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Faculty of Electronics and Information Technology

Electrical and Computer Engineering

Master of Science Thesis

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Title of Thesis: *Steganography as an aspect of secure data maintenance*

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I was born on September 29, 1980 in Warsaw, Poland. I attended XXVIII LO under the patronage of Jan Kochanowski in Warsaw. In October 1999 I started my studies at Warsaw University of Technology. In October 2003 I graduated with a Bachelor's degree. My Bachelor Thesis concerned application of digital signature to electronic forms. Starting from October 2003 I continue my studies at Warsaw University of Technology, at the Faculty of Electronics and Information Technology with specialization Computer Systems and Networks. I am an owner of a Certificate in Advanced English (CAE) and Zentrale Mittelstufenprüfung (ZMP) German certificate. My interests are chess and bridge.

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Signature of the Student

M.Sc. Examination

Examination was held on ……………………………………………………………………

With the result: ……………………………………………………………………………….

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Suggestions and Remarks of the M.Sc. Examination Committee ……………………………..

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SUMMARY

The thesis presents methods, which can be applied to ensure secure data maintenance under Microsoft Windows operating system. The described concept bases on steganography, which is a technique of hiding information inside other data, such as for instance, structure of image files. The idea is to increase security of such hidden information, by combining the watermarking process together with data encryption.

A detailed analysis of most popular graphics file formats was essential from the point of view of the Theis, to check and verify all possible ways of achieving the intended goal. Apart from graphical analysis, a research on data encryption algorithms has also been performed, in order to choose the most suitable algorithm for project's purposes.

The obtained results show, that application of various methods results in wide choice of possibilities, of making the most of such approach to maintaining data security. Moreover, this idea has numerous expansion possibilities, and may be used with great intensity in our expanding computer environment.

Keywords: steganography, watermark, data security, data encryption, graphics file formats

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I. Introduction

1.1 Idea of data security

If someone asked you why we need data security, would you find a brief answer for such stated question? Rather not. Concept of data security is very wide in today's computerized society. Various aspects of every day's life depend on how well certain portions of data are secured. We are not only talking about issues connected with computers, however the concept of data security is used most widely as it comes to dealing with information, which is being kept or exchanged using computers and internet. Information is always secured for a certain purpose, such as for example:

- hiding contents of some data (privacy), which is being realized by the means of data encryption algorithms
- exchanging data between two parties is performed by the means of public key encryption of data
- data verification, which is also a subject to public key infrastructure
- authentication and authorization concepts
- secure protocol encryption such as SSL, which is used in general to establish secure connection between a server and a client
- prevention from all sorts of internet attacks
- network security
- and a wide range of other concepts, which will not be mentioned here, as there would be simply too many of them to cover

The concept, which will be applied as far as the thesis is concerned, will be dedicated to data privacy. The question arises, how to keep data on a computer, such that it would be secured and on the other hand such secured data will be hardly recognizable by a potential intruder? The following chapter named Aim of the Thesis should disperse all uncertainties.

1.2 Aim of the Thesis

There are many ways of securing information against an attack. One of the most secure and commonly used approaches is data encryption. Various encrypting algorithms have been developed over the years, but all of them share similar problems as it comes to obtaining expected security. Their consistence is endangered by various kinds of attacks, many of which are designed especially for particular algorithms. Security of data encryption is usually bound by the length of key, which is being used in the encryption and decryption processes. Of course the longer the key, the smaller the chance of breaking the protection. However, generation and usage of such long keys, results in many problems, such as high complexity of the algorithm, necessity of large computational power, and time-consuming execution of the cryptographic processes.

The question arises, if all of this is really necessary. The answer is quite simple. If the information is kept in such way, that it is obvious for a skilled hacker to determine, what kind of algorithm to encrypt the data had been used, or what the length of the plain text message or the key is, than it is indeed necessary to preserve maximum security. On the other side, if it was practically impossible to determine if some data contains encrypted information, than it would be enough to take some reasonable precautions as it comes to cryptographic approach. There would be no need of using extremely long keys and all of the necessary operations would be performed faster.

The idea is to include cryptographic information inside the structure of some file format, thus in fact in the image itself. This process must be performed in such way, that it would be impossible to notice at first glance that the file has been modified. Graphical file formats come in handy in this situation. They offer many interesting possibilities, as modification of their file structure is concerned. The interference with such files should be done in such a way, that while comparing the original image with the modified one, no visual difference should be observed by the human's eye.

The process of attaching information to image or sound file formats is called *steganography*, while the information itself is denoted as a *watermark*. So, the idea is to combine both of the above-mentioned techniques. The intention is to first encrypt the information, and than distribute it inside an image file in some clever way, as to leave no trace for a potential attacker. Such information will be afterwards protected in two ways, first by a cryptographic algorithm, second by steganography. It is worth mentioning that standard steganographic approaches apply to data, which is not encrypted in any way, thus the approach used in the project is twice as secure.

A detailed analysis of the most popular graphical file formats is essential, to determine all possible ways of applying the idea of steganography to each of them.

II. Preliminary specification

2.1 Project assumptions and constraints

There are two important aspects of the work one has to explain, before further steps may be accomplished. The first one concerns image modification, the second one is connected to cipher algorithms. Since the image files are a subject to file modification, it must be clearly determined if such modifications undergo any copyright constraints. The same applies to functions and algorithms used in the encryption and decryption of data. It must be clearly explained if such functions may be used or modified without any bounds.

In general, graphics file formats are not subject to copyrights, because for a product to be copyrighted, it must fulfill two conditions: it must be work of authorship, and must be fixed in a tangible medium of expression. Only documentation on specific file formats is a subject of copyrights, as it often states, that the name of a company, which developed this format, should be mentioned. For example, the GIF (Graphics Interchange Format) is a registered trademark. Copyrights of this file format belong to the CompuServe Company and documentation of GIF files has been given away freely. One of the terms of the license states, that if a GIF file format is used by some commercial software, it must be stated that this format is under license of CompuServe.

Apart from the file structure itself, there may be some other constraints as it comes to image modification. Namely, some algorithms, which are being used to compress data within graphics file formats, undergo copyrights. As an example of such situation, an algorithm called Lempel-Ziv-Welch (LZW) can be mentioned. Raster data used in GIF files is compressed using this algorithm. Its copyrights are held by Unisys Corporation, thus it must not be modified in any way.

The same applies to cryptographic functions, which may be used for commercial purposes. It must be clearly stated which algorithm is used, and who holds its copyrights.

2.2 Functional requirements

2.2.1 Software requirements

The application is being built under Visual Basic, which is part of Microsoft Visual Studio. Nature of the program needs to be of visual type, because the user has to have opportunity to observe how the image is being changed and if such change is acceptable from the user's point of view. These aspects make the potential application run under Microsoft Windows Operating Systems. Such systems are most commonly used visual operating systems in the world. The program is created under MS Visual Basic. It is obvious that the result of its compilation will be an executable file, which should be able run under different versions of MS Windows OS, such as Windows 98, NT, XP.

It is possible to create an installation package of the program, which will contain all necessary libraries needed to run it. Another option is to create some script to register all necessary libraries needed to run the program, and keep the application as a standalone version, without having to create any installation package and thus making probably more interference to the system, having to install some unnecessary libraries or to modify system's registry file. The second option seems to be a better choice, since size of the executable file will be rather small and there will not be many other file dependencies (i.e. with libraries). Portability of the application is an interesting aspect as well, since it will probably be possible to transport the program using even a floppy disk, thus allowing the user to transport it quickly from one software platform to another, without having to make much effort in installing and running the program.

Finally, an important assumption needs to be mentioned. Namely, potential methods of implementation are not a subject to any particular operating system (or in other words software requirements). The overall idea is to propose some concepts and test them by the means of an application, which would run under Microsoft Windows operating system. The same applies of course to hardware requirements.

2.2.2 Hardware requirements

Apart from the above mentioned software requirements, one has to think about the hardware aspect as well. The problem concerns speed of the methods applied during the attachment and extraction of information. This problem is quite important and must not be neglected. Speed of the calculations will depend on certain factors, which include: processor strength, size of RAM, size of file which is being modified, length of the attached message, speed of the encryption algorithm and complication of the applied method. This leads to a conclusion, that the code of the program should be implemented very cautiously, to ensure that the above factors would not influence calculation speed too drastically.

Of course there are certain things, which we cannot control. The better the processor and the more operational memory, the quicker the calculations will follow. The processor however, will be the most important factor of the platform. Other issues, such as described size of file or message length are rather a subject to method implementation, than to hardware requirements, however they were mentioned to present an overall idea, what the speed of the calculations will depend on.

2.2.3 Image standards

The main goal of the project is to attach information to an image file format. The choice what image file formats are suitable for the project was really simple. Two factors have been taken into consideration. The images must be of very popular and commonly used type and secondly this type should not be restricted by too many factors. Such aspects have been already mentioned in the preliminary specification part of the thesis.

In general, three of the most popular image formats have been chosen for further implementation. These include: Windows OS/2 Bitmap (or shortly BMP), Graphics Interchange Format (GIF) and Joint Photographic Experts Group (JPG or JPEG). These formats are used in most of the aspects of image maintenance on the Internet but for individual purposes on personal computers as well. Methods of implementation have to ensure, that after attaching the information to such files, they stick to their own standards, which means that other application responsible for operating on such file types have to be able to open them and treat their structure contents properly.

So, a detailed file structure analysis needs to be performed. Apart from it, it was assumed that no one's own file formats are introduced, only predefined and commonly known file types are used in the project.

2.2.4 Image consistency

An aspect of visuality of the image is understood by the above term. Part of the main goal of the project is not only to be able to attach encrypted information to the image and then to extract it from the image in order to decrypt it afterwards. An important condition should also be fulfilled. Namely, the modified image should not differ visually from the initial picture. This function however, cannot be realized by any means of the implementation phase. The user must be able to decide and accept the obtained results or not.

In other words, the application should present the initial and modified images in such way, that it would be possible for the user to compare both of the pictures in order to make the decision if he wishes to save the modified image or not. A nice idea would be also to prepare some simulation mechanism, which would operate on the initial image file taking on input some condition the user wishes to meet and displaying a modified image afterwards. Such process should be of course quicker than the original attachment phase, to make it more convenient for the user to use such tool.

2.2.5 Encryption standards

An important aspect of project's implementation is the choice of suitable encryption algorithms. There are several important standards, that such an algorithm should fulfill, to qualify for further steps of the implementation. One of the most important factors is of course its security standard. This without any doubts depends on key length used during the encryption. The longer the key, the more secure the encoding will be. On the other hand, the longer the key, the more time it takes to perform the encryption.

Another aspect related to key length is how the key will be stored. It is considered, that the key will be stored inside the image itself, which in case of very small size of an image may be hard to perform, and thus preserve high standard of encryption security. So the conclusion is as following: the algorithm should be fast, but there should not be a big significance between keys, which are longer or shorter. Of course such issue will always exist, but the choice must take such aspect into consideration as well. In general, one must choose between two groups of encryption algorithms, which are symmetric and asymmetric ciphers. Results and conclusions will be presented in the analysis section of the thesis.

III. Analysis

3.1 Popular image file formats

3.1.1 BMP (OS/2 Bitmap)

As some may incorrectly believe, the term “bitmap” does not apply only to .BMP files. A bitmap is an image which is stored and which can be displayed as a set of pixels. A .BMP file extension applies to Windows DIB files. All of this may look little confusing, but the easiest way of defining what a .BMP file is, is as following. Windows bitmap files are being stored in a DIB (device-independent bitmap) format. It means that such bitmaps may be displayed on any kind of a display device. The default filename extension of a DIB file is .BMP, however .DIB files can be encountered as well.

A bitmap image file consists of four major parts: bitmap-file header, bitmap-information header, color table, and array of bytes, which represents bits of the bitmap. The structure of an OS/2 Bitmap for version 1.x is represented as follows:

```
BITMAPFILEHEADER  bmfh;
BITMAPINFOHEADER  bmih;
RGBQUAD           aColors[];
BYTE              aBitmapBits[];
```

The bitmap-file header covers information on type, size, and layout of the file. The bitmap-information header contains information about image size, type of compression used (if any) and color format of the image. The color table is an array of length equal to the number of colors used in the bitmap. This applies only to bitmaps of bit-depth equal to 1, 4, and 8, and does not occur in 24-bit bitmaps, since in 24-bit files each pixel is represented by RGB values. The colors in a color table should appear in their importance order, because it may happen, that on some machines it is impossible to represent a particular bitmap using the available color palette. The array of bytes follows the color table. Pixel values are represented horizontally (as rows), starting from left to right, and from bottom to top (!). The first byte of the array is in fact the bottom-left-hand corner of the image, and the last byte represents the top-right-hand corner.

A few words must be introduced as bit count (bit depth) of a bitmap is considered. It may be equal to 1,4,8 or 24. When we consider the simplest monochrome 1-bit bitmap, it is obvious that we may deal here with only 2 colours. These colours are defined in the color table, and if a data bit is set to 0, first entry in the color table is being taken, and similarly when it equals 1, the second entry is being considered. Thus a conclusion can be made, that the simplest way to reverse colors in a 1-bit bitmap is to interchange the two entries of the color table, without making any interference with the data bytes. Similar approach may be used for 4 and 8 bit images, however not for 24-bit files. These bitmaps do not contain any color table to which their pixels could refer. The bitmap array is simply represented by a set of “triplets”, which represent RGB values of a pixel. Each color can have values from 0 to 255, which is in fact representation of 8 bits ($2^8 = 256$), and since we have red, green and blue bytes, it makes in total of 24 bits.

Bitmap compression is an aspect, which may turn out crucial for the project, as it may allow possible interference with the file structure. It is worth mentioning, that only 4 and 8 bit bitmaps may undergo compression. Compression used in bitmap compressing is lossless, which means that after the decompression process, we obtain the initial file without any changes made to it (equivalent quality). In other file formats, such as jpeg for instance, we cannot obtain the initial image after its compression. The compression used in bitmap encoding is so called Group Encoding or Run-Length Encoding (RLE). It uses two modes: Encoded Mode and Absolute Mode. The compression slightly differs for 4- and 8-bpp bitmaps.

It is somewhat easier to explain at first how compression of an 8-bpp bitmap is interpreted, since the whole byte is used throughout the process, not taking into consideration 4-bit blocks. In Encoded Mode a block of information consisting of two bytes is being considered. The first value holds the number of repetitions of the second byte, which holds color index of a pixel (reference to the color table). So, to present a small example, we may write down the following:

05 2E is in fact 2E 2E 2E 2E 2E, and 06 05 is 05 05 05 05 05 05

The first byte may be set to 0, to indicate a special condition, which takes place. It is interpreted as follows:

00 00	is end of line
00 01	is end of file
00 02	is delta

The delta may occur the most important factor as the project's goal is concerned. Two bytes that follow delta (00 02) indicate the position of the next pixel, relative to the current position. So, having the following example:

```
00 02 03 01
```

it means, that the position of the next pixel is three positions right and one position down relative from the current pointer position in the data array. Second mode used during compression is Absolute Mode. It allows indicating a number of bytes, which are treated as single pixels. In other words, instead of such notation:

```
01 05 01 1A 01 53 01 A4 01 11 01 6B
```

we may use the following:

```
00 06 05 1A 53 A4 11 6B 00
```

which is obviously shorter, especially for long "single pixel" sequences. As it may be noticed, the Absolute Mode is indicated, when a sequence of bytes starts with 00 and follows by values from 03 to FF. Values from 00 to 02 are reserved for special escape characters in the Encoded Mode.

The difference in 4-bpp image compression is that in the Encoded Mode the second byte of data is in fact treated as two 4-bit blocks. These blocks are called nibbles, and so, a high-order nibble represents low-order bits of a byte. Similarly, a low-order nibble represents high-order bits of a byte. What follows, is that the second byte (reference to the color table) holds two values instead of one, as in the 8-bpp compressed bitmap. The pixels are being drawn alternately, starting from the high-order nibble. An example below demonstrates how it is being done:

```
05 13 is in fact 1 3 1 3 1, and 06 A0 is A 0 A 0 A 0
```

The end of line (00 00), end of file (00 01) and delta (00 02) behave identically as in the 8-bpp compression. The Absolute Mode is almost identical to the previous one; the difference is that the nibbles are picked, instead of whole bytes:

```
00 06 1A 34 04 00 is 1 A 3 4 0 4
```

Conclusions:

It seems that the .BMP files are suitable for the project and will allow some additional data to be put inside their file structure, without spoiling "visuality" of the image. However, there are some constraints, namely, only 4 and 8 bits-per-pixel compressed bitmaps may be used. It comes as a result of a property of the compressed data, namely the so-called "delta". It allows jumping from a current pointer position to another location in the data array, while parsing the image. This property allows putting additional data (as an encrypted information for example) in the space, which is present between the two jump points.

3.1.2a GIF (version 87a)

Graphics Interchange Format (or shortly GIF) has been designed in 1987 by CompuServe Inc. It combines high quality together with portability of an image. The structure of a GIF87a file consists in general of the following:

- GIF Signature
- Screen Descriptor
- Global Color Map
- Image Descriptor
- Local Color Map
- Raster Data

- GIF Terminator

GIF Signature identifies the file itself as a valid GIF file. It has length of 6 bytes, and in this version the signature is simply GIF87a. Characters 87a denote the version number.

Screen Descriptor follows the GIF Signature. Its length is 7 bytes. Bytes 1 and 2 denote raster width in pixels (called also Screen Width). Two of the following bytes (3 and 4) contain raster height in pixels (Screen Height). The next byte (5) is slightly more complicated. Bit 7 (most-significant bit of the byte) holds information about the Global Color Map. Its symbol is denoted as *M*, and if it's set to 1 – the Global Color Map follows the Screen Descriptor, otherwise – not. 3 proceeding bits (6,5,4) are called *cr*. These bits denote color depth of the image, and *cr+1* may be equal to 1,4 or 8. The next bit (3) is reserved and set to 0. Last three bits (2,1,0) of the fifth byte are called *pixel* and contain information on the number of bits per pixel of the image. Once again *pixel+1* value is considered. The next byte (6) contains information about the background color of the image; the index is defined from the Color Map. The final byte (7) indicates the end of the Screen Descriptor and is set to 0.

Global Color Map follows the Screen Descriptor, if the bit *M* has been set to 1. The number of entries is of course equal to the number of bits per pixel multiplied by three, since entries for red, green and blue values are considered. The structure starts by defining red, green and blue values for the color index 0, and proceeds till all RGB values are defined. The size of the Global Color Map is equal to $3*2^{\text{pixel+1}}$ bytes.

The following three structures (Image Descriptor, Local Color Map and Raster Data) are repeated *n* times, where *n* is the number of images contained in the GIF file. This feature is especially useful, when animated GIFs are concerned.

Image Descriptor is a structure, which holds information about a particular image. Its size is 10 bytes and it starts with a byte containing so-called image separator character, or simply a comma (,). Its hexadecimal value is equal to 2C. What is important here is that GIF decoders ignore any characters, which might occur between the end of an image, and an image separator of another image. Following four 2-byte blocks (bytes 2 and 3, 4 and 5, 6 and 7, 8 and 9) contain information about image starting left position relative to the screen, image starting top position relative to the screen, width of the image, and finally height of the image. The last byte (10) is very important, and so, the most-significant bit (7) is once again called *M*, only this time it refers to Local Color Map if set to 1, otherwise it refers to Global Color Map. The following bit (6) is called *I*, and denotes if the image is formatted in sequential order (1) or interlaced order (0). This feature will be explained later. Following three bits (5,4,3) are set to 0. Last three bits (2,1,0) denote pixel depth, as in Global Color Map, for this particular image.

Local Color Map follows the Image Descriptor if its *M* bit is set to 1. Otherwise it is not present and Global Color Map is used.

Raster Data holds of course references to a Color Map (whichever is taken into consideration). The pixels are stored from left to right and top to bottom in a sequential order. Depending on the *I* bit value of the Image Descriptor, the rows were placed either sequential or interlaced. The sequential term means that the rows in the image are exactly in the same order as these, which will appear on the screen. In other words the picture will be drawn from top to bottom. The interlaced mode allows drawing a picture as a number of layers (four in fact), which results in a more visual effect. It can be achieved by placing the rows in the file in an order, which will then be "smartly" picked, namely, the first pass will draw every 8-th row starting from the top row, the second pass will draw every 8-th row starting from the fifth row from the top, third pass draws every 4-th row, and the last pass all of the remaining rows. This feature is especially useful while viewing GIFs via Internet, while the image is read and displayed "on the fly", and the effect is more pleasing to the eye. The pixel values are compressed by a LZW (Lempel-Ziv-Welch) algorithm, which will be described later.

GIF Terminator is a character, which will terminate the decoding process of a GIF file. This happens, when a semicolon character is encountered (;). Its hexadecimal value is equal to 3B.

GIF Extension Blocks are additional information blocks, which may occur in the GIF file structure. They are preceded by an exclamation mark (!), and end with a standard 0 byte. They may precede an Image Descriptor or the GIF Terminator.

The GIF files are compressed using LZW compression algorithm. Similarly to bitmap compression, the compression of GIFs is lossless. It bases on repeating streams of pixels, but expresses the correlations among the pixels differently from the bitmap interpreter. Similar data streams are sought out, and every repeating one is represented as a pointer to the previous one, and a number of pixels, which are to be copied. This may sound a bit complicated, but an example below should reveal all doubts:

Initial data stream:
1 1 1 1 2 3 3 2 1 1 1 1 3 2 1 1

Compressed data:
1 1 1 1 2 3 3 2 [1,4] [7,4]

The numbers represent references to a color map. It can be observed that the initial data stream consists of 16 bytes, while the compressed stream has been reduced to 8 bytes, plus two pointers weighting 2 bytes each, thus 12 bytes in total. These pointers indicate which data block is being repeated and how many elements it consists of (e.g. from position 7, 4 pixels in length, repeats the block 3 2 1 1).

Conclusions:

It turns out that GIF87a format is suitable for the project. Additional information can be added to this file type, because of the following property. Namely, one of the features of a GIF file is that any characters, which may occur between the end of an image, and the image separator character (,) will be ignored by a GIF decoder. This feature should not only apply to GIF files which contain more than one image, but to single-image GIFs as well, since it is as well possible to attach information after the end of an image and before the termination character (;). Adding the information after this character may be also possible, however, this approach will not be as secure as previous ones, because it will force to put another termination character after the change has been made. The implementation phase will show if such approach is also possible, since we do not know how different GIF interpreters will treat such modification to GIF files, especially if it is possible to modify the image using such an editor.

3.1.2b GIF (version 89a)

This version of a GIF file has been developed in 1989 and its variations are more common today as compared to the previous 87a version. It was improved and contains several additional blocks of data, which are not present in the previous version. The structure of a GIF89a file consists of the following data blocks:

▪ Header	→	
▪ Logical Screen Descriptor	→	like in 87a version
▪ Global Color Table	→	
▪ Comment Extension	→	
▪ Application Extension	→	new features of 89a version
▪ Graphics Control Extension	→	
▪ Plain Text Extension	→	
▪ Local Image Descriptor	→	
▪ Local Color Table	→	like in 87a version
▪ Image Data	→	
▪ Trailer		

The new features of the 89a version need to be commented. New features, which were added to the GIF image file, allow to control rendering of graphical data, which is stored in this GIF file. The 87a version allowed displaying a single image or a slideshow of images. The improved version allows a textual as well as bitmap-based graphical data to be displayed. Moreover, it supports such functions as overlaying and deletion of such data. This additional information belongs to so called Control Extensions. Four blocks were introduced, and these are Graphics Control Extension, Plain Text Extension, Application Extension and Comment Extension. Control Extensions may occur anywhere in the file, following the Global Color Table. They begin with the Extension Introducer, a byte of value 0x21.

Graphics Color Extension is responsible for controlling the way the bitmap is being displayed. This includes if the graphic is displayed in transparent or in opaque way, if this graphic is to be restored or deleted, and if user input is required for further continuation. The block starts with byte value 0xF9. It is being followed by BlockSize with value 0x04, which is constant and determines the size of remaining fields, which are: Packed, DelayTime, ColorIndex and Terminator. The Packed byte consists of the following: starting from the most significant bits; bits 7-5 are Reserved, bits 4-2 specify the Disposal Method (how it is to be interpreted, after the graphic has been displayed – if to overwrite it or not), bit 1 is the User Input Flag (if 1 – user action such as key press or mouse click is required to continue displaying the image, otherwise 0 – no action required to continue), bit 0 is called Transparent Color Flag, and if is set to 1, the ColorIndex will contain a color transparency index, otherwise it will be set to 0. The DelayTime block (of length word) specifies the delay in hundredths of a second between continuous displayments. The ColorIndex contains a value only if the Transparent Color Flag bit is set to 1. The Terminate byte of value 0x00 ends the Graphics Color Extension block.

Plain Text Extension allows mixing plain text ASCII with a bitmap image. This extension is especially useful when it comes to displaying a readable text, which may be included in the GIF file. Such text can be overlaid onto an image itself. The block starts with byte of value 0x01 and follows with BlockSize with constant value of 0x0C. The following data contains information about the text itself, its position, specific data about how to display particular characters in the grid of pixels, and foreground and background color of the text. The block ends as usual with a block terminator of value 0.

Application Extension allows storing such data, which is to be understood only by software applications, displaying GIF image files. Such information may turn out vital, when it comes to display the image. The block is 14 bytes long, and starts with Label byte 0xFF. Then follows the BlockSize byte (always 0x0B). The following data contains information specific for a particular information, such as Application Identifier, Application Authentication Code, and pointer to Application Data sub-blocks. The block ends with a standard Terminator.

Comment Extension holds comments, which are “human-readable”, and are stored in a similar way as for example comments in C language. Each one of the comments may contain 255 ASCII characters, and may include ASCII control codes. The number of comments in a GIF file is not limited. The label identifying this block has value of 0xFE. Afterwards, the CommentData bytes follow. The comment ends if the Terminator byte is encountered.

Conclusions:

As in the following case (GIF file version 87a), the GIF89a image may be applied into the project. What may turn out to be an advantage, as in comparison to the previous case, is the possible occurrence of extended information contained in Extension Blocks. For example, Comment Extension can surely be used for attaching additional data to the file; however, such approach will not be that secure, because the comment information contained in this Extension Block is human-readable. The Plain Text Extension may be of greater benefit for the project, since not only plain information is contained in such a block, but also it allows manipulating with this information using several other controls. What might occur to be the greatest profit of using the Extension Blocks, which support plain text/comments, is that using such notation, appropriate bytes of data, included in actual raster data of an image, may be pointed out, as to being part of an encoded message. In other words, plain text may be used to point to bytes of image data, which will in fact be parts of the message, and will bind the whole message together. In such approach it must be of course considered, that some data bytes, which do not occur in image data, may be necessary for the proper message binding, but in this case another approach should be used. Such “missing bytes” would have to be encoded separately (possibly as parts of Plain Text Extension or Comment Extension blocks), but this will be planned during the late phases of the implementation part of the work.

3.1.3 JPEG

Joint Photographic Experts Group (or shortly JPEG) is a file format, which is nowadays widely used in many aspects of image management. JFIF however, an abbreviation of JPEG File Interchange Format, was designed to allow data exchange among different systems and applications. So, a JFIF file is a JPEG, which has some restrictions and identifying markers. JPEG data stream stores 16-bit word values in big-endian format.

Each JPEG stream starts with a SOI (Start Of Image) marker. First two bytes of the file have values 0xFF and 0xD8. In a JFIF file, Application marker (APP0) follows the SOI marker. This marker has values 0xFF and 0xE0. In general, a JFIF header of a JPEG file consists of the following:

▪ Start Of Image (SOI) marker	2 bytes (0xFF, 0xD8)
▪ Application (APP0) marker	2 bytes (0xFF, 0xE0)
▪ Length of APP0 field	2 bytes
▪ Identifier	5 bytes (“JFIF”, 0x00)
▪ JFIF format revision	2 bytes
▪ Units used for resolution	1 byte
▪ Xdensity (horizontal resolution)	2 bytes
▪ Ydensity (vertical resolution)	2 bytes
▪ XThumbnail (horizontal pixel count)	1 byte
▪ YThumbnail (vertical pixel count)	1 byte

The Length field is responsible for keeping the byte length of the whole APP0 marker, including its own field size (2 bytes). Such property is very useful while decoding a JPEG file into blocks of data, because after detecting a marker, we may move to the next one using basing on this value. A thumbnail image may be included inside a JPEG, file so the Length field equals to *16 + 3 * XThumbnail * YThumbnail*, because such an image is stored using 3 byte blocks of RGB values.

A JFIF identifier follows the Length field. It is a zero terminated string consisting of characters “JFIF”. This field has a size of 5 bytes. The 2 following bytes represent revision of the JFIF file. First byte contains major revision number, while second one contains its minor one. Version, which is being used today is 1.02, previous revisions were 1.00 and 1.01. These are the most important information contained in an APP0 Application marker.

Revision of a JFIF file is quite important, since optional JFIF extensions may follow the APP0 marker, if the revision version is 1.02. So if we wish to add some extension blocks to a JFIF file, we must remember to keep the revision number as 1.02, otherwise some applications may not display the image correctly. A JFIF extension consists of the following fields:

▪ Application (APP0) marker	2 bytes (0xFF, 0xE0)
▪ Length of APP0 field	2 bytes
▪ Identifier	5 bytes ("JFXX", 0x00)
▪ Extension Code	1 byte

Three first fields are similar to these in the SOI marker. The last field however, contains information about the data, which is being stored after this field. This filed may have a various value, which will indicate purpose of this extension. It may describe the following properties of a JPEG file: 0x10 - thumbnail encoded using JPEG, 0x11 - thumbnail stored using 1-byte pixels and a palette, or 0x13 – thumbnail stored using 3-byte RGB pixels.

<u>Conclusions:</u>

As it may be observed, a JPEG file may also come in handy as it comes to storing information inside its file structure. However, the noise method is not advisable in this case, since the image data is always compressed inside a JPEG. Of course, this does not exclude implementing the noise method, since it looks like it would be enough to decode the data, modify it and encode the modified data once again. This approach is however not possible, because if we encode a JPEG and decode it afterwards, we would not get the same result, meaning that file comparison of the initial and final file would differ. It is a result of various processes a JPEG undergoes during the encoding or decoding process. Such processes as quantization, cosine transforms always result in creation of unwanted rubbish, which does not affect visuality of an image, but unfortunately affects its file content. Instead, various block methods may be applied, starting from creation of one's own marker blocks, or making the most of already predefined file segments, such as a number of thumbnail images which may be included inside a JPEG file.

3.2 Data encryption algorithms

It is assumed that the goal of the project is to create such application of message encryption, that it would be secure enough to face against any possible hacker attack. A detailed file-formats analysis shows, that in most cases it is practically impossible for a third-party to notice that an image file has been modified and contains additional information. Such information will be often divided into blocks of smaller size, to ensure more secure allocation of such message parts inside a file, thus making it harder, if not entirely impossible, for an attacker to work out the way it has been stored, especially without use of a proper user-interface as well. However, the message must not be of a totally plain type, meaning not encrypted at all. Such approach would not be that secure and would allow an attacker to breach the file structure easier, to get into possession of such information.

The task is to propose such encryption algorithm, which would match the above conditions, and will not be bounded by to many constrains, such as for example: maximal message length, key length, key generation problems and many more. The idea is to implement some kind of a symmetric-key algorithm. The reasons for choosing such type of algorithm are simple. Such algorithms require usage of only one key, not a pair of keys like in nonsymmetric-key algorithms. Thus, the key generation phase is much easier too. Moreover, their big advantage is the fact, that they are much more faster than nonsymmetric-key algorithms. They also have their drawbacks, such as for example having to store the key in a very secure manner. When it comes to interchanging information between two parties, it may look as these algorithms are much less secure, but an interesting assumption can be made.

At first, it must be considered, what is the purpose of attaching the message to an image file. One of the reasons is simply to store hidden information for some private purposes, not including any second-parties at this moment. This approach is the easier part. Another reason may be that we would like to interchange some information with another party. This approach is more dangerous, since we would have to consider having to transfer such a file, which could of course be intercepted by a third-party on the way. And here we encounter a problem of key exchange.

One idea is that the key may be attached to the image file containing a message as well. Of course, it would not be stored as plain text, but rather in some other smart way, similar to message storing, and split throughout the file in some way. Another idea is however being considered; namely, both parties will have a set of keys stored somewhere on their disk space. These sets would be identical, and the encryption process would only include choosing one of the keys from the database (lat us call it a *key-repository* or shorter a *repository*), encrypting the message and attaching the index of a key to the message. To decrypt the message, the second party would only have to find a proper key in their repository according to the received index.

In fact, some calculations would probably have to be made, since symmetric-key cryptography does not actually use the same cryptographic key for encryption and decryption processes, but it is assumed that it is easy to compute the decryption key knowing the encryption key (and the other way around). The symmetric-key algorithms are divided in general into two groups: stream ciphers and block ciphers. The first type encrypts the message bit after bit, and the second type deals with blocks of bits, usually 64-bits long, but some of the ciphers use 128-bits blocks and others as well. Since the way the algorithm deals with the message is important from the point of view of the project, a detailed analysis of these two kinds of symmetric-key algorithms has to be made.

3.2.1 Block ciphers

A block cipher in comparison to a stream cipher is an algorithm, which operates on groups of bits of fixed length, which are called blocks. Size of a block is individually determined by the algorithm being considered, however the most common block-size is 64 bits and possibly 128 bits. It can be observed that certain functions are very common to this kind of ciphers. These are: logical operations (XOR), S-Boxes and permutations.

What is an interesting aspect is the number of various attacks against block ciphers, all of which base on certain properties of these ciphers. This includes: partial differential cryptanalysis, slide attacks, boomerang attacks, integral attacks, algebraic attacks, and many more. In general, a good block cipher must be tested against all of these attack types to prove its reliability. The most common block ciphers are: AES, DES, Blowfish, IDEA, Lucifer, SHARK, Triple DES, RC5 and many more. The variety of block ciphers is much greater than the number of commonly used stream ciphers.

3.2.2 Stream ciphers

A stream cipher is an algorithm, which encrypts data bit by bit (meaning one bit at a time), or in some cases one byte at a time. Their other name is *state ciphers* because an action at the current time depends on the current state. Their advantage is that they are usually much faster than block ciphers, which is somewhat obvious, since they require less complicated operations while dealing with one bit (or byte) at a time. Most of stream ciphers consist of a PRNG (a pseudo-random number generator) and a XOR gate. The PRNG outputs a key stream having a key on input. The key stream is then being XORed with the plain text, obtaining an encrypted message. A similar process is used do decrypt an encrypted message, meaning that appropriate key stream bits are being XORed with the encrypted message bits. Its advantage is that having an error in a single bit of a cipher text, it results in an error of a corresponding bit of the plain text. This feature is especially useful when dealing with high transmission error rate.

A stream cipher is useful when it comes do encryption of data of unknown length, and no bits are “wasted” as a result of padding, like in block ciphers for instance. The most popular and known stream ciphers include: RC4, A5/1, A5/2, FISH, Helix, SEAL, and many others. An example of a stream cipher is presented in the following chapter.

3.2.2.1 RC4 stream cipher

The RC4 stream cipher was designed in 1987 by Ron Rivest, one of the creators of the well-known RSA algorithm. The RC4 algorithm is very popular, because it is very simple to implement. It does not need large quantities of RAM to work, as it requires only 256 bytes for the state array, n bytes for the state key (n is from 1 to 255), however it is obvious that the longer the key is, the more secure the encrypted message will be. Values of n equal to 64 or 128 are very common. The algorithm consists of two parts: the KSA (Key Setup Algorithm), and PRGA (Pseudo-Random Generation Algorithm).

The KSA phase is used to initialize the pseudo-random number generator. It may be presented in such a way:

pseudo c-code

```
j = 0
for i = 0 to 255
      S[i] = i
for i = 0 to 255
      j = (j + S[i] + key[i mod n]) mod 256
      swap (S[i], S[j])
```

S is the state array, *key* is the state key, and *n* is the state key length. *i* and *j* are integer variables. The swap function interchanges appropriate bytes of the state array, with indices *i* and *j*. After the generator has been initialized, the proper process of encrypting or decrypting can be performed. It is being done in such a manner:

```
i = 0
j = 0
loop
      i = (i + 1) mod 256
      j = (j + S[i]) mod 256
      swap (S[i], S[j])
      k = S[(S[i] + S[j]) mod 256]
      output XOR of k with the next byte of input
end loop when there are no more bytes of input
```

By input, we mean the plain text data to be encrypted, or in the second case, the encrypted data which is to be decrypted. In both cases the same key is being used, because of the property of the XOR function. A table below should explain the idea:

input		key		encrypted
0	XOR	0	=	0
0	XOR	1	=	1
1	XOR	0	=	1
1	XOR	1	=	0

encrypted		key		decrypted
0	XOR	0	=	0
1	XOR	1	=	0
1	XOR	0	=	1
0	XOR	1	=	1

Table 1. XOR tables

As it can be observed, the XOR function returns 0 if both inputs are the same, and 1 if the inputs differ. This property is very useful, since as the table on the right shows, the decryption process reverses the encryption process using the same key. Such property is a subject to symmetric ciphers.

An important assumption must be mentioned in the case of the RC4 algorithm. Namely, it is very important, from the point of view of the algorithm's security, that a number of bits are discarded before the actual input data. It means, that when the output data (encrypted data) is achieved, a number of its initial bits are meaningless for the decryption process. These bits are called discards, and at least 256 of such bits are recommended for the algorithm to be secure.

If such precaution is not taken into consideration, the encrypted message is exposed to various kinds of attacks. The most dangerous is so called Fluhrer, Mantin, and Shamir attack. It bases on the fact, that while getting into possession of many encrypted messages, which have been encoded using the same key, it is possible to rediscover that key on the basis of these messages. Thus an important collorary can be made at this point, that it is vital not to use the same key too many times, because it decreases security level of the encryption process.

3.2.3 Cryptographic services under MS Windows

Since the operating system, which is intended to cope with the desired tasks, is a Microsoft Windows operating system, it would be worth knowing, if there are any tools supported by MS Windows, which cover some of the above mentioned encryption algorithms. In fact, a technology called CryptoAPI has been implemented under Microsoft Windows, thus it may be interesting to describe this tool, in order to check if it may come in handy.

CryptoAPI is a technology supported by the Microsoft Windows operating system. It provides a way for applications to get cryptographic services, like for example encryption and decryption of data. This technology supports special modules, called Cryptographic Service Providers, or shortly CSPs, which actually support all necessary cryptographic functions. They perform cryptographic operations, generate, and store private keys.

To generalize the Cryptographic Service Providers, they can be divided into three major categories:

1. Hardware based
2. Software based
3. Combined - partially hardware and software based

Because private keys and cryptographic operations are isolated from the operating system in hardware based CSPs, we may say that such convention is more secure than the software based cryptography. However, using hardware based cryptographic functions may have its disadvantages. First of all, storage space of such hardware is limited, so is the calculation power. It may take longer time for hardware based CSPs to generate keys. Hardware based CSPs are usually used when extreme security is required, for example while logging with use of smart cards. Combined Cryptographic Service Providers usually involve some hardware unit (like smart card verifier), together with fast computation speed achieved by use of some software.

It is worth mentioning, that all CSPs, which are intended to be used under Microsoft Windows operating system, need to obtain a certificate from Microsoft, otherwise they will simply not work under this system.
The following Cryptographic Service Providers are being supported under Microsoft Windows operating system:

- Microsoft Base Cryptographic Provider - provides basic cryptographic functions, uses RSA technology, is not subject to United States government cryptography export restrictions and therefore can be exported to other countries
- Microsoft Enhanced Cryptographic Provider - it is similar to the previous one, but provides additional algorithms thus increasing security, however is restricted by the US government
- Microsoft DSS Cryptographic Provider - supports signature verification and electronic data signing by using SHA and DSA algorithms. It is not restricted
- Microsoft Base DSS and Diffie-Hellman Cryptographic Provider - supports similar function as the previous one, provides additionally Diffie-Hellman key exchange. It is restricted
- Schannel Cryptographic Providers - support data integrity, session key exchange, and authentication while using SSL and TLS protocols. These providers are not restricted by any international organizations

It can be noticed, that providers, which support better cryptographic functions, are usually subjects to United States government cryptography export restrictions. A question arises, what kind of functionality is provided by both kind of CSPs. It can be shown on example of the Microsoft Base CSP and Microsoft Enhanced CSP. A table below shows different algorithms used by those providers, as well as supported key lengths:

Algorithm	**Base CSP**	**Enhanced CSP**
	key length in bits	
RSA public key signature algorithm	512	1024
RSA public key exchange algorithm	512	1024
RC2 block encryption algorithm	40	128
RC4 stream encryption algorithm	40	128
DES	N/A	56
Triple DES (2-key)	N/A	112
Triple DES (3-key)	N/A	168

Table 2. Algorithms supported by CSPs

It can be easily noticed, that the Microsoft Enhanced Cryptographic Service Provider provides better security and variety of different cryptographic algorithms in comparison to the Base Cryptographic Service Provider.

To conclude this chapter, it may be said, that the Microsoft Windows operating system has been well equipped with tools, which support many cryptographic functions which fulfill different roles, such as encryption and decryption of data, digital document signing, hashing, key exchange, authenticity verification and many more, and can really satisfy user's needs.

3.3 Methods of applying steganography

3.3.1 Noise method

Most of the popular graphical file formats base on existence of so called Color Table. Pixels are coded as a reference to this table, as it would be hideous to define each time a color to each single pixel. Size of the Color Table is determined by the color depth of an image, or in other words bpp (bits per pixel). A bmp file can have 1,4,8 or 24-color depth, while a gif file has up to 8-bpp color depth. This means that each color is represented by red, green and blue values, all of which cover 1 byte. It is easy to notice that the maximal size of such table is dependant on the color depth. For example, for a file with 24-bpp color depth, the number of all possible combinations of the RGB values is equal to 2^{24}, which equals roughly 16 million colors.

The concept is, to make use of such Color Table, by using the LSB (least significant bit) of each RGB color. Such concept is an idea of using the noise of an image. Imagine, that one of the components, say red, has the following bit representation in the Color Table: 11011011, which makes a total of 219. Suppose the last bit would change its value from 1 to 0. The obtained representation would be: 11011010, equaling 218. Such small difference of color intensity cannot be detected by human's eye. Thus, such approach bases on using the noise. Having *n* colors used in the Color Table, we obtain possible *3*n* bits, to place additional information into. If the number of colors used in the image is small, it may be necessary to use not only one LSB, but two or more. However, this approach would rapidly decrease quality of the image, making it more exposable for a potential attacker.

The noise method does not apply only to a palette of an image. In case of files with 24-bpp color depth, such as BMP files for example, there cannot be a color table present inside the file. The reason is obvious. In order to make use of such a palette, the size of the image would have to be at least 16 Megabytes, which is enormous. In this case no palette is used and data is written as a sequence of pixels, represented by triplets of RGB values. So, in fact, the number of pixel to store information into, instead of using a color table, will be equal to: *3*image_width*image_height*. So, the bigger the dimensions of the image are, the more information may be stored inside it.

3.3.2 Block methods

Apart from noise method described above, another approach may be used. Namely, various block methods may be applied to store information. But before explaining the idea, an important assumption must be mentioned. Namely, security level of a noise method is much higher than the one present in block methods. The conclusion is, that these methods may be used only as supplements to the above described techniques and will not provide as much security as the noise method.

The idea of block methods has nothing to do with hiding information inside LSB of a sequence of bytes. The concept is to make use of special markers, extensions and other blocks, which do not hold any important information from the point of file viewing, but they may be of benefit as far as the project's goal is concerned. The first possibility arises while taking into consideration modification of GIF files. A property of a GIF89a may be used, which are extensions. Comment extension holds plain text in human-readable form. Each of these blocks has limited length of 255 characters, however the number of blocks in such file is not limited. Thus this makes a perfect opportunity to make use of such property and put encrypted information inside comment extensions of a GIF89a file.

A similar approach may be used in case of JPEG files. As described in the analysis section, a JPEG file has a structure built from blocks, which are called markers. Each of these markers has a marker indicator and a length field, which allow detecting what kind of block this is and where the following block resides. This gives us an opportunity to attach a block inside the JPEG file structure, which may contain the encrypted information. However, if such block is not recognizable by some graphical application, than in case of saving this file under this program the attached watermark may disappear. So, this type of non-recognizable block will be denoted as a weak watermark.

There are however some places inside a JPEG file structure, which allow storing some additional information, without having to take a risk of an accidental erase. This may for example be space contained in the first marker of each JPEG file. The application marker (or shortly APP0) contains fields, which allow storing a thumbnail of an image. There are two bytes responsible for keeping width and height of a thumbnail. The picture itself is not compressed and represented by a sequence of RGB triplets. The maximum size of the APP0 marker is limited to 64 Kilobytes, which allows storing almost 64 Kb inside the thumbnail image field.

IV. Project description

4.1 Implementation choices

4.1.1 Programming platform

The application requires use of graphical user interface. Moreover, it must run under Microsoft Windows operating system. In general, two possible programming platforms were considered at the beginning of the implementation phase: MFC and Visual Basic, both contained in Microsoft Visual Studio. Finally, Visual Basic was chosen as the programming platform. Its programming interface is very used-friendly, it contains many useful tools, most of which are of type – put on form/program event/use with ease. Programming using MFC is not that simple, however one can achieve almost the same effect.

4.1.2 Application type

As stated before, the application requires being of visual type, because the user must be able to observe how the image has changed after it has been processed. It should also be equipped with tools making it easy for the user to be able to open and save files, display them on the screen and observe how each change affects the images. That is why it should support many different file types to increase functionality of the application. The choice of available cryptographic functions should also be quite spread out, since the user might want to choose different functions for encryption of different file types.

4.1.3 Application simplicity vs. high functionality

The application has to fulfill two important goals. At first, and the most important one too, should be its functionality. It is essential, that the program is equipped with many functions and is able to perform all of the desired activities without any errors. The second important thing is simplicity of the application. The user must be able to perform the desired task without any problems or hesitation while he tries to achieve his goal, in this case encrypt information, and put it inside an image. He must not have any doubts of what he is doing and how he should achieve it. That is why the overlook of the application must be simple and user-friendly. It should also be equipped with some help features, such as context help, or some general information on all of the functions, which may be used.

4.1.4 Installation

As it has been already stated in the Software requirements chapter, the application should run under different versions of MS Windows operating system, starting from MS Windows '98 and finishing on Windows XP. Moreover, it was assumed, that there should be no installation package, as it is usually much bigger in size and makes many unnecessary modifications to the system's registry file. The executable file of the application itself is quite small and may be run even from a floppy disk.

However, on some older systems, like Windows '98 for instance, a problem with running the program may actually occur. Namely, there is one library, which needs to be registered, before being able to execute and use the application. It should be already registered under systems like Windows 2000 or XP, but one could never know. Moreover, the user should not mess with such operation like registering a library, so a script named *register.bat* has been created to minimize the effort of performing the desired task. The control, which needs to be registered, is named *comdlg32.ocx*. It is responsible for performing all operations connected with Common Dialog Control, which will be described in the following chapter.

The idea to register a library makes the most of an executable file named *regsvr32.exe*, which should be present on all Windows systems with 32-bit environment. This application allows registering services such as dynamic link libraries (dlls) or ocx files. The problem arises, because on different operating systems the *regsvr32.exe* file is placed in different directories. On Windows 98 it is *.../system/*, while on Windows NT or XP it is named *.../system32/*. More problem arise, while on Windows 98 and XP the default Windows directory is C:\Windows, while on Windows NT it is C:\WinNT. The problem is solved with help of simple instructions combined with reading some environment system variables.

At first, two variables are being set to hold paths to proper locations of the *regsvr32.exe* file, depending on the location of Windows directory, which is held on system variable windir, which is present on all of the MS Windows operating systems:

ms-dos script code

```
set NTFile=%windir%\system32\regsvr32.exe
set noNTFile=%windir%\system\regsvr32.exe
```

Then, the name of the library is being read and a variable named os is being tested if it contains the *Windows_NT* string:

ms-dos script code

```
set LibFile=%1
if "%os%"=="Windows_NT" goto ISNT
```

More instructions follow, but probably the most important one will be the one responsible for registering the control. It is being achieved in such way:

ms-dos script code

```
%NTFile% /s %LibFile%
if errorlevel 1 goto ERR
```

The *s* flag is set to make sure that no message box pops up; all comments are presented to the user within the console window. If the process of registering the control is unsuccessful, a corresponding instruction will be executed and a proper error message will be displayed. Finally, all created variables must be removed from the system environment, so following calls are executed:

ms-dos script code

```
set NTFile=
set noNTFile=
set LibFile=
```

The above instructions remove the variables, so no unnecessary rubbish is left within the system. The library has been now registered and the program may be executed with no error message to be displayed.

4.2 The main process

4.2.1 Attaching information to an image

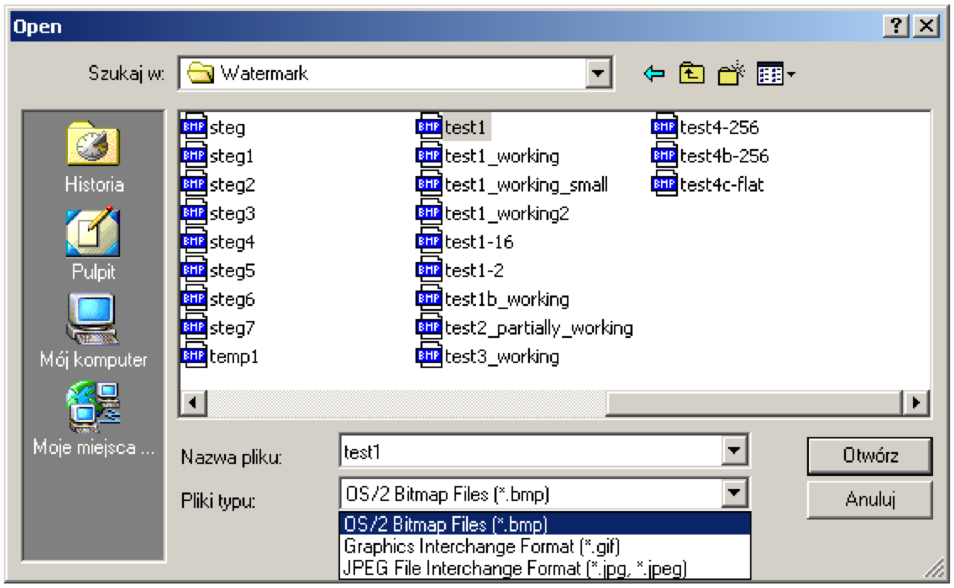
- opening / reading / displaying an image

At first, when we wish to perform any operation on any file, we have to open it for reading. Thanks to special components, which can be included in a Visual Basic Project, usage of some forms especially designed for management of file reading/writing can be implemented much easier. A control named *Microsoft Common Dialog Control* has been added to the Project. It has been designed as a standard form, which supports the above-mentioned conditions. It has been programmed to support opening and saving certain file types and the code with which it has been set is as following:

vb code

```
With CommonDialog1
     .DialogTitle = "Open"
     .InitDir = App.Path
     .Filter = "OS/2 Bitmap Files (*.bmp)|*.bmp|_
            Graphics Interchange Format (*.gif)|*.gif|_
            JPEG File Interchange Format
            (*.jpg,*.jpeg)|*.jpg;*.jpeg"
     .ShowOpen
End With
```

The above *With* statement allows setting for example the initial directory or the filter for the file extensions. The form looks as follows when displayed:



Picture 1. Common Dialog Control

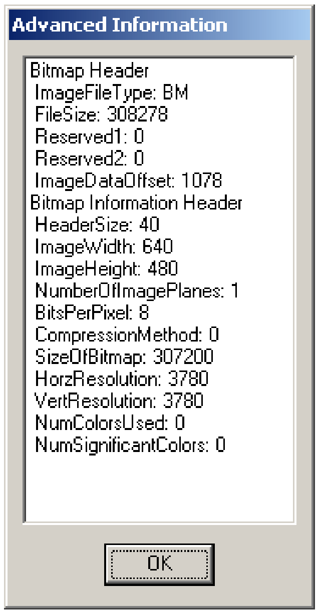
The control however does not support image detection, as far as different file-extensions are considered. One could rename extension of any file say to bmp and attempt to open the file using the application afterwards, which would result in an error. To prevent this, each file, which is being opened, is verified to check if it is indeed a supported image file type. This approach is also needed, since some important file properties need to be extracted from an image, to make it easier to process the file in the upcoming phases. As an example, some features of a bmp file header are being read below and saved onto a list, which may be displayed to get some additional information about the file:

vbcode

```
List1.AddItem "Bitmap Header"
List1.AddItem " ImageFileType:
"+Chr(read_byte(1))+Chr(read_byte(2))
List1.AddItem " FileSize: "+Format(read_dword(3))
List1.AddItem " ImageDataOffset: "+Format(read_dword(11))
List1.AddItem "Bitmap Information Header"
List1.AddItem " ImageWidth: " + Format(read_dword(19))
List1.AddItem " ImageHeight: "+Format(read_dword(23))
List1.AddItem " BitsPerPixel: "+Format(read_word(29))
```

```
List1.AddItem " CompressionMethod: "+Format(read_dword(31))
List1.AddItem " SizeOfBitmap: "+Format(read_dword(35))
```

A sample file content of a bmp file is being presented below:



```
Bitmap Header
 ImageFileType: BM
 FileSize: 308278
 Reserved1: 0
 Reserved2: 0
 ImageDataOffset: 1078
Bitmap Information Header
 HeaderSize: 40
 ImageWidth: 640
 ImageHeight: 480
 NumberOfImagePlanes: 1
 BitsPerPixel: 8
 CompressionMethod: 0
 SizeOfBitmap: 307200
 HorzResolution: 3780
 VertResolution: 3780
 NumColorsUsed: 0
 NumSignificantColors: 0
```

Picture 2. Advanced Information box

Such information is very important as far as image processing or debugging is concerned. So finally, after the image has been opened using the *Microsoft Common Dialog Control* and verified for all special characters that such particular file type should possess, it may be displayed on a form. How it is done and a visual sample will be presented in the next chapter.

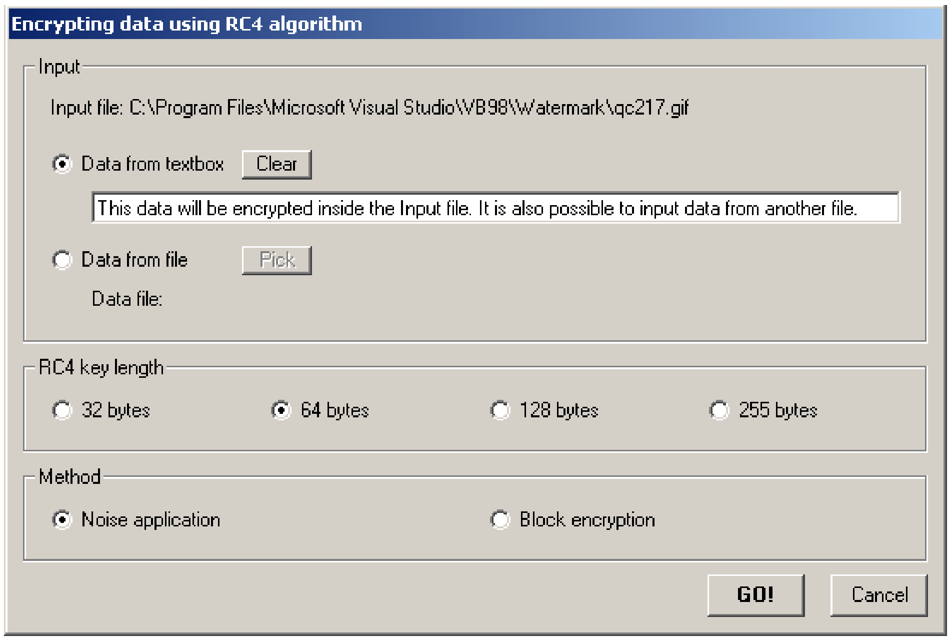
❖ pre-encryption phase – key management

Before any data may be encrypted, two things must be cleared. Namely, which algorithm is being chosen for data encryption and basing on this information, what the constraints concerning the key used in this algorithm there are. As explained in detail in the stream ciphers analysis chapter, the key used by such cipher may be an arbitrary stream of bits. Such feature allows not only putting the key inside the image file contents, but it allows to use part of the image data as the key itself. It means, that it is enough to extract a stream of bits from some place of the file, only having to remember the offset and the stream length. These values will be in fact the key-in-file offset and key length.

❖ encrypting information / cryptographic functions

Since now we have all components necessary to perform the encryption process, we may move forward to processing the data to be encrypted. There are two possible ways we may encrypt the data. It is either inputted from a textbox or directly from some file. The second option is quite interesting, while this data may be in fact some other image file containing encrypted data! This way this information is even more secure.

Let us imagine, that we wish to encrypt some text using RC4 algorithm inside a gif file. After an appropriate position from the program menu has been picked, a similar monit will appear:


Encrypting data using RC4 algorithm

Input

Input file: C:\Program Files\Microsoft Visual Studio\VB98\Watermark\qc217.gif

[✓ Data from textbox] Clear

This data will be encrypted inside the Input file. It is also possible to input data from another file.

Data from file Pick

Data file:

RC4 key length

32 bytes [✓ 64 bytes] 128 bytes 255 bytes

Method

[✓ Noise application] Block encryption

GO! Cancel

Picture 3. Encryption form

As it may be observed, certain options need to be picked before the actual process may be started. These are the above-mentioned possibilities of picking data either from textbox or a file, choosing the key length and the method of applying the information to the file. The form has been designed carefully and it contains all necessary functions needed to perform the encryption process combining together with ease of use.

❖ attaching information to the image

This is the calculation part. It is probably the most important one, because all of the information needs to be written to the file with great care, to avoid errornous decryptions of data. There are several features, which need to be put inside the file apart from the encrypted data itself. An so, dealing for example with noise method:

- LCD – number of least significant bits used – is responsible for determining how many bits of each data byte are used to store data
- Key length – number of bytes of a key used for encryption/decryption processes
- Data length – number of bytes, parts of which contain encrypted data
- Checksum – a byte containing information if there is a watermark included in the file. This is usually a bit operation of some sort, which may be performed during the decryption process and this way verified
- Reserved bytes – may be used for storing data for some purpose in the future (considered for some software updates, additional data needed by some encryption algorithms, etc.)
- Key – these bytes are not written to file, they are read in both encryption and decryption processes
- Encrypted data – the data encrypted using the above key

A sample code of how it is in fact being achieved, is presented below:

vb code

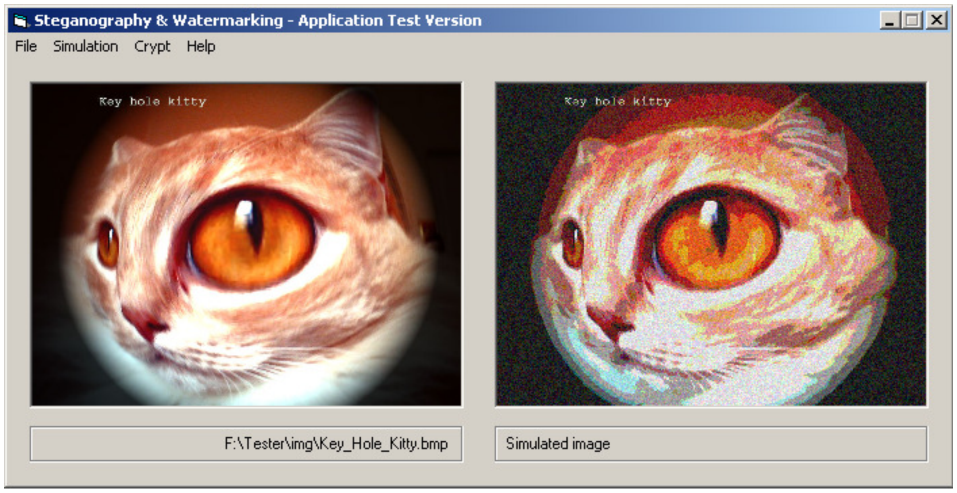
```
size = 3 * (2 ^ bpp) - 20
LSB = (8 * Len(emsg)) \ size + 1
mask = &HF8
c = read_byte(data_start + 1)
c = c And mask Or LSB
write_byte(data_start + 1, c)
```

These lines of code calculate the necessary LSB value and write it in a proper place inside an image. In this case, data will be put inside a Color Table of a file, so the maximum size to fit the data is calculated first. Three bytes representing RGB values are being used, and the amount depends on the bits-per-pixel value. On the other hand, the value 20 stands for number of bytes necessary to store the above mentioned features, such as key length, data length, checksum, etc. So, the number of LSB will depend on the size of the possible place and message (*emsg*) length. It was assumed that three bits of the first entry byte would be used for storage, so mask was set to value 11111000 (in binary). Afterwards, a byte is read, then it undergoes bit operations: it is being And-ed with the mask and Or-ed with the LSB data itself. Finally, the modified byte is written back to the file in the same place.

Such scheme follows throughout the whole process of file modification. Some values are being calculated, than a proper mask is being established (basing on certain factors), than a corresponding byte of image data is being read, modified and finally written back in the same place. All of this may look a bit complicated but is in fact the only way to do it.

❖ displaying original / modified images

After all of necessary information has been written inside a file, and no error message such as for example (file to small to perform operation etc.) was displayed, the modified image is displayed right from the original one. This feature is especially useful, since the user must determine if the result is satisfactory. An example of such comparison is presented below:


Steganography & Watermarking - Application Test Version
File
Simulation
Crypt
Help
Key hole kitty
Key hole kitty
F:\Tester\img\Key_Hole_Kitty.bmp
Simulated image

Picture 4. Image comparison

Such view may be also achieved after using another useful feature of the application, namely the Simulation. A set number of LSB of the image are arbitrarily chosen, to simulate how a real image would look like after encryption.

❖ saving the modified image

After user approval the obtained image may be saved to disk. This feature is being realized once again by the *Microsoft Common Dialog Control*. Of course caution must be taken, to prevent file overriding or some other malfunctioning. The user may choose from the menu Save or SaveAs option. The Save operation overrides the file the program works on, while the SaveAs feature allows to create a new file, or replace some existing one.

4.2.2 Extracting information from an image

❖ opening / reading / displaying an image

This phase does not differ in any way from the one from previous section. After the file is opened using the *Microsoft Common Dialog Control*, it is being read for characters and data specific for its file extension. If the received information is correct, the file is displayed on the form.

- ❖ watermark presence verification

To be able to process with further steps of the extraction phase, we must first determine if the image contains a watermark. To verify its presence, we should use the checksum field, which has been set during the attachment phase. This field contains a value which has been set on a basis of certain bit operations, and so:

vb code

```
c = read_byte(some_offs + 1) Xor read_byte(some_offs + 2)
checksum = read_byte(other_offs)
```

The above code is used to verify the checksum. The bit operation used during the attachment phase is made once again, but this time the checksum is not written but read from the file. If both of the above values are equal, than there is high probability that the image contains a watermark. We cannot be sure with 100% that it is really true, because it might happen that these values are equal by coincidence, however such case should not happen very often.

In fact, probability of occurrence of such case may be easily calculated. Namely, if a byte consisting of eight bits is considered, all possible combinations of bit values have to be taken into consideration. There are 2^8 combinations, making a total of 256 possibilities. Thus, probability that a watermark is detected and is in fact not present inside an image is equal to *P(1 byte) = 1 / 256*, which makes it roughly 0.39 %. This result is quite satisfactory, however one could consider using two or more bytes as checksum fields. In case of two bytes usage, the probability would be equal to *P(2 bytes)* $= (1 / 256)^2$, which is equal to mere 0.001 %.

In case of the noise method, the checksum is hidden inside noise of the image, because there is no other place to store the checksum information. Otherwise, such information could be probably stored in some additional block, but such concept should not be used within the noise method.

❖ extracting the data

This step is similar to the attachment step, however it's made 'backwards'. Certain factors are extracted from the file, and some are calculated basing on the obtained values:

- Checksum – assuming that its verification is positive, following extractions may follow
- LSB – determines how many bits of each data byte are used to store data
- Key length – number of bytes of a key which will be used for decryption
- Data length – number of bytes, parts of which contain encrypted data
- Key – corresponding bytes which are read from the file, which must be identical with these used for encryption
- Encrypted data – the data encrypted using the above key, bases on obtained value of LSB

❖ decrypting the data

Having extracted all necessary values from during the previous step, we may follow with data decryption. Since stream ciphers are used, the key used for decryption is exactly the same as the one used for encryption. So, the process of decryption is almost the same as encryption, differing only on the input stream. In case of encryption it was plain text or a file we wished to encrypt, in the second case it will be the encrypted stream itself.

After having chosen an appropriate option from the menu, which allows decrypting data, a form will appear, which will allow the user to choose form of the output. He may display the decrypted data into a textbox, or save it as a file. Of course caution must be taken to avoid overwriting an existing file.

❖ separating the plain image file - if possible

In case of block methods, meaning the solutions, which attach encrypted data by means of additional blocks, it is usually possible to detach the original file from the attached data. Since these blocks are generated by the application, the mechanism of their addition and usage is well known, thus they may be removed from the file afterwards.

4.3 Application features

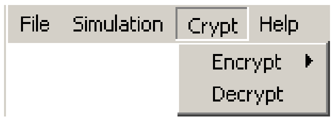
4.3.1 Stick to the standards

This chapter is devoted to describing all of the visual features of the application. It is obvious that a nice user-friendly program must have an interface, which does not require much thinking to be made from the user's side. In fact, a potential consumer expects not to come across any difficulties and to use the application intuitively. This means, that all of the features have to be designed with great care, taking into consideration specific standards, which are widely used today. The mentioned standards include for example:

- clear Windows-type buttons
- menu bar in top section of the main window frame
- keyboard shortcuts
- mouse behavior typical for MS Windows OS
- popping up message boxes
- extended help sections

Implementation of Windows-type buttons is an example of simple drag-and-drop operations. The buttons are simply dragged onto a form and an event may be programmed to each of them. Visual Basic takes care of proper behavior of these controls, however it can be mentioned, that they may be programmed to allow the user to switch between them using a TAB button on the keyboard. Such feature may come in handy in some situations and is a nice idea of sticking to Windows standards.

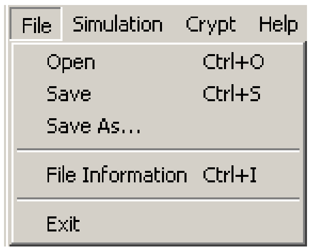
The menu has been designed with great care to allow the user to move through its options without any hesitation.



Picture 5. The menu

It may be observed that the names of each section have been designed in such way, that the user is sure what each particular option is responsible for. For example the File submenu manages all necessary file operations, while the Help submenu displays application help information. Such approach is indeed made as intuitive for the user as it can be.

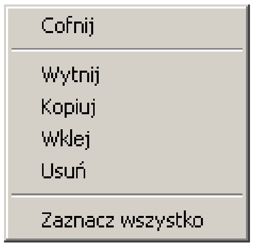
Keyboard shortcuts are another example of proper standards, which needs to be used while designing an application.



Picture 6. Keyboard shortcuts

The figure shows that most of the options may be executed in two ways. The first one is using a mouse and the menu bar, the second one involves keyboard. There are shortcut standards like for example Ctrl+O for opening a file, Ctrl+S for saving a file or F1 for displaying help. All of this has been covered by the created application.

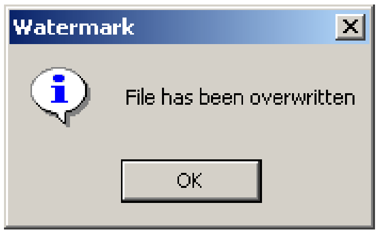
Another aspect is mouse behavior. This feature requires that all of the menu options and command buttons to be pressed using the left mouse button. This is of course fulfilled. However, there are some events typical for the right mouse button, as the picture below illustrates:



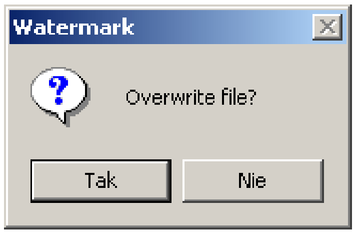
Picture 7. Right-click mouse submenu

Thanks to Visual Basic properties such possibilities as text copying/pasting can be achieved. This may be especially useful while pasting or copying data from/to textboxes before the encryption process or after the decryption process.

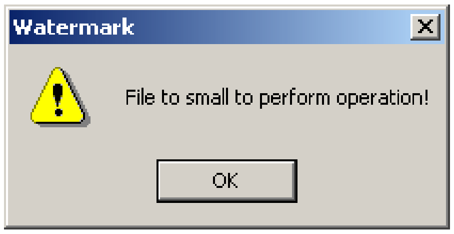
In case of possible improper behavior of a user, a form of foolproof mechanism had to be implemented. The idea is to disallow the user to crush the application by performing some random actions (maybe by accident), no matter how hard he tries. This will involve informing the user by the means of proper popping-up message boxes about some status, as a reaction to his actions. In general, four types of message boxes may appear:

1.

Watermark

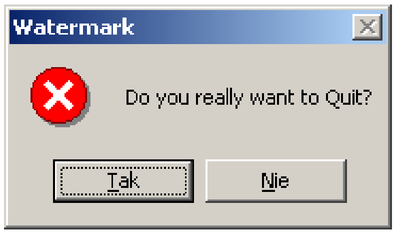
File has been overwritten

2.

Watermark

Overwrite file?

3.

Watermark

File to small to perform operation!

4.

Watermark

Do you really want to Quit?

Figure 1. Different types of message boxes

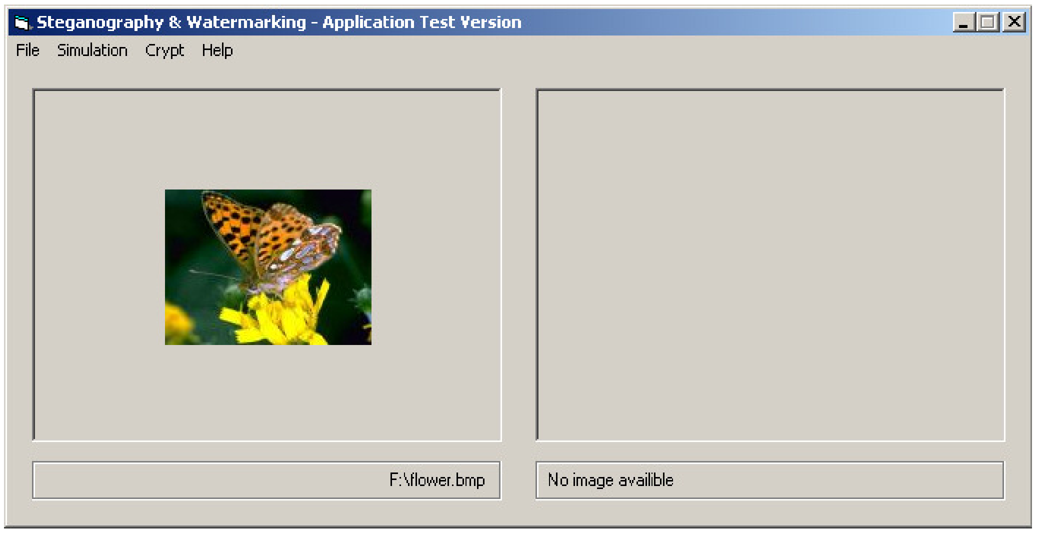
1. Information message boxes
2. Question message boxes
3. Exclamation message boxes
4. Critical message boxes

The first type of message boxes will provide the user about status of an operation if it has been completed successfully, such as for example successful encryption, decryption or file saving. Question type message boxes demand taking an action from a user. Such popup may appear while overwriting a file. Exclamation message boxes are intended to warn the user that he has performed some illegal action. Critical message boxes are displayed as the user begins to mess with the program. For example if he attempts to delete a file after it's been opened and perform some attachment operations afterwards. Such actions should be strictly prevented.

Help sections include various help information, which is presented to the user while he is coping with the application. To these belong: application help, context help, and tool tip help. The application help contains all information about the application, making it easier for the user to perform all of the desired operations. Context help and tool tip help are types of help information, which applies to particular areas of interest of the user as far as the graphical interface of a form is concerned. Controls and objects, which reside on a form, should be "monitored" by the application while the user stops a mouse over them. In such cases he may want to read some information on a particular control and it is usually displayed in a yellow rectangular box close to the mouse cursor. This really helps the user moving through the program interface.

4.3.2 Image preview

The idea of the project was to confront the initial image and the modified one, to make it possible for the user to choose if the result of data attachment satisfies his needs. This feature is especially useful in case of the noise method, because the distortions may be too big for the user to accept. On the other hand, the user should have a chance to see if an applied block method did not cause any damage to the image and if it is displayed correctly. So, the conclusion is as following – the user should be able to observe both of the images. It could be achieved either by switching the both images located in the same place, or by displaying the images close to each other to have a clear real-time view. The second option has been chosen to minimize user's interference with image displaying. Moreover, the images have been presented as miniatures, in two 320x240 picture boxes, as the image below shows:



F:\flower.bmp

No image availible

Picture 8. Image scaling

To display the miniatures, the images have to be scaled before displaying. Basic code for achieving this is presented below:

<u>*vb code*</u>

```
Picture1(ind).Cls
Picture2 = LoadPicture(file_name)
Picture1(ind).PaintPicture Picture2, hor_offs, ver_offs,_
Int(320 * 15 * hor), Int(240 * 15 * ver)
```

Picture1 control represents an indexed picture box (0 = initial file, 1 = modified file). *Picture2* is a hidden control, which holds a full image preview. The PaintPicture method allows making the most of the content of the *Picture2* control, and displaying it after modifications in a proper *Picture1* box. The *hor_offs* and *ver_offs* represent offset of the picture, which is being displayed. They are used if one of the coordinates (width or height) is smaller than the corresponding size of 320x240 picture box. The *hor* and *ver* values represent the actual size of a corresponding coordinate, which is responsible for how many times the actual image is being shrinked (these values are calculated earlier and base on information obtained from the image structure such as *image_width* and *image_height*). The magic constant *15* stands for pixel size under Visual Basic scale (1 pixel equals 15 units).

4.3.3 Method simulation

As mentioned in one of the preceding chapters, it is especially helpful to be able to present to the user the outcome of a data attachment process, before having to perform the actual task, meaning encryption process, file modification, file saving, etc. This is achieved by means of simulation. The user may choose an option from the menu bar, to see what result would a particular event have on a file he wishes to modify.

The event may be for example simulating the possible outcome of performing the noise method on an image. It is possible to choose the number of least significant bits of each byte, which will be used as information carriers. The actual simulation process intends to cover the place responsible for data attachment using a random bit stream. It is being achieved like so:

vb code

```
mask2 = 0
      For j = LSB To 7
            mask2 = mask2 + 2 ^ j
      Next j
// loop start ...
mask = 0
      For n = 0 To LSB - 1
            mask = mask + Int(2 * Rnd) * 2 ^ n
      Next n
c = read_byte(...)
c = c And mask2 Or mask
write_byte(c)
// loop end
```

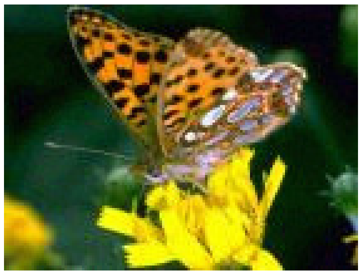
At first a mask called *mask2* is established. It will be used to mask all of the HSB (high significant bits), which will be left out unchanged from each read byte. Then a loop is executed. Each time, a mask called *mask* is being calculated, basing on random values (*Rnd* parameter). Having the two masks, it is possible to modify a particular byte. After it has been read, the HSB is kept using the *mask2*, and additional random bits are applied using the mask. The loop continues as long as all necessary bytes have been modified.

The method allows observing simulations of eight different byte fills, starting from 1 bit used, and finishing on all bits used. The results are quite interesting and for some may be a bit surprising:

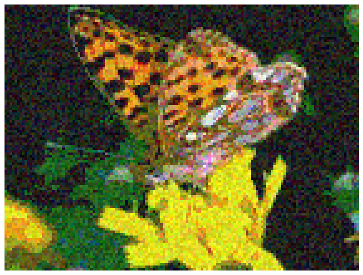
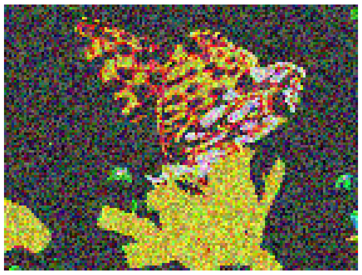
0.

1.

2.

3.

4.

5.

6.

7.


Picture 9. Noise simulation

Nevertheless, the opportunity to perform simulations saves time and allows the user to test different parameter settings before he will decide to perform the actual task.

V. Research

The program operates on three most popular graphics file format: BMPs, GIFs and JPEGs. Thus, a detailed research has to be made, to assure that the program really fulfills all of the desired tasks and if the application would not crash in some special conditions. To these conditions belong the following possibilities:

- using extremely small files in order to make it impossible to read a key from such files, or store any information inside their file structure
- using extremely large files or amounts of data to crash the application
- renaming extensions of files to fool the program's parser, which checks throughout fixed sections of each of the file formats
- messing with the file structure in such ways, that afterwards it would not be recognizable by the parser or will cause malfunctioning of the program

The program has been tested to check if the above-mentioned conditions do not cause program malfunctioning. The testing platform was Windows 2000 with an AMD Athlon 1800+ processor and 512 Mb of RAM. Some basic tests have also been made under Windows 98, to ensure that the application is installed correctly and runs without any problems.

5.1 Method comparison

A table below presents methods, which are supported by different formats. Each of the possibilities is characterized by the maximum length of a message to be applied and a comparison of watermark strength and security for each particular case. These last two fields determine how each of the methods influences factors important from the point of the view of project's thesis. Watermark strength determines how well the attached information is able to withstand modification of the file by some outside application. Security tells us how well the data is hidden inside the file. Of course, the stronger the watermark, and the more secure it is, the better.

File type	Characteris-tics (bpp)	Method	Message length	Watermark strength	Security
BMP	8	Noise	under 768 b	high	high
BMP	24	Noise	long / file size dependant	medium	high
GIF	8	Noise	under 768 b	high	high
GIF	ALL	Block (extensions)	under 64 Kb / may be more	medium	low
JPEG	ALL	Block (own markers)	unlimited	low	low
JPEG	ALL	Block (thumbnail)	under 64 Kb	medium	medium

Table 3. Method comparison

It may be observed, that the most secure methods involve using noise as information carrier. The possibly worst solution looks to be using own markers block method in a JPEG file, because these markers are destroyed while opening and saving this file in most of image editors. However, message length is not limited in any way in this case, so such method may be also found useful. By low security it is understood that the attacker would find easy access to blocks containing encrypted information, so the only thing he would have to do, would be to find a way to decrypt the message.

Distinction among different bits-per-pixel values of BMP files, as it comes to watermark strength, has been introduced to underline a fact, that it is easier (medium strength) to destroy file content of a file without a color table (24-bpp BMP), than of one containing one (8-bpp BMP).

5.2 Processing speed

A sample 24-bpp BMP file of size close to 1 Mb was chosen to test it prior to the speed of calculations. A precise timing mechanism, implemented within the project measured the actual encryption and decryption speeds. This process involved reading system data from so-called GetTickCount variable, which in fact pointed to number of milliseconds, which expired from the time the system was booted. The following results have been obtained:

Process \ data	100 Kb	200 Kb	300 Kb	400 Kb	500 Kb	600 Kb	700 Kb
Encryption [s]	2,06	3,56	5,06	6,76	8,17	9,48	10,98
Decryption [s]	3,26	4,68	5,75	7,42	8,42	9,65	11,07

Table 4. Processing speeds

Certain amounts of data with step of 100 Kb were taken to check speeds of encryption and decryption processes. Results of these calculations are presented on a graph below:

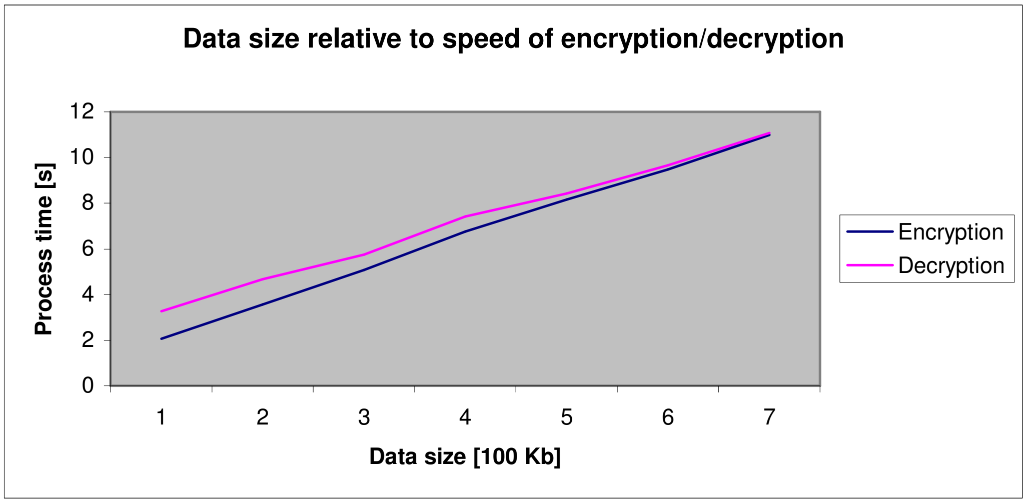


Figure 2. Encryption vs. decryption speed

It may be observed, that both of the processes are presented by functions close to linear and the longer the time of calculations is, the closer the processing times are.

VI. Summary

6.1 Summary of the work

To determine if the goal of the project has been established, one has to review all assumptions regarding the thesis, as stated in the Aim of the Thesis chapter. The objective was to prepare an application compatible with MS Windows operating systems, which would allow maintaining data security as far as privacy of information is concerned. It was assumed, that the application should perform such operations, as making the most of graphics file formats and treating them as potential information carriers, allowing the user to perform all activities concerning encryption and decryption of data and supporting him in all necessary ways in order to provide him with a friendly graphical user interface and help information.

The steganographic approach used in the project bases on certain assumptions, which have been fulfilled throughout careful implementation phase. The watermark, which is being added to a file, is making the most of two general approaches implemented by the application. It may be distributed inside the file using noise of the image or making advantage of certain block structures, which are present in most of the popular graphics file formats. Both of the methods have their advantages and the user may choose which one suits him better. In case of noise methods the quality of the image decreases, however the security level of such approach is very high. On the other hand, the block methods support far more storage space (mostly unlimited) but presence of a watermark may be detected easier.

As it states in the Aim of the Thesis, the attached information should not only be cleverly hidden and distributed inside a file, but it should be encrypted as well to preserve more security than plain-text information. This concept is especially important as it comes to block methods, since in case of these, it would be much more easier to detect and read the block contents. The application supports the user with tools necessary to perform the desired operations, meaning the encryption, and decryption of data. It allows the user to choose among various options, such as setting the key length, choosing the desired method, or determining the input/output form of the processed information.

The application combines high functionality with a simple, intuitive graphical user interface. The user may observe how the encryption process affects the visual outcome of an image, by the means of a real-time preview. He may also perform a simulation of a process to save time and try different program settings before performing the actual task. Number of help features makes the application a tool, which one may use with real ease and comfort.

To conclude the summary, it must be said with full responsibility, that the desired goals stated in the Aim of the Thesis have been fulfilled, thus making the created application a tool worth giving a try.

6.2 Possible expansion chances

6.2.1 Other graphics file formats

Expansion to other graphics file formats is quite simple. The only thing, which needs to be done, is a detailed analysis of each of the file types. Of course, there may be some image file format, to which two of the implemented methods may not apply. However, most of the graphics file formats are built from similar data structures, as described in the analytical part of the thesis, and contain such elements as headers, color palettes, and other blocks representing certain properties of image files. This is surely very convenient from the programmer's point of view, since the only necessary thing during the implementation phase would be to read all necessary information from the file and, basing on this data, adapt it to serve such purposes as the ones included in the thesis.

Another aspect, which needs to be mentioned, is application of the mentioned methods along with lossy compression of image data. Such issue is quite an interesting problem, since it is much more difficult to preserve the attached data, which is hidden inside compressed information of some file. In this case, one of the block methods would be found useful, however if it comes to the noise method, one could consider tempering with the color table of a file, like in 4- and 8-bpp BMP or GIF files for instance, and not with the actual compressed data itself. Modification of the compressed raster data would be much more difficult, since as for example in JPEG files, the information present before decompression and repeated compression differs. In such case, one could take into consideration possible loss of parts of the attached data, since a stream cipher is being used. One of its benefits is that errors in the decrypted data result in errors in the same places of the encrypted data. Thus, the rate of error would depend only on how the information can be adapted to face lossy compression of such files.

6.2.2 Other file formats

Expansion to other file formats apart from graphics file formats may be quite an interesting topic. Expansion chances depend on how a particular file format can adapt itself to the proposed methods. The block method is probably more flexible, and may be adapted to many types of files, however these must be of binary and not of text type. So, it would probably be possible to use such document formats as popular DOC and PDF files, because their structure consists of blocks and such concept is similar to the one used in image file format manipulation. Block methods cannot be applied to plain-text files like TXT files for instance, since such approach would not differ in any way from standard encryption procedure and the goal of the thesis was to combine a steganographic approach together with data encoding.

As it comes to noise method, it cannot be applied to the above mentioned document formats, since there is no place to treat as a distortion of a file in order to store some information inside. However, there are some files, which could meet project's requirements. To these belong music file formats, such as WAV and MP3 for instance. In this case, we would not talk about visual distortions of a file like in an image, but on the other hand rather about audible distortions. Similar to the approach used in the project, noise of a music file could be used as information carrier. Probably there would be a similar perception border like in the case of graphics file formats. Human's ear would not determine if changes have been made to the file, as long as it would be a gentle one. Probably after using all space provided for sound peaks of a music file, the human would hear only a monotonous noise, similarly to the case when all LSB of an image have been used, which would result in a completely grainy picture.

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