each byte in the file depends on the previous byte. If the sequence is random, this value will be close to zero.

Both values are pretty close to zero, meaning the file is quite random on what is related to the dependency of a byte on its predecessor.

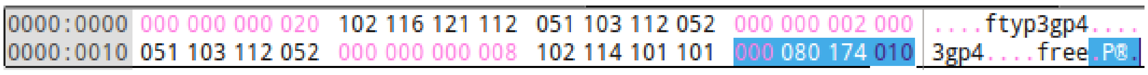
By comparing the original file values (Figure 4.4) and the stego-file values (Figure 4.5) provided by *ent*, it can be seen that the values are very similar and do not raise any suspicious upon the stego-file.

If we approach this attack as a **Known Cover Attack**, and since it is based on the comparison of both the original and stego files, it can be concluded that the known stego-file contains hidden data, therefore this attack can be considered successful. However, if the original file was not known, the attack known as **Stego Only Attack** would fail.

4.1.1.3 Structural Attack

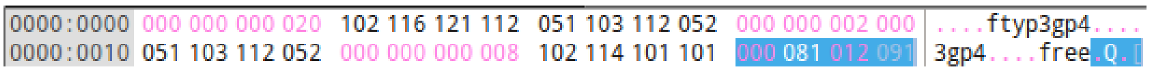
The structural attack is based on the comparison of the original file and the stego-file (it can either be considered a **Known Cover Attack** or a **Chosen Message Attack**).

To perform this attack an hexdump of both files was analyzed. Figures 4.6 and 4.7 represent the file type header of both files.



```
0000:0000 000 000 000 020  102 116 121 112  051 103 112 052  000 000 002 000  ....ftyp3gp4....
0000:0010 051 103 112 052  000 000 000 008  102 114 101 101  000 080 174 010  3gp4....free.P®.
```

Figure 4.6: File type header hexdump from the original file

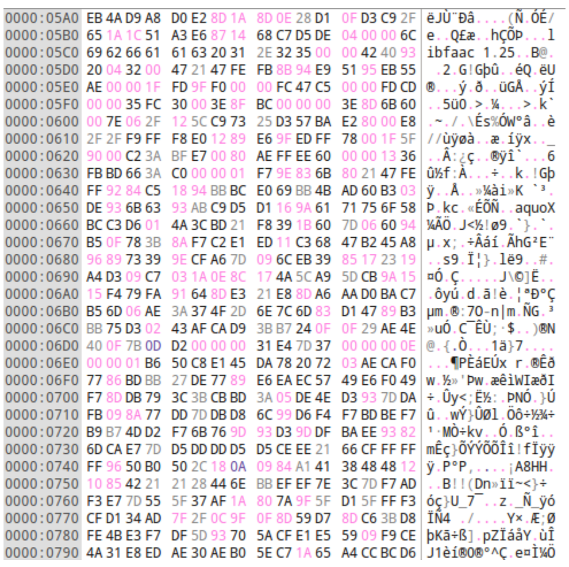


```
0000:0000 000 000 000 020  102 116 121 112  051 103 112 052  000 000 002 000  ....ftyp3gp4....
0000:0010 051 103 112 052  000 000 000 008  102 114 101 101  000 081 012 091  3gp4....free.Q.[
```

Figure 4.7: File type header hexdump from the stego-file

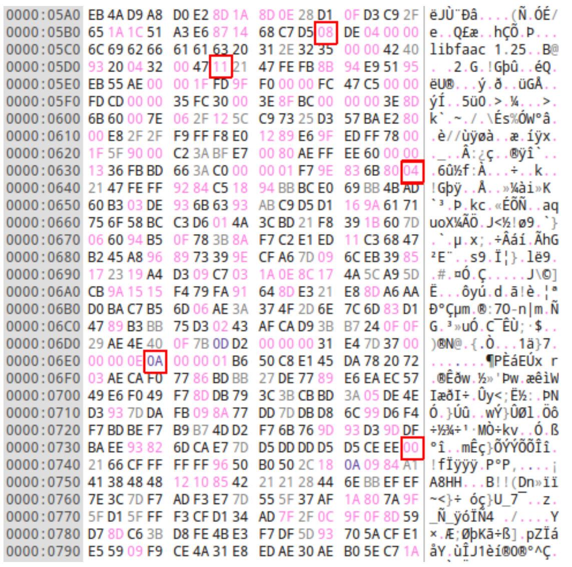
As can be seen highlighted in blue, the last four bytes of the header are changed. These bytes are an offset pointing to the beginning of the header that belongs to the MOOV box. The MOOV box defines the timescale, duration, display characteristics of the movie, as well sub-boxes containing information for each track in the movie.

The stego-file MOOV box header offset is different from the original file MOOV box header because some bytes were inserted outside this box, as can be seen on Figures 4.8 and 4.9. This pattern is followed through out the stego-file outside the MOOV box.



```
0000:05A0 EB 4A D9 A8  D0 E2 8D 1A  8D 0E 28 D1  0F D3 C9 2F  ëJÙ¨Ðâ....(Ñ.ÓÉ/
0000:05B0 65 1A 1C 51  A3 E6 87 14  68 C7 D5 DE  04 00 00 6C  e..Q£æ..hÇÕÞ...l
0000:05C0 69 62 66 61  61 63 20 31  2E 32 35 00  00 42 40 93  ibfaac 1.25..B@.
0000:05D0 20 04 32 00  47 21 47 FE  FB 8B 94 E9  51 95 EB 55   .2.G!Gþû..éQ.ëU
0000:05E0 AE 00 00 1F  FD 9F F0 00  00 FC 47 C5  00 00 FD CD  ®...ý.ð..üGÅ..ýÍ
0000:05F0 00 00 35 FC  30 00 3E 8F  BC 00 00 00  3E 8D 6B 60  ..5ü0.>.¼...>.k`
0000:0600 00 7E 06 2F  12 5C C9 73  25 D3 57 BA  E2 80 00 E8  .~./.\És%ÓWºâ..è
0000:0610 2F 2F F9 FF  F8 E0 12 89  E6 9F ED FF  78 00 1F 5F  //ùÿøà..æ.íÿx.._
0000:0620 90 00 C2 3A  BF E7 00 80  AE FF EE 60  00 00 13 36  ..Â:¿ç..®ÿî`...6
0000:0630 FB BD 66 3A  C0 00 00 01  F7 9E 83 6B  80 21 47 FE  û½f:À...÷..k.!Gþ
0000:0640 FF 92 84 C5  18 94 BB BC  E0 69 BB 4B  AD 60 B3 03  ÿ..Å..»¼ài»K `³.
0000:0650 DE 93 6B 63  93 AB C9 D5  D1 16 9A 61  71 75 6F 58  Þ.kc.«ÉÕÑ..aquoX
0000:0660 BC C3 D6 01  4A 3C BD 21  F8 39 1B 60  7D 06 60 94  ¼ÃÖ.J<½!ø9.`}.`.
0000:0670 B5 0F 78 3B  8A F7 C2 E1  ED 11 C3 68  47 B2 45 A8  µ.x;.÷Âáí.ÃhG²E¨
0000:0680 96 89 73 39  9E CF A6 7D  09 6C EB 39  85 17 23 19  ..s9.Ï¦}.lë9..#.
0000:0690 A4 D3 09 C7  03 1A 0E 8C  17 4A 5C A9  5D CB 9A 15  ¤Ó.Ç.....J\©]Ë..
0000:06A0 15 F4 79 FA  91 64 8D E3  21 E8 8D A6  AA D0 BA C7  .ôyú.d.ã!è.¦ªÐºÇ
0000:06B0 B5 6D 06 AE  3A 37 4F 2D  6E 7C 6D 83  D1 47 89 B3  µm.®:7O-n|m.ÑG.³
0000:06C0 BB 75 D3 02  43 AF CA D9  3B B7 24 0F  0F 29 AE 4E  »uÓ.C¯ÊÙ;·$..)®N
0000:06D0 40 0F 7B 0D  D2 00 00 00  31 E4 7D 37  00 00 00 0E  @.{.Ò...1ä}7....
0000:06E0 00 00 01 B6  50 C8 E1 45  DA 78 20 72  03 AE CA F0  ...¶PÈáEÚx r.®Êð
0000:06F0 77 86 BD BB  27 DE 77 89  E6 EA EC 57  49 E6 F0 49  w.½»'Þw.æêìWIæðI
0000:0700 F7 8D DB 79  3C 3B CB BD  3A 05 DE 4E  D3 93 7D DA  ÷.Ûy<;Ë½:.ÞNÓ.}Ú
0000:0710 FB 09 8A 77  DD 7D DB D8  6C 99 D6 F4  F7 BD BE F7  û..wÝ}ÛØl.Öô÷½¾÷
0000:0720 B9 B7 4D D2  F7 6B 76 9D  93 D3 9D DF  BA EE 93 82  ¹·MÒ÷kv..Ó.ßºî..
0000:0730 6D CA E7 7D  D5 DD DD D5  D5 CE EE 21  66 CF FF FF  mÊç}ÕÝÝÕÕÎî!fÏÿÿ
0000:0740 FF 96 50 B0  50 2C 18 0A  09 84 A1 41  38 48 48 12  ÿ.P°P,....¡A8HH.
0000:0750 10 85 42 21  21 28 44 6E  BB EF EF 7E  3C 7D F7 AD  ..B!!(Dn»ïï~<}÷ 
0000:0760 F3 E7 7D 55  5F 37 AF 1A  80 7A 9F 5F  D1 5F FF F3  óç}U_7¯..z._Ñ_ÿó
0000:0770 CF D1 34 AD  7F 2F 0C 9F  0F 8D 59 D7  8D C6 3B D8  ÏÑ4 ./....Y×.Æ;Ø
0000:0780 FE 4B E3 F7  DF 5D 93 70  5A CF E1 E5  59 09 F9 CE  þKã÷ß].pZÏáåY.ùÎ
0000:0790 4A 31 E8 ED  AE 30 AE B0  5E C7 1A 65  A4 CC BC D6  J1èí®0®°^Ç.e¤Ì¼Ö
```

Figure 4.8: Original file hexdump



```
0000:05A0 EB 4A D9 A8  D0 E2 8D 1A  8D 0E 28 D1  0F D3 C9 2F  ëJÙ¨Ðâ....(Ñ.ÓÉ/
0000:05B0 65 1A 1C 51  A3 E6 87 14  68 C7 D5 08  DE 04 00 00  e..Q£æ..hÇÕ.Þ...
0000:05C0 6C 69 62 66  61 61 63 20  31 2E 32 35  00 00 42 40  libfaac 1.25..B@
0000:05D0 93 20 04 32  00 47 11 21  47 FE FB 8B  94 E9 51 95  . .2.G.!Gþû..éQ.
0000:05E0 EB 55 AE 00  00 1F FD 9F  F0 00 00 FC  47 C5 00 00  ëU®...ý.ð..üGÅ..
0000:05F0 FD CD 00 00  35 FC 30 00  3E 8F BC 00  00 00 3E 8D  ýÍ..5ü0.>.¼...>.
0000:0600 6B 60 00 7E  06 2F 12 5C  C9 73 25 D3  57 BA E2 80  k`.~./.\És%ÓWºâ.
0000:0610 00 E8 2F 2F  F9 FF F8 E0  12 89 E6 9F  ED FF 78 00  .è//ùÿøà..æ.íÿx.
0000:0620 1F 5F 90 00  C2 3A BF E7  00 80 AE FF  EE 60 00 00  ._..Â:¿ç..®ÿî`..
0000:0630 13 36 FB BD  66 3A C0 00  00 01 F7 9E  83 6B 80 04  .6û½f:À...÷..k..
0000:0640 21 47 FE FF  92 84 C5 18  94 BB BC E0  69 BB 4B AD  !Gþÿ..Å..»¼ài»K 
0000:0650 60 B3 03 DE  93 6B 63 93  AB C9 D5 D1  16 9A 61 71  `³.Þ.kc.«ÉÕÑ..aq
0000:0660 75 6F 58 BC  C3 D6 01 4A  3C BD 21 F8  39 1B 60 7D  uoX¼ÃÖ.J<½!ø9.`}
0000:0670 06 60 94 B5  0F 78 3B 8A  F7 C2 E1 ED  11 C3 68 47  .`.µ.x;.÷Âáí.ÃhG
0000:0680 B2 45 A8 96  89 73 39 9E  CF A6 7D 09  6C EB 39 85  ²E¨..s9.Ï¦}.lë9.
0000:0690 17 23 19 A4  D3 09 C7 03  1A 0E 8C 17  4A 5C A9 5D  .#.¤Ó.Ç.....J\©]
0000:06A0 CB 9A 15 15  F4 79 FA 91  64 8D E3 21  E8 8D A6 AA  Ë...ôyú.d.ã!è.¦ª
0000:06B0 D0 BA C7 B5  6D 06 AE 3A  37 4F 2D 6E  7C 6D 83 D1  ÐºÇµm.®:7O-n|m.Ñ
0000:06C0 47 89 B3 BB  75 D3 02 43  AF CA D9 3B  B7 24 0F 0F  G.³»uÓ.C¯ÊÙ;·$..
0000:06D0 29 AE 4E 40  0F 7B 0D D2  00 00 00 31  E4 7D 37 00  )®N@.{.Ò...1ä}7.
0000:06E0 00 00 0E 0A  00 00 01 B6  50 C8 E1 45  DA 78 20 72  ........¶PÈáEÚx r
0000:06F0 03 AE CA F0  77 86 BD BB  27 DE 77 89  E6 EA EC 57  .®Êðw.½»'Þw.æêìW
0000:0700 49 E6 F0 49  F7 8D DB 79  3C 3B CB BD  3A 05 DE 4E  IæðI÷.Ûy<;Ë½:.ÞN
0000:0710 D3 93 7D DA  FB 09 8A 77  DD 7D DB D8  6C 99 D6 F4  Ó.}Úû..wÝ}ÛØl.Öô
0000:0720 F7 BD BE F7  B9 B7 4D D2  F7 6B 76 9D  93 D3 9D DF  ÷½¾÷¹·MÒ÷kv..Ó.ß
0000:0730 BA EE 93 82  6D CA E7 7D  D5 DD DD D5  D5 CE EE 00  ºî..mÊç}ÕÝÝÕÕÎî.
0000:0740 21 66 CF FF  FF FF 96 50  B0 50 2C 18  0A 09 84 A1  !fÏÿÿÿ.P°P,....¡
0000:0750 41 38 48 48  12 10 85 42  21 21 28 44  6E BB EF EF  A8HH...B!!(Dn»ïï
0000:0760 7E 3C 7D F7  AD F3 E7 7D  55 5F 37 AF  1A 80 7A 9F  ~<}÷ óç}U_7¯..z.
0000:0770 5F D1 5F FF  F3 CF D1 34  AD 7F 2F 0C  9F 0F 8D 59  _Ñ_ÿóÏÑ4 ./....Y
0000:0780 D7 8D C6 3B  D8 FE 4B E3  F7 DF 5D 93  70 5A CF E1  ×.Æ;ØþKã÷ß].pZÏá
0000:0790 E5 59 09 F9  CE 4A 31 E8  ED AE 30 AE  B0 5E C7 1A  åY.ùÎJ1èí®0®°^Ç.
```

Figure 4.9: Stego-file hexdump

Although it could not be proved, these bytes might be related to the size of the file being hidden, as well as the password(s) used to encrypt the message. This assumption is made based on [9], where it is stated that 32 state bits are hidden, 16 bits for a seed and 16 bits for an integer containing the length of the message being hidden.

It is important to notice that since the video container format may change, the optimal location of the moov box will depend on the selected delivery method. This way the MOOV box can come right away after the file header, implicating the MOOV box header offset to remain remain the same for both the original and the stego-file (since the bytes are being inserted only outside this box).

After the 32 state bits are hidden, the secret information is hidden inside the carrier file. In order to hide this information 2 steps are followed:

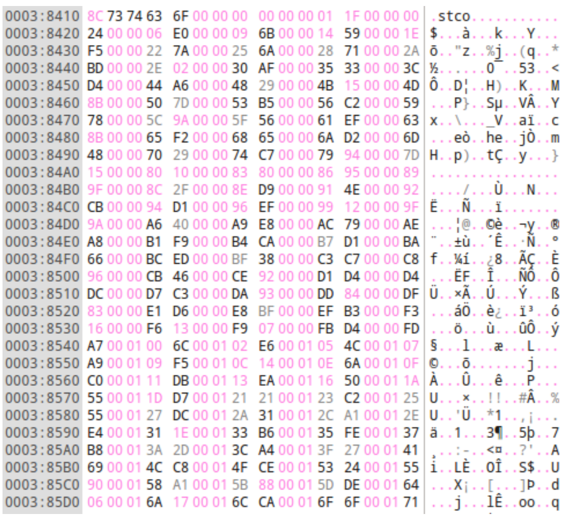
Identification of redundant bits

Redundant bits are bits that can be changed without noticeably degrading the carrier medium. These redundant bits are dependent on the specific output file.

Selection of bits to hide information

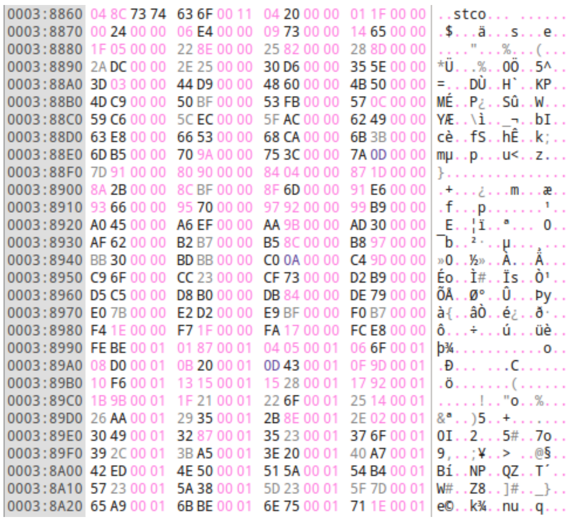
The selection of the redundant bits that will be used to hide the information is done by choosing a maximum of 50% of the redundant bits available. This is done for two specif reasons, to give the selection process a chance to find a better embedding (one which will make less changes to the carrier medium) and to preserve the frequency count base statistics.

While analyzing in detail the MOOV box, it was noticed that the bytes were modified. Figures 4.10 and 4.11 show the differences between both the original and the stego-file.



```
0003:8410 8C 73 74 63  6F 00 00 00  00 00 00 01  1F 00 00 00  .stco...........
0003:8420 24 00 00 06  E0 00 00 09  6B 00 00 14  59 00 00 1E  $...à...k...Y...
0003:8430 F5 00 00 22  7A 00 00 25  6A 00 00 28  71 00 00 2A  õ.."z..%j..(q..*
0003:8440 BD 00 00 2E  02 00 00 30  AF 00 00 35  33 00 00 3C  ½......0¯..53..<
0003:8450 D4 00 00 44  A6 00 00 48  29 00 00 4B  15 00 00 4D  Ô..D¦..H)..K...M
0003:8460 8B 00 00 50  7D 00 00 53  B5 00 00 56  C2 00 00 59  ...P}..Sµ..VÂ..Y
0003:8470 78 00 00 5C  9A 00 00 5F  56 00 00 61  EF 00 00 63  x..\..._V..aï..c
0003:8480 8B 00 00 65  F2 00 00 68  65 00 00 6A  D2 00 00 6D  ...eò..he..jÒ..m
0003:8490 48 00 00 70  29 00 00 74  C7 00 00 79  94 00 00 7D  H..p)..tÇ..y...}
0003:84A0 15 00 00 80  10 00 00 83  80 00 00 86  95 00 00 89  ................
0003:84B0 9F 00 00 8C  2F 00 00 8E  D9 00 00 91  4E 00 00 92  ..../...Ù...N...
0003:84C0 CB 00 00 94  D1 00 00 96  EF 00 00 99  12 00 00 9F  Ë...Ñ...ï.......
0003:84D0 9A 00 00 A6  40 00 00 A9  E8 00 00 AC  79 00 00 AE  ...¦@..©è..¬y..®
0003:84E0 A8 00 00 B1  F9 00 00 B4  CA 00 00 B7  D1 00 00 BA  ¨..±ù..´Ê..·Ñ..º
0003:84F0 66 00 00 BC  ED 00 00 BF  38 00 00 C3  C7 00 00 C8  f..¼í..¿8..ÃÇ..È
0003:8500 96 00 00 CB  46 00 00 CE  92 00 00 D1  D4 00 00 D4  ...ËF..Î...ÑÔ..Ô
0003:8510 DC 00 00 D7  C3 00 00 DA  93 00 00 DD  84 00 00 DF  Ü..×Ã..Ú...Ý...ß
0003:8520 83 00 00 E1  D6 00 00 E8  BF 00 00 EF  B3 00 00 F3  ...áÖ..è¿..ï³..ó
0003:8530 16 00 00 F6  13 00 00 F9  07 00 00 FB  D4 00 00 FD  ...ö...ù...ûÔ..ý
0003:8540 A7 00 01 00  6C 00 01 02  E6 00 01 05  4C 00 01 07  §...l...æ...L...
0003:8550 A9 00 01 09  F5 00 01 0C  14 00 01 0E  6A 00 01 0F  ©...õ.......j...
0003:8560 C0 00 01 11  DB 00 01 13  EA 00 01 16  50 00 01 1A  À...Û...ê...P...
0003:8570 55 00 01 1D  D7 00 01 21  21 00 01 23  C2 00 01 25  U...×..!!..#Â..%
0003:8580 55 00 01 27  DC 00 01 2A  31 00 01 2C  A1 00 01 2E  U..'Ü..*1..,¡...
0003:8590 E4 00 01 31  1E 00 01 33  B6 00 01 35  FE 00 01 37  ä..1...3¶..5þ..7
0003:85A0 B8 00 01 3A  2D 00 01 3C  A4 00 01 3F  27 00 01 41  ¸..:-..<¤..?'..A
0003:85B0 69 00 01 4C  C8 00 01 4F  CE 00 01 53  24 00 01 55  i..LÈ..OÎ..S$..U
0003:85C0 90 00 01 58  A1 00 01 5B  88 00 01 5D  DE 00 01 64  ...X¡..[...]Þ..d
0003:85D0 06 00 01 6A  17 00 01 6C  CA 00 01 6F  6F 00 01 71  ...j...lÊ..oo..q
```

Figure 4.10: Original file MOOV box hexdump



```
0003:8860 04 8C 73 74  63 6F 00 11  04 20 00 00  01 1F 00 00  ..stco... ......
0003:8870 00 24 00 00  06 E4 00 00  09 73 00 00  14 65 00 00  .$...ä...s...e..
0003:8880 1F 05 00 00  22 8E 00 00  25 82 00 00  28 8D 00 00  ...."...%...(...
0003:8890 2A DC 00 00  2E 25 00 00  30 D6 00 00  35 5E 00 00  *Ü...%..0Ö..5^..
0003:88A0 3D 03 00 00  44 D9 00 00  48 60 00 00  4B 50 00 00  =...DÙ..H`..KP..
0003:88B0 4D C9 00 00  50 BF 00 00  53 FB 00 00  57 0C 00 00  MÉ..P¿..Sû..W...
0003:88C0 59 C6 00 00  5C EC 00 00  5F AC 00 00  62 49 00 00  YÆ..\ì.._¬..bI..
0003:88D0 63 E8 00 00  66 53 00 00  68 CA 00 00  6B 3B 00 00  cè..fS..hÊ..k;..
0003:88E0 6D B5 00 00  70 9A 00 00  75 3C 00 00  7A 0D 00 00  mµ..p...u<..z...
0003:88F0 7D 91 00 00  80 90 00 00  84 04 00 00  87 1D 00 00  }...............
0003:8900 8A 2B 00 00  8C BF 00 00  8F 6D 00 00  91 E6 00 00  .+...¿...m...æ..
0003:8910 93 66 00 00  95 70 00 00  97 92 00 00  99 B9 00 00  .f...p.......¹..
0003:8920 A0 45 00 00  A6 EF 00 00  AA 9B 00 00  AD 30 00 00   E..¦ï..ª.... 0..
0003:8930 AF 62 00 00  B2 B7 00 00  B5 8C 00 00  B8 97 00 00  ¯b..²·..µ...¸...
0003:8940 BB 30 00 00  BD BB 00 00  C0 0A 00 00  C4 9D 00 00  »0..½»..À...Ä...
0003:8950 C9 6F 00 00  CC 23 00 00  CF 73 00 00  D2 B9 00 00  Éo..Ì#..Ïs..Ò¹..
0003:8960 D5 C5 00 00  D8 B0 00 00  DB 84 00 00  DE 79 00 00  ÕÅ..Ø°..Û...Þy..
0003:8970 E0 7B 00 00  E2 D2 00 00  E9 BF 00 00  F0 B7 00 00  à{..âÒ..é¿..ð·..
0003:8980 F4 1E 00 00  F7 1F 00 00  FA 17 00 00  FC E8 00 00  ô...÷...ú...üè..
0003:8990 FE BE 00 01  01 87 00 01  04 05 00 01  06 6F 00 01  þ¾...........o..
0003:89A0 08 D0 00 01  0B 20 00 01  0D 43 00 01  0F 9D 00 01  .Ð... ...C......
0003:89B0 10 F6 00 01  13 15 00 01  15 28 00 01  17 92 00 01  .ö.......(......
0003:89C0 1B 9B 00 01  1F 21 00 01  22 6F 00 01  25 14 00 01  .....!.."o..%...
0003:89D0 26 AA 00 01  29 35 00 01  2B 8E 00 01  2E 02 00 01  &ª..)5..+.......
0003:89E0 30 49 00 01  32 87 00 01  35 23 00 01  37 6F 00 01  0I..2...5#..7o..
0003:89F0 39 2C 00 01  3B A5 00 01  3E 20 00 01  40 A7 00 01  9,..;¥..> ..@§..
0003:8A00 42 ED 00 01  4E 50 00 01  51 5A 00 01  54 B4 00 01  Bí..NP..QZ..T´..
0003:8A10 57 23 00 01  5A 38 00 01  5D 23 00 01  5F 7D 00 01  W#..Z8..]#.._}..
0003:8A20 65 A9 00 01  6B BE 00 01  6E 75 00 01  71 1E 00 01  e©..k¾..nu..q...
```

Figure 4.11: Stego-file MOOV box hexdump

Once again, although it was not possible to prove the secret information is being hidden inside the MOOV box, it is believed this is the actual behavior.

The impossibility to determine whether the bytes being inserted are related to the size of the file being hidden, as well as the password(s) used to encrypt or not, and the impossibility to determine if the message and the bytes being modified are related to the secret information are due to two reasons: the fact that the secret information is encrypted and the use of deniable steganography techniques (see Section 4.2.1).

4.2 Anti-Forensics

Anti-forensics pursuits to make the analysis and/or examination of evidence difficult or impossible to conduct and relies on several weaknesses of the forensic process, such as the human element or the dependency on tools. Encryption and steganography are among the ways to make it successful.

However, there is always the chance of being detected using these techniques. Resisting to these unpredictable attacks is also possible, even when the user is forced (by legal or physical coercion) to provide a valid password to extract the data.

4.2.1 Deniable Steganography

As in cryptography, also in steganography there is the possibility for deniable steganography. Deniable steganography is a camouflage based technique that, even if the steganalyst is able to state that data is being hidden, allows the breaker to convincingly deny that fact.

OpenPuff implements deniable steganography by allowing the user to hide two different messages in the cover file. One which contains the sensitive data and one which although is plausible to be considered sensitive, the user us willingly to give away.

This method is one of the reasons why the statistical attacks are ineffective.

Chapter 5

Conclusion

The purpose of this work is to identify the available methods to do steganography on videos, as well as steganalysis. Also the available techniques to avoid steganalysis was discussed.

Throughout this project different steganographic techniques were presented and, from the literature, it can be concluded that techniques used on images and audio can also be applied to videos. The most common techniques used the spacial domain (LSB) and the frequency domain (DCT).

Even though steganography is usually undetectable by the human eye, the use of statistical analysis can reveal the presence of hidden data. However, as could be seen throughout this paper, detecting hidden data, being it done in images or videos, is a difficult process to carry out, whether the carrier files are known or not. Even if the carrier files are known it cannot be guaranteed that the hidden information can be determined and recovered. With the use of the correct techniques, hidden information tends to be nearly impossible to be undetectable. And, if it was not enough the fact that steganography is already quiet difficult to detect, new techniques, such as deniable steganography, are made available to the users.

Therefore, the best way to prevent steganography would be to alter or destroy files which are considered suspicious. The introduction of new video compression methods where less redundant bits are available is also a possibility.

Although steganography is becoming more advanced it is still a science that is not well-known.

Future Work

The attacks performed against *OpenPuff* during this project proved to be insufficient to determine whether there is hidden data inside a file, if the carrier file is not know. However, when the cover data is known, the analysis of the original and stego-files raise some suspicion. Although the hidden information could not be determined.

As a future project it would be interesting to assess if the hidden information can be retrieved.

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