SECURITY PROTECTION OF SOFTWARE PROGRAMS BY INFORMATION SHARING AND AUTHENTICATION TECHNIQUES USING INVISIBLE ASCII CONTROL CODES*

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ABSTRACT

A new method for software program protection by information sharing and authentication techniques using invisible ASCII control codes is proposed. A scheme for sharing a secret source program among a group of participants, each holding a camouflage program to hide a share, is first proposed. The secret program is divided into shares. Each share is encoded next into a sequence of special ASCII control codes which are invisible when the codes are inserted in the comment of the Visual C^{++} program. These invisible codes then are hidden in the camouflage program, resulting in a stego-program for a participant to keep. Each stego-program can still be compiled and executed to perform the original function of the camouflage program. A secret program recovery scheme is also proposed. To enhance security three security measures via the use of a secret random key are also proposed. Experimental results show the feasibility of the proposed method.

1. INTRODUCTION

Software programs written in various computer languages are important resources of intellectual properties. They need protection from being tampered with. One technique of information protection is *information sharing*. When applied to software programs, this technique means that a secret program is, via a certain sharing scheme, transformed into several copies, called *shares*. Each share is individually different from the original secret program in appearance, content, and/or function. The secret program cannot be recovered unless the shares are collected and manipulated with a reverse sharing scheme. Such a technique of program sharing may be regarded as one way of *secret keeping*, which is necessary in many software-developing organizations.

The concept of secret sharing was proposed first by Shamir [1]. By a so-called (k, n)-threshold scheme, the idea is to encode a secret data item into n shares for n participants to keep, and any k or more of the shares can be collected to recover the original secret, but any (k – 1) or fewer of them will gain no information about it. A similar scheme, called *visual cryptography*, was proposed by Naor and Shamir [2] for sharing an image. The scheme provides an easy and fast decryption process consisting of xeroxing the shares onto transparencies and stacking them to reveal the original image for visual inspection. This technique has been investigated further in [3-5], though it is suitable for binary images only. Verheul and van Tilborg [6] extended the visual cryptography technique for processing images with small numbers of gray levels or colors. Lin and Tsai [7] proposed a digital version of the visual cryptography scheme for color images with no limit on the number of colors. The n shares obtained from a color image are hidden in n camouflage images which may be selected to have well-known contents, like famous characters or paintings, to create additional steganographic effects for security protection of the shares.

Sharing of software programs *in source form* has not been studied yet. In this paper, we propose a method for this purpose, which is based on the use of some specific ASCII control codes *invisible* in certain software editors. Invisibility of such ASCII control codes is a finding of this study through a systematic investigation of the visibility of all the ASCII codes in the window of the Visual C^{++} editor of Microsoft Visual Studio .NET 2003, Service Pack 1 (abbreviated as the VC^{++} editor in the sequel). By the use of the logic operation of "exclusive-OR," each source program to be shared is transformed into a number of shares, say N ones, which are then hidden respectively into N pre-selected *camouflage source programs*, resulting in N *stego-programs*. Each stego-program still can be compiled and executed to perform the function of the original camouflage program, and each camouflage program may be selected arbitrarily, thus enhancing the steganographic effect.

To improve the security protection effect further, we propose additionally an authentication scheme for verifying the correctness of the contents of the stego-programs brought by the participants to join the process of secret program recovery. This is advantageous to prevent any of the participants from accidental or intentional provision of a false or destructed stego-program. The verified contents include the share data and the camouflage program contained in each stego-program. Any "bad" share or camouflage program will be identified and picked out in the secret program recovery

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process. This double capability of authentication is based on the use of certain *authentication signals* embedded in the stego-programs. Each signal is generated from the contents of the share data and the camouflage program content. A third measure proposed to enhance security protection in this study is to prohibit recovery of the secret program with *illegally* collected stego-programs. All of these protection capabilities are carried out with the provision of a secret random key through the use of certain mathematical operations.

In the remainder of this paper, we describe in Section 2 the finding of the invisible ASCII codes and a scheme of binary data encoding into such codes for use in generating stego-programs. In Section 3, an algorithm describing the proposed source program sharing and authentication signal generation schemes is presented, and in Section 4, an algorithm for stego-program authentication and secret source program recovery is described. In Section 5, discussions on and measures for security issues are given. And finally in Section 6, some experimental results are presented, followed by a conclusion in Section 7.

2. INVISIBLE ASCII CONTROL CODES FOR BINARY DATA ENCODING

ASCII codes, usually expressed as hexadecimal numbers, are used very commonly to represent texts for information interchanges on computers. Some of the ASCII codes of 00 through 1F were used as *control codes* to control computer peripheral devices like printers, tape drivers, teletypes, etc. (see Table 1). But now they are rarely used for their original purposes because of the rapid development of new peripheral hardware technologies, except those codes for text display controls, such as 0A and 08 with the meanings of "line feed" and "backspace," respectively. It is found in this study that some of the ASCII control codes, when displayed by certain text editors under some OS environments, are *invisible*. Such ASCII codes may be utilized for various secret data hiding purposes [8].

The finding of such invisible codes resulted from a systematic test of all the ASCII control codes in the environment of the VC^{++} editor of Microsoft Visual Studio .NET 2003, Service Pack 1. Four of such codes so found are 1C, 1D, 1E, and 1F, which are invisible in the *comments* or *character strings* of VC^{++} programs (see Table 2). Such codes will simply be said *invisible* in subsequent discussions.

As an illustrative example, in Fig. 1 we show a simple source program in Fig. 1(a) with a short comment "test a file." In the comment, we inserted consecutively the four codes 1C, 1D, 1E, and 1F between the letters "s" and "t" in the word "test." Their existences can be checked with the text editor UltraEdit 32, as can be seen from Fig. 1(b). But the four codes are invisible in the VC^{++} editor, as can be seen from Fig. 1(a). Such invisibility usually will arouse no suspicion and so achieve a steganographic effect, since, unless necessary, people will always use the VC^{++} editor for program inspection and development. We utilize such an "invisibility phenomenon" for hiding both share data and authentication signals in source programs in this study, as described in the following.

For the purpose of program sharing among several participants, after a given secret source program is transformed into shares, each share is transformed further into a string of the above-mentioned invisible ASCII control codes, which is then embedded into a corresponding camouflage source program held by a participant. And for the purpose of security protection, authentication signals, after generated, are transformed as well into invisible ASCII control codes before embedded. These two data transformations are based on a binary-to-ASCII mapping proposed in this study, which is described as a table as shown in Table 2, called *invisible character coding table* by regarding each ASCII code as a character.

Table 1. ASCII control codes and descriptions.

Dec	Hex	Char	Description	Dec	Hex	Char	Description
0	0	NUL	null character	16	10	DLE	data link escape
1	1	SOH	start of header	17	11	DC1	device control 1
2	2	STX	start of text	18	12	DC2	device control 2
3	3	ETX	end of text	19	13	DC3	device control 3
4	4	EOT	end of transmission	20	14	DC4	device control 4
5	5	ENQ	enquiry	21	15	NAK	negative acknowledge
6	6	ACK	acknowledge	22	16	SYN	synchronize
7	7	BEL	bell (ring)	23	17	ETB	end transmission block
8	8	BS	backspace	24	18	CAN	cancel
9	9	HT	horizontal tab	25	19	EM	end of medium
10	A	LF	line feed	26	1A	SUB	substitute
11	B	VT	vertical tab	27	1B	ESC	escape
12	C	FF	form feed	28	1C	FS	file separator
13	D	CR	carriage return	29	1D	GS	group separator
14	E	SO	shift out	30	1E	RS	record separator
15	F	SI	shift in	31	1F	US	unit separator

Table 2 Invisible character coding table.

Bit pair	Corresponding invisible ASCII code
00	1C
01	1D
10	1E
11	1F

Specifically, after the share and the authentication signal data are transformed into binary strings, the bit pairs 00, 01, 10, and 11 in the strings are encoded into the hexadecimal ASCII control codes 1C, 1D, 1E, and 1F, respectively. To promote security, a secret random key is also used in generating the authentication signal. The details are described in the next section.

3. PROPOSED PROGRAM SHARING SCHEME

In the sequel, by a program we always mean a *source* program. A sketch of the proposed process for sharing a secret program

is described as follows. We assume that the number of participants in the secret program sharing activity is N, and that the input secret random key has a value of Y.

(1) *Creating shares* --- Apply exclusive-OR operations to the contents of the secret program and all the camouflage programs, and divide the resulting string into N segments as shares, with the one for the k-th participant to keep being denoted as E_k.

(2) *Generating authentication* signals --- For each camouflage program P_k, use the random key value Y to compute two modulo-Y values from the binary values of the contents of P_k and E_k, respectively; and concatenate them as the authentication signal A_k for P_k.

(3) *Encoding and hiding shares and authentication signals* --- Encode E_k and A_k respectively into invisible ASCII control codes by the invisible character coding table (Table 2) and hide them evenly at the right sides of all the characters of the comments of camouflage program P_k, resulting in a stego-program for the k-th participant to keep.

A detailed algorithm for the above scheme is given in the following. We assume that the length of a program is measured as the number of the ASCII characters in it. Also, given two ASCII characters C and D, each with 8 bits, denoted as $C = c_0c_1...c_7$ and $D = d_0d_1...d_7$, we define the result of "exclusive-ORing" the two characters as $E = C \oplus D = e_0e_1...e_7$ with $e_i = c_i \oplus d_i$ for $i = 0, 1, ..., 7$ where $\oplus$ denotes the bitwise exclusive-OR operation. Note that E has eight bits, too. And given two equal-lengthed character strings S and T, we define the result of exclusive-ORing them, $U = S \oplus T$, as that resulting from exclusive-ORing the corresponding characters in the two strings.

Algorithm 1. *Program sharing and authentication.*

Input: (1) a secret program P_s of length ℓ_s; (2) N pre-selected camouflage programs $P_1, P_2, ..., P_N$ of lengths $\ell_1, \ell_2, ..., \ell_N$, respectively; and (3) a secret key which is a random binary number Y with length ℓ_Y (in the unit of bit).

Output: N stego-programs, $P_1', P_2', ..., P_N'$, in each of which a share and an authentication signal are hidden.

Steps:

Stage 1. Creating shares from the secret program.

1. Create $N + 1$ character strings, all of the length ℓ_s of P_s, from the secret program and the camouflage programs in the following way.
   1.1 Scan the characters (including letters, spaces, and ASCII codes) in the secret program P_s line by line, and concatenate them into a character string S_s.
   1.2 Do the same to each camouflage program P_k, $k = 1, 2, ..., N$, to create a character string S_k of length ℓ_s (not ℓ_k) either by discarding the extra characters in P_k if $\ell_k > \ell_s$ or by repeating the characters of P_k at the end of S_k if $\ell_k < \ell_s$, when $\ell_k \neq \ell_s$.
2. Compute the new string $E = S_s \oplus S_1 \oplus S_2 \oplus ... \oplus S_N$.
3. Divide E into N segments $E_1, E_2, ..., E_N$ as *shares*.

Stage 2. Generating authentication signals from the contents of the shares and the camouflage programs.

4. Generate an authentication signal A_k for each camouflage program P_k, $k = 1, 2, ..., N$, using the data of S_k and E_k as follows.
   4.1 Regarding S_k as a sequence of 8-bit integers with each character in S_k composed of 8 bits, compute the sum of the integers, take the modulo-Y value of the sum as A_{S_k}, transform A_{S_k} into a binary number, and adjust its length to be ℓ_Y, the length of the key Y, by padding leading 0's if necessary.
   4.2 Do the same to E_k to obtain a binary number A_{E_k} with length ℓ_Y, too.
   4.3 Concatenate A_{S_k} and A_{E_k} to form a new binary number A_k with length $2\ell_Y$ as the authentication signal of P_k.

Stage 3. Encoding and hiding the share data and authentication signals.

5. For each camouflage program P_k, $k = 1, 2, ..., N$, perform the following tasks.
   5.1 Concatenate the share E_k and the authentication signal A_k as a binary string F_k.
   5.2 Encode every bit pair of F_k into an invisible ASCII control code according to the invisible coding table (Table 2), resulting in a code string F_k'.
   5.3 Count the number m of characters in all the comments of P_k.
   5.4 Divide F_k' evenly into m segments, and hide them in order into P_k, with each segment hidden to the right of a character in the comments of P_k.
6. Take the final camouflage programs $P_1', P_2', ..., P_N'$ as the output stego-programs.

In Step 3, we assume that the number of characters in the secret program is a multiple of N, the number of participants, for simplicity of algorithm description; if not, it can be made so by appending a sufficient number of blank spaces at the end of the original secret program. In Steps 4.1 and 4.2, the purpose we compute the signals A_{S_k} and A_{E_k} from the contents of the camouflage program P_k and the share E_k, respectively, for use in generating the authentication signal A_k is to prevent any participant from intentionally or accidentally changing the contents of the original camouflage program or the hidden share; illegal tampering with them will be found out in the process of secret program recovery described in the next section. It is also noted that each stego-program yielded by the algorithm still can be compiled and executed to perform the function of the original camouflage program.

4. SECRET PROGRAM RECOVERY SCHEME

A sketch of the proposed process for recovering the secret source program is described as follows, for which it is assumed that the stego-program brought to the recovery activity by participant k is denoted as P_k'. Also, the original key with value Y used in Algorithm 1 is provided.

(1) *Extracting hidden shares and authentication signals* --- Scan the comments of each stego-program P_k' to collect the invisible ASCII control codes hidden in them and concatenate the codes as a character string; decode the string into a binary one by the invisible character coding table (Table 2); and divide the string into two parts, the share data E_k and the authentication signal A_k. Also, remove the hidden codes from P_k' to get the original camouflage program P_k.

(2) *Authenticating the shares and the camouflage programs* --- Use the authentication signal A_k as well as the key Y to check the correctness of the contents of the extracted share data E_k and the camouflage program P_k by decomposing A_k into two signals and matching them with the modulo-Y values of the binary values of P_k and E_k, respectively. Issue warning messages if either or both authentications fail.

(3) *Recovering the secret program* --- Apply exclusive-OR operations to the extracted share data E_1 through E_N and the camouflage programs P_1 through P_N to reconstruct the secret program P_s.

The secret program recovery process is described as a detailed algorithm in the following.

Algorithm 2. Authentication of the stego-programs and recovery of the secret program.

Input: N stego-programs P_1', P_2', ..., P_N' provided by the N participants and the secret key Y with length ℓ_Y used in secret program sharing (Algorithm 1).

Output: the secret program P_s hidden in the N stego-programs if the shares and the camouflage programs in the stego-programs are authenticated to be correct.

Steps:

Stage I. extracting hidden shares and authentication signals.

1. For each stego-program P_k', k = 1, 2, ..., N, perform the following tasks to get the contents of the camouflage programs and the authentication signals.
   - 1.1 Scan the comments in P_k' line by line, and collect the invisible ASCII codes located to the right of the comment characters as a character string F_k'.
   - 1.2 Remove all the collected characters of F_k' from P_k', resulting in a program P_k with length ℓ_k, which presumably is the original camouflage program.
   - 1.3 Decode the characters in F_k' using the invisible character coding table (Table 2) into a sequence of bit pairs, denoted as F_k.
   - 1.4 Regarding F_k as a binary string, divide it into two segments E_k and A_k with the length of the latter being fixed to be $2\ell_Y$, which presumably are the hidden share and the authentication signal, respectively.
   - 1.5 Divide A_k into two equal-lengthed binary numbers A_{S_k} and A_{E_k}.

Stage II. Authenticating share data and camouflage programs.

2. Concatenate all E_k, k =1, 2, ..., N, in order, resulting in a string E with length ℓ_E which presumably equals ℓ_s, the length of the secret program to be recovered.
3. For each k = 1, 2, ..., N, perform the following authentication operations.
   - 3.1 Create a character string S_k of length ℓ_E from the characters in P_k either by discarding extra characters in P_k if $\ell_k > \ell_E$ or by repeating the characters of P_k at the end of S_k if $\ell_k < \ell_E$, when $\ell_k \neq \ell_E$.
   - 3.2 Regarding S_k as a sequence of 8-bit integers with each character in S_k composed of 8 bits, compute the sum of the integers, take the modulo-Y value of the sum as A_{S_k}', transform A_{S_k}' into a binary number, and adjust its length to be ℓ_Y, the length of the key Y, by padding leading 0's if necessary.
   - 3.3 Do the same to E_k, resulting in a binary number A_{E_k}'.
   - 3.4 Compare A_{S_k}' with the previously extracted A_{S_k}; if mismatching, issue the message "the camouflage program is not genuine," and stop the algorithm.
   - 3.5 Compare A_{E_k}' with the previously extracted A_{E_k}; if mismatching, issue the message "the share data have been changed," and stop the algorithm.

Stage III. Recovering the secret program.

4. Compute $S_s = E \oplus S_1 \oplus S_2 \oplus ... \oplus S_N$, and regard it as a character string.
5. Use the ASCII codes 0D and 0A ("carriage return" and "line feed") in S_s as separators, break S_s into program lines to reconstruct the original secret program P_s as output.

Note that in Step 4 above, we conduct the exclusive-OR operations of $E \oplus S_1 \oplus S_2 \oplus ... \oplus S_N$. This will indeed result in the desired S_s because E was computed as $E = S_s \oplus S_1 \oplus S_2 \oplus ... \oplus S_N$ in Step 2 of Algorithm 1, and so

$$
\begin{aligned}
&E \oplus S_1 \oplus S_2 \oplus ... \oplus S_N \\
&= (S_s \oplus S_1 \oplus S_2 \oplus ... \oplus S_N) \oplus S_1 \oplus S_2 \oplus ... \oplus S_N \\
&= S_s \oplus (S_1 \oplus S_1) \oplus ... \oplus (S_N \oplus S_N) \\
&= S_s \oplus \mathbf{0} \oplus \mathbf{0} \oplus ... \oplus \mathbf{0} \\
&= S_s
\end{aligned}
$$

by the commutative and associative laws of the exclusive-OR operation and the facts that $X \oplus X = 0$ and $X \oplus 0 = X$ for any bit X, where the bold character **0** is used to represent 8 consecutive bits of zero, i.e., **0** = 00000000.

5. DISCUSSIONS ON SECURITY PROTECTION

In the previous discussions, we assume that the proposed algorithms of secret sharing and recovery (Algorithms 1 and 2) are known to the public, and that the key Y is held by a supervisor other than any of the N participants. The key is provided by the supervisor as an input to the secret program sharing and recovery processes described by Algorithms 1 and 2; it is not available to any participant. Under these assumptions and by Algorithm 2 above, if any participant changes the content of the camouflage program or that of the share contained in the stego-program which he/she holds before the secret program recovery process, such illegal tampering will be found out and warnings issued during the recovery process.

However, there still exists in the two algorithms another kind of weakness in security protection of the secret program. That is, the secret program may be recovered illegally if *all* the stego-programs are stolen by a person who knows the algorithms, because then he/she may run Algorithm 2 to extract the secret program without performing Step 3, as can be figured out!

One way to remove this weakness is to use the secret key to randomize the result of $E = S_s \oplus S_1 \oplus S_2 \oplus ... \oplus S_N$ computed in Step 2 in Algorithm 1 before E is divided into shares in the next step. We implement this by letting the secret key Y join the exclusive-OR operation of Step 2 after expanding Y repeatedly to have a length equal to that of the secret program S_s. That is, in Step 2 of Algorithm 1 we repeat the key Y's and concatenate them until the length of the expanded key Y' in the unit of character (8 bits for a character) is equal to ℓ_s, the length of S_s, and then compute E instead as $E = S_s \oplus S_1 \oplus S_2 \oplus ... \oplus S_N \oplus Y'$. Correspondingly, in Step 4 of Algorithm 2 we expand Y similarly to get Y', and then compute S_s instead as $S_s = E \oplus S_1 \oplus S_2 \oplus ... \oplus S_N \oplus Y'$. The properties of the exclusive-OR operation assure that the S_s so computed is the desired secret program in its string form. In this way, without the key Y, S_s obviously cannot be recovered, and so the previously-mentioned weakness is removed.

6. EXPERIMENTAL RESULTS

In one of our experiments, we applied the proposed schemes described previously to share a secret program among three

participants. The main part of the secret program seen in the window of the Microsoft VC^{++} editor is shown in Fig. 2(a), which has the function of generating a secret key from an input seed. And part of one of the three camouflage programs is shown in Fig. 2(b). After hiding the shares and the authentication signals in the comments of each camouflage programs, the stego-program resulting from Fig. 2(b) appears to be the upper part of Fig. 2(c) which is not different from that of Fig. 2(b). The real content of the stego-program seen in the window of the UltraEdit 32 editor is shown in the lower part of Fig. 2(c) which includes the ASCII codes representing the program on the left and the appearance of the codes as characters on the right. The recovered secret program is shown in Fig. 2(d), which is identical to that shown in Fig. 2(a).

We also tested the case of recovery with one of the stego-images (the second one) being damaged, as shown in Fig. 3(a). The proposed scheme issued a warning message, as shown in Fig. 3(b).

7. CONCLUSION

For the purpose of protecting software programs, new techniques for sharing secret source programs and authentication of resulting stego-programs using four special ASCII control codes invisible in the window of the Microsoft VC^{++} editor have been proposed. The proposed sharing scheme divides the result of exclusive-ORing the contents of the secret program and a group of camouflage programs into shares, each of which is then encoded into a sequence of invisible ASCII control codes before being embedded into the comments of the corresponding camouflage program. The resulting stego-programs are kept by the participants of the sharing process. The original function of each camouflage program is not destroyed in the corresponding stego-program. The sharing of the secret program and the invisibility of the special ASCII codes as share data provides two-fold security protection of the secret program.

In the secret program recovery process, the reversibility property of the exclusive-OR operation is adopted to recover the secret program using the share data extracted from the stego-programs. To enhance security of keeping the camouflage programs, a secret random key is adopted to verify, during the recovery process, possible incidental or intentional tampering with the hidden share and the camouflage program content in each stego-program. The key is also utilized to prevent unauthorized recovery of the secret program by illegal collection of all the stego-programs and unauthorized execution of part of the proposed algorithms.

Experimental results have shown the feasibility of the proposed method. Future research may be directed to applying the invisible ASCII control codes to other applications, such as watermarking of software programs for copyright protection, secret hiding in software programs for covert communication, authentication of software program correctness, and so on.

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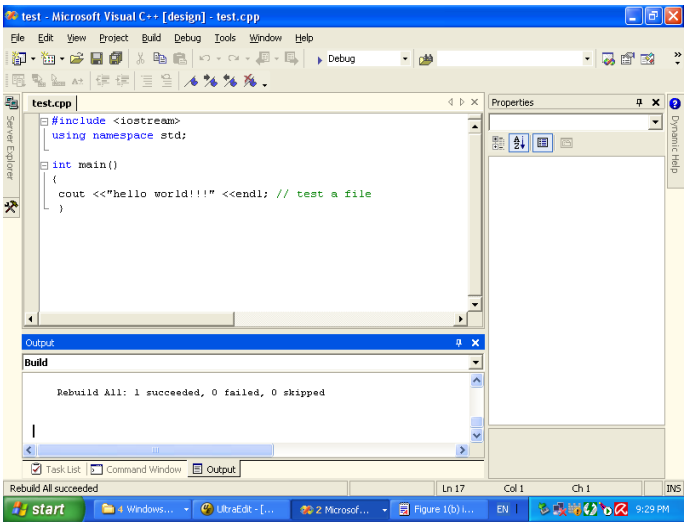
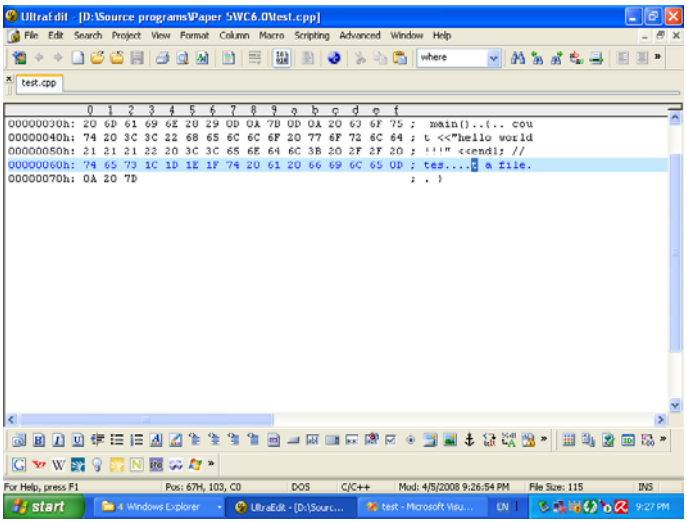
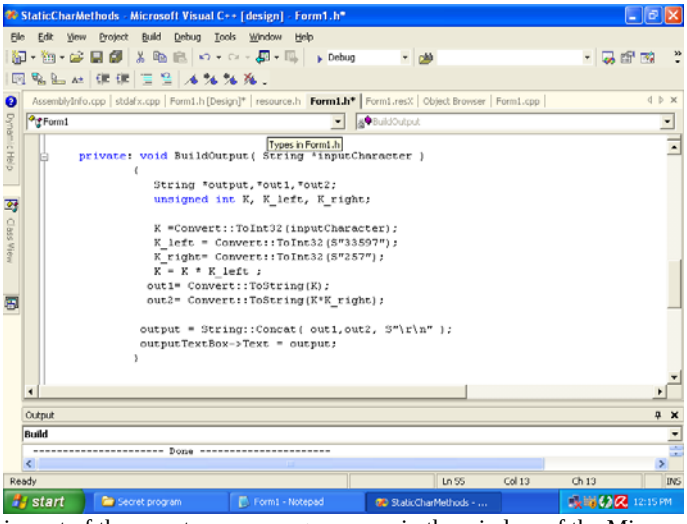


(a) A source program with four invisible ASCII control codes inserted in the comment "test a file."



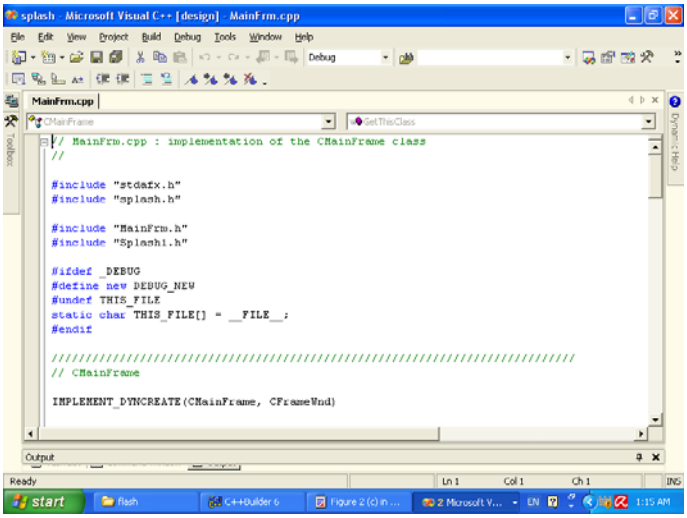
(b) The program seen in the window of the text editor UltraEdit with the four ASCII control codes visible between the letters "s" and "t" of the word "test" in the comment.

Fig. 1 Illustration of invisible ASCII control codes in a comment of a source program.

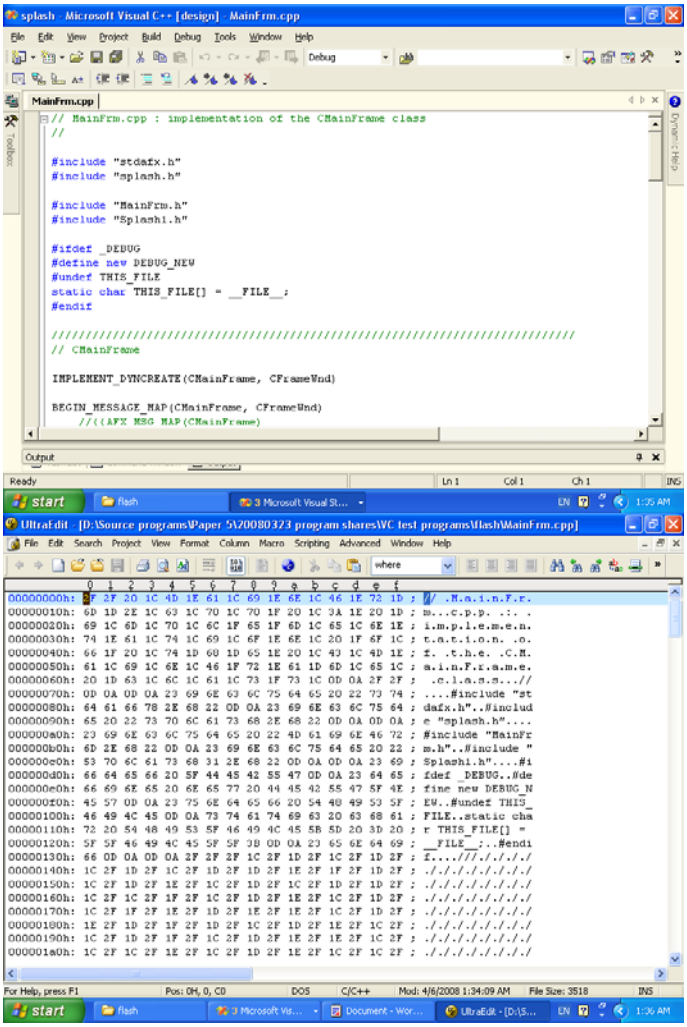


(a) Main part of the secret source program seen in the window of the Microsoft VC^{++} editor.

Fig. 2 Experimental results of sharing a secret program.

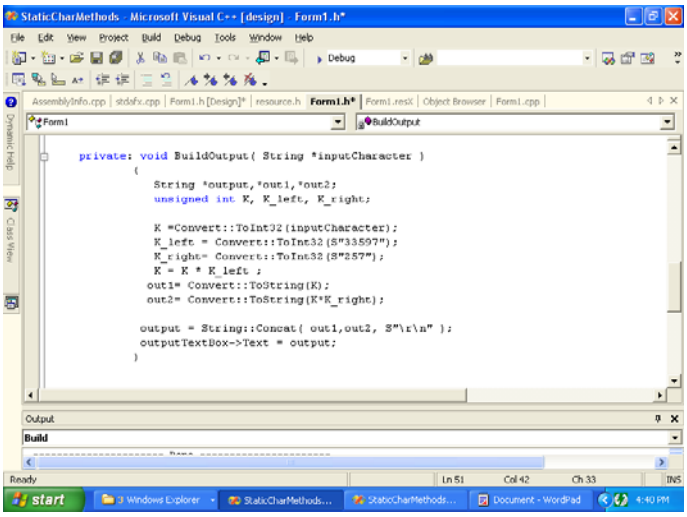


(b) Part of one camouflage program seen in the window of Microsoft Visual C^{++} editor.



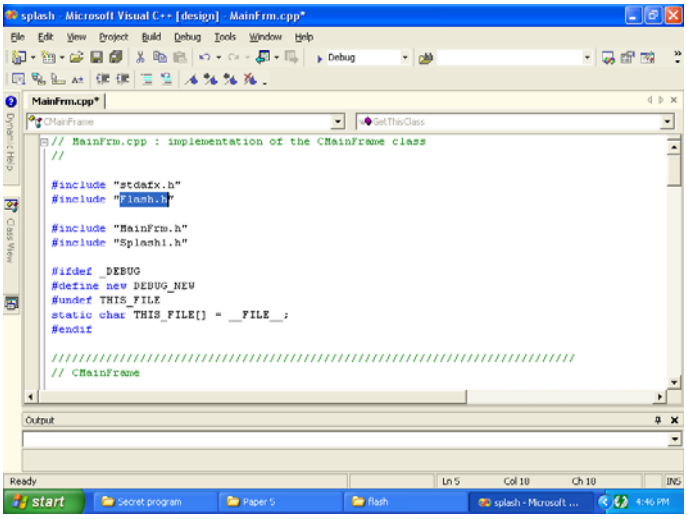
(c) The stego-program resulting from (b) seen in the window of Microsoft Visual C^{++} editor (upper part) and UltraEditor 32 editor (lower part).

Fig. 2 Experimental results of sharing a secret program (continued).

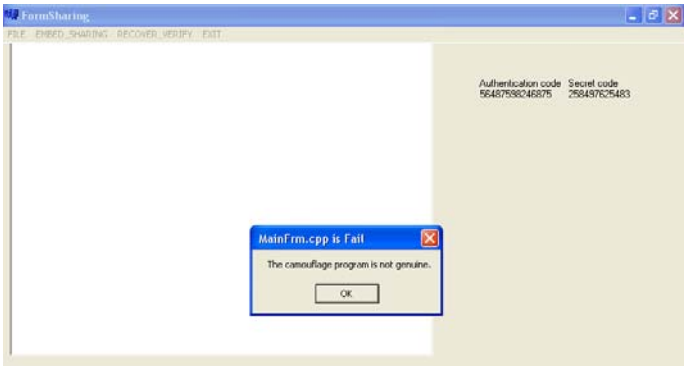


(d) Recovered secret program seen in the window of Microsoft Visual C^{++} editor.

Fig. 2 Experimental results of sharing a secret program (continued).



(a) Destructed stego-program of Fig. 2(b) seen in the window of Microsoft Visual C^{++} editor (the changed characters are highlighted).



(b) A message showing the content of the original camouflage program has been changed.

Fig. 3 An experimental result of authenticating a destructed stego-program (continued).