行政院國家科學委員會專題研究計畫 成果報告

老舊影片之雜訊偵測及修補
研究成果報告(精簡版)

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行政院國家科學委員會補助專題研究計畫 ■ **成果報告** □**期中進度報告**

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中文摘要

重建老舊影片包含兩個重要步驟：雜訊偵測及雜訊去除。經常發生於老舊影片中的雜訊有三種：斑點、長線條、或任意等。每一類雜訊各有不同特性，我們很難只透過一種方法來偵測所有狀況的雜訊，相同的，對於雜訊移除後的修補也會因週圍影像的影響而增加修補的困難度。因此，如果只單單利用空間關係想要進行修補似乎不是好的方法，勢必要加以考慮時間關係(即前後影片)才能有較好的修補結果。本計畫提出兩個於老舊影片中偵測斑點及長線條雜訊的方法，並提出一個考慮了時間關係後的影像修補演算法，此演算法可克服掉修補過程中，因先後修補所造成的錯誤。因此，由實驗結果看出，本計畫最後所得結果確實比他人結果有較好的視覺效果。

Abstract

Reconstruction on aged films contains two important processes: defect detection and defect removal. Aged films may contain different types of defects, such as spikes and scratch lines. Each type of defect has its different properties. It is relatively hard to precisely detect these defects on aged films by using only a single solution. Besides, it is relatively hard to precisely restore aged films if the continuation of image property is not considered in the temporal domain. This project proposes two techniques to detect spikes and scratch lines on aged films and we also propose a technique on restoring aged films based on simultaneously considering the outmost patches/pixels which are going to be inpainted. The inpainting order plays an important factor for human visualization. The results of defect detection have good accuracy as compared to two well-known approaches and by eliminating the inpainting order problem, the results of restored films have good quality as compared to earlier approach. Application of our technique can be used in the recovery and restoration of aged films.

目錄

研究內容

1. 前言

對於年代已久的影片中多少會有雜訊的發生，像是汙點雜訊或直線雜訊等。而每一種類雜訊都具有不同的特性，所以很難只利用單一方法修復任何類型的雜訊。因此，本研究提出以動量估測與影像處理之相關技術為基礎，針對於汙點雜訊以及直線雜訊之修復方法，並應用在實際的例子驗證方法的可行性。

2. 研究目的

在一般的老舊(黑白)影片中可能會存在許多缺陷，這些雜訊是會影響到老舊影片品質的重要關鍵因素。普遍來說，老舊影片的缺陷可以為四種類型。第一種缺陷是影片亮度的不穩定，這類型雜訊可以透過正規化影片的平均亮度方式來穩定影片亮度性。第二種缺陷主要是發生在拍攝影片時所產生的晃動情況，對於影片的晃動可以透過光流法與修補技術來維持畫面的穩定性。第三種缺陷是隨機的汙點雜訊，這種汙點類型的雜訊是以較明亮或較灰暗的亮度出現在畫面上。汙點雜訊一般是因為空氣中的灰塵或是膠捲變質造成的，因此出現時間是很短暫的(例如一到二張影格)。由上述特性的描述可知，這一類型雜訊可以利用時間上的性質(temporal)與像素的屬性來偵測汙點雜訊[4]。最後的缺陷類型是直線雜訊，產生原因是由於在放映時機器對於膠捲所產生傷害，因此可以看到直線雜訊出現在畫面有數分鐘的時間，且一般會以很長的直線線段出現在畫面上，甚至會同等畫面的高度一樣長。對於直線雜訊可以經由空間與時間的連續性分析與偵測。在空間資訊是以在單張影像上所可取得的資訊進行分析，像是亮度、形狀等。時間資訊主要是直線雜訊在連續影格中的軌跡來進行分析[6]。在修補方面，本研究提出受損區域上由外部向內部修補，在每一階段的修補都會參考到周圍可利用的資訊，並會維持與周圍像素的關連性，因此在修補出來的結果在會看起來很平順、自然。

本研究主要的貢獻是在本報告的第三部份，在研究方法中將提出雜訊的偵測與修補的方法。在第四部份，實驗結果是以實際的例子來驗證方法的可行性。最後部份是本研究的結論。

3. 研究方法

參考國內外之相關研究，規劃出雜訊修補之流程(圖 1)。首先，對於輸入的影片會進行”雜訊偵測”程序，本研究將對於常見之類型”汙點雜訊”與”直線雜訊”進行偵測。接下來在”雜訊修補”程序，是將從前一個程序所偵測到的不同類型之雜訊進行修補，最後將結果以影片的方式輸出。

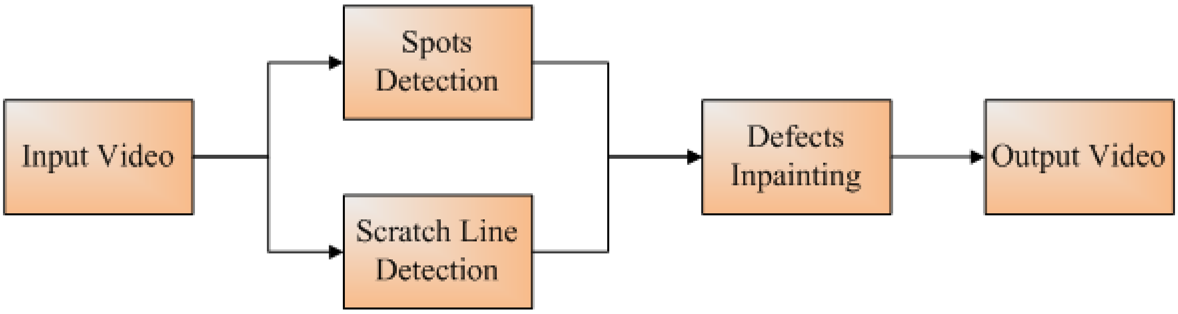


圖 1，雜訊修補流程

■ 雜訊偵測

➢ 汙點雜訊偵測

在觀察許多老舊影片後，針對汙點雜訊可以規納出以下幾點特性(1)在影片中出現的時間很短暫(一到兩張影格，圖 2所示)(2)每次以隨機性的方式出現不同的位置上，非固定(3)一般是以明亮的或深暗的點方式出現。動量估測技術可以用來對於影片中畫面或特定物體的進行位移的估測，依據於在前面有提到汙點雜訊存在於影片中的時間很短暫，因此可以利用動量估測偵測物體技術以反向思考方式來偵測物件消失情況。以下是汙點雜訊偵測之流程圖(圖 3)。

圖 2，連續的影格(像)

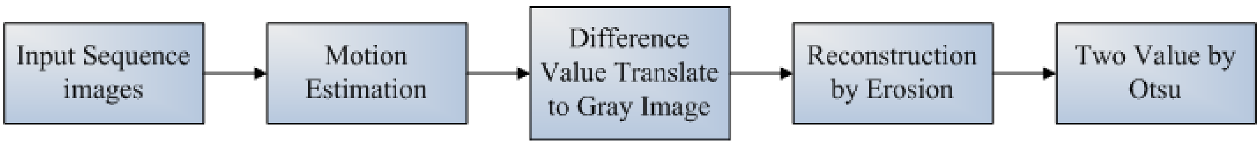


圖 3，汙點雜訊偵測流程

在動量估測程序中，每一張影格以 n*n 區塊大小(在實驗中是設定為 3*3 像素)進行切割，接下來對於每一個區塊進行 Circular Zones Search[7]搜尋演算法。在此演算法中，對於每個要搜尋之區塊視為搜尋範圍中心，由圓的中心每次增加固定位移量向外漸進方式搜尋，在每次搜尋中會評估所搜尋之區塊與中心區塊之間的相似度 MAE(Mean Absolute brightness Error)。假如相似計算 MAE 值低於門檻，表示該搜尋區塊與中心區塊很相似。當計算出 MAE 值高於門檻，即表示該區塊無法在下一張影像中搜尋到相似的區塊。

對於每兩張影格之間所計算出的MAE值轉換成灰階影像，如圖 4(a)所示。對於會消失的部份(Ex.汙點雜訊)相對於周圍MAE還高，因此可以在圖 4 (a)中看出較消失的部份在灰階影像中會相較於周圍顯著。除了消失的汙點雜訊外，在背景也存有其它雜訊資訊，為了去除這一類雜訊，引用了形態影像學Reconstruction by erosion的方法(公式一)。

$$R_g^*(f) = \varepsilon_g^{(i)}(f) \qquad \text{(公式一)}$$

在公式一中，f和g分別表示marker與mask，ε 表示是geodesic erosion函式，在每回合i中f在g的限制下執行geodesic erosion，直到 $\varepsilon_g(i) \equiv \varepsilon_g(i+1)(f)$ 為止。在本研究中，以MAE灰階影像做為marker，MAE灰階影像外框做為mask。在經過reconstruction by erosion運算後的結果(圖 4 (b))，減去原影像(圖 4 (a))再透過顏色之轉換，最後再經由Otsu二值化方法後，則可得到最後偵測雜訊之結果(圖 4 (c))。

(a) (b) (c)

圖 4，Reconstruction by Erosion

➢ **直線雜訊偵測**

直線雜訊一般是以明亮或深暗的垂直線方式出現在影片中，由於雜訊本身是可以歸類於資料遺失這一類，因此在[2]中提出利用Luminance cross-section方式來偵測直線雜訊。另外，直線雜訊會在水平方向上，與中心位置上間距 3~10 像素距離方式在影片中移動。針對上述幾點，本研究提出利用明亮度之投影與watching windows機制進行直線雜訊之偵測。以下是直線雜訊偵測之流程圖(圖 5)。

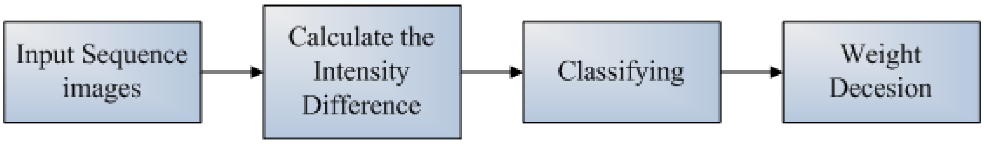


圖 5，直線雜訊偵測流程

首先對於每一影格分割出數個horizontal bands(圖 6)。對於每一個horizontal band，計算出在x軸每一個位置上的watching windows(在實驗裡windows寬度設為 21 個像素點)之亮度平均值，減去在每一個x座標位置上之亮度平均。通常直線雜訊的亮度會呈現偏暗或明亮，相對在x軸上所亮度也會相對周圍計算出的平均亮度來得低或高。因此可以經由計算在每一個x座標上的亮度與平均亮度，來呈現出雜訊與非雜訊之間的差異(圖 7)。

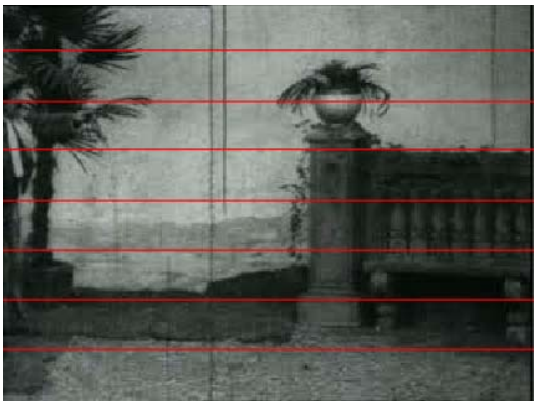


圖 6，分割影格

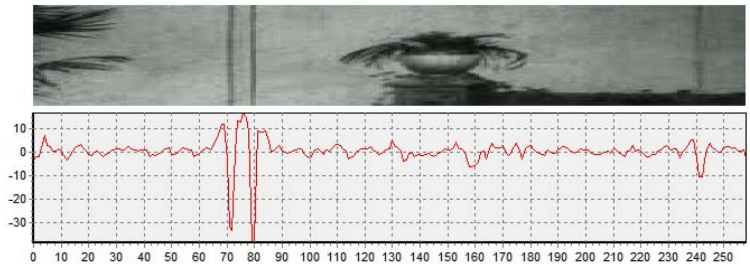


圖 7，Mean Difference

在圖 7的數據結果是各別對應到每條直線，依據公式二所列出的條件判斷及各別分類。對於這三個種類各別是”非雜訊(non-defect)”、”可能為雜訊(probable-defect)”以及”雜訊(defect)”這三類。

$$\begin{cases} \text{non}-\text{defect} & ,\text{if } |p_i - m_i| < (m_i + d_i) \\ \text{prob.}-\text{defect} & ,\text{if } |p_i - m_i| \geq (m_i + d_i) \\ \text{defect} & ,\text{if } |p_i - m_i| \geq (m_i + k * d_i) \end{cases}$$ (公式二)

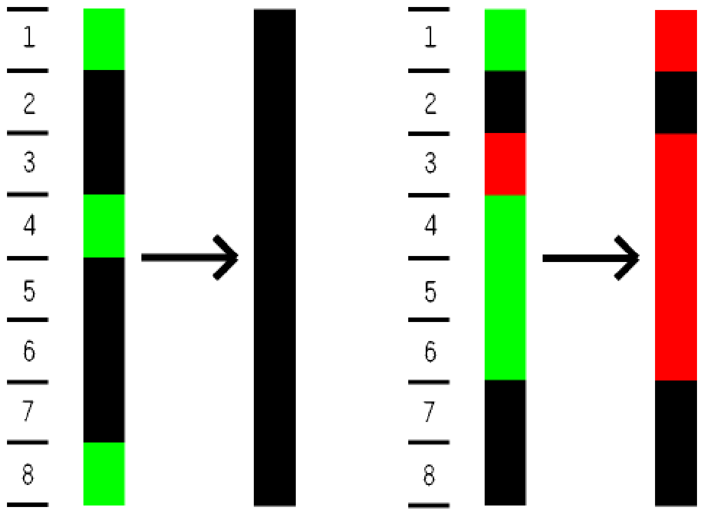
其中，p_i、m_i、d_i 各別代表在 x 軸 i 座標上的平均亮度、watching windows 平均亮度與亮度標準差，而 k 是量化參數(在實驗裡，k 的設定會依不同的例子會有適當的調整)。在本研究中假設直線雜訊大是以完整且連續的線段出現在影片中，又存在一些雜訊並與周圍並非具有很明顯的差異，而在前面已提到將每一條直線標示為三種不同的直線類型，其中”非雜訊”與”雜訊”皆已明確說明該直線是否為雜訊，剩下”可能為雜訊”是接下來要處理之對象。

對於”可能為雜訊”要判定為”雜訊”或”非雜訊”，以下提出以累計權重的方式來確定是否為”雜訊”。首先，對於先前已分類之直線各別給予不同的權重值，不同權重值各別代表著不同的雜訊之可信程度，且”雜訊”權重值必大於”可能為雜訊”權重值。累計在每一完整垂直線上所擁有的權重值，當累計的結果值大於影格水平分割數的一半，則將”可能為雜訊”重新判斷為”雜訊”。圖 8是說明判斷”可能為雜訊”是”非雜訊”或”雜訊”的例子，在圖 8中是屬於”非雜訊”之線段會標上黑色，”可能為雜訊”之線段標上綠色，”雜訊”之線段則標上紅色。

$$g = \Upsilon * \text{no. of defect} + \beta * \text{no. of probable} - \text{defect}$$

$$\begin{cases} \text{non} - \text{defect} & ,\text{if } g < \text{half number of bands} \\ \text{defect} & ,\text{otherwise} \end{cases}$$ (公式三)

在公式三，g表示垂直線上累計權重之結果。在實驗中，設定γ與β的值各為 2 和 1。因此在圖 8(a)例子中，由於g的權重總和為 3 (=2*0+1*3)小於門檻 4 (horizontal bands分割個數之一半)，因此可判斷該線為”非雜訊”。在圖 8(b)例子中， g的權重總和為 6 (=2*1+1*4)大於門檻 6，因此可判斷此線段為雜訊。



(a) (b)

圖 8，判斷”可能為雜訊”線段例子

■ 雜訊修補技術

在雜訊偵測程序是使用亮度和時間連續之特質。接著在修補程序中，為了能得到滿意的結果，本研究以地區(local)與時域(temporal)等方式來進行雜訊修補。演算法一開始，對於在先前步驟中偵測存有雜訊區域Ω之影格I，對於破損區域利用未受損區域Φ做為修補資訊。在本研究中直線雜訊存在於多張連續影像中，因此$I_i = \Phi_k \cup \Omega_i$，其中$I_i$表示在影片中第幾張影格，$\Omega_i$表示在第i張影格中偵測到的所有雜訊。可使用的修補資訊$\Phi_{k,}$，包含了連續的k張影格且$\Phi_k \cap \Omega_i \phi$(空集合)，也就是說非雜訊的區域將會用來做為修補的參考。在圖9中，$\partial\Omega_i$是在屬於Φ_i且又是圍繞Ω_i(灰色區域)的輪廓。$\partial\Omega_i$是包含n個區塊(patches)，如公式四所示。

$$\partial\Omega_i = \{p_j | p_j(x, y) \in \Phi_i,\ 1 \leqq j \leqq n\} \qquad \text{(公式四)}$$

把這些區塊(patches)依順時鐘方式排序可得到矩陣 B，B□Rn*1，R 是表示區塊的值，且區塊的大小是可以調整或者是單一像素。對於受損的區域從周圍區塊或像素依據轉換矩陣 A 的比率分配來進行修補，如公式五所示，其中 B□Rn*n，n = | $\partial\Omega$i |。

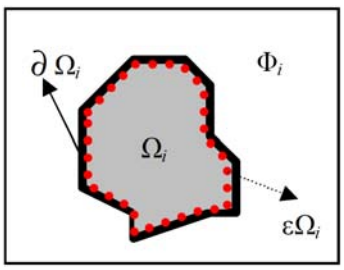


圖 9，修補區域

$$A=\begin{bmatrix} 4 & -1 & 0 & 0 & 0 & . & . & . & 0 & -1 \\ -1 & 4 & -1 & 0 & 0 & 0 & . & . & 0 & 0 \\ 0 & -1 & 4 & -1 & 0 & 0 & 0 & . & 0 & 0 \\ 0 & 0 & -1 & 4 & -1 & 0 & . & . & 0 & 0 \\ 0 & & & -1 & . & . & & & . & \\ & 0 & & & . & . & . & & & 0 \\ & & . & & & . & . & . & & \\ & & & . & & & . & . & . & \\ & & & & . & & & -1 & 4 & -1 \\ -1 & & & & & 0 & & & -1 & 4 \end{bmatrix}_{n*n}. \qquad \text{(公式五)}$$

因為矩陣 A 是一個三對角線矩陣，因此可以容易計算出逆矩陣 A^{-1}，再經由公式六，計算出受損區域應填入的數值。

$$X = A^{-1}B,\ \text{其中}\ X \in R^{n*1} \qquad \text{(公式六)}$$

矩陣B是順時針記錄著圍繞受損區域的亮度值，在經由公式六計算求出矩陣X後，依照順時針的方向把矩陣X的數值填回到受損區域 $\varepsilon\Omega_i$。圖 10是本研究提出修補演算法。

Algorithm: Video Inpainting

Input: $\forall\ 1 \le i \le frame\text{-}number$, Ω_i is separated from I_i

Output: $\forall\ 1 \le i \le frame\text{-}number$, $I'_i = \Phi_k \cup \Omega'_i$ and
$\Omega'_i \approx \psi$

For each Ω_i

  Find initial $\partial\Omega_i$, $\Omega'_i = \Omega_i$

  Repeat until $\Omega'_i \approx \psi$ (i.e., empty set)

    Compute $B \in R^{n*1}$ for $\partial\Omega_i$

    Compute $X=A^{-1}B$

    Inpaint inner contour using X

    $\Omega'_i = \Omega'_i \setminus \varepsilon\Omega_i$

end of for

圖 10，修補演算法

4. 實驗結果

本章節中將驗證在本研究中提出雜訊修補的演算法之可行性，以利用來自不同來源之影片片段做為實際測試之樣本，在經由所提出演算法來實際呈現出雜訊修復後的結果。

實驗樣本取自於不同的來源，例如圖書館、網際網路(http://www.open-video.org)、影片租出店等，而這些影片解析度是 320*240 大小，對於這些影片中存在的雜訊將會利用本研究提出的方法進行修復。在圖 11中，(a)(e)(h)是原始的影片，(b)(f)(i)是本研究提出雜訊偵測方法所得到的結果，(c)(g)(j) 是本研究提出雜訊修補方法所得到的結果。

(a)The Original Video	
(b)Defect Detection	
(c)Inpainting Result	
(e)The Original Video	
(f)Defect Detection	
(g)Inpainting Result	
(h)The Original Video	
(i)Defect Detection	
(j)Inpainting Result	

圖 11，老舊影片雜訊偵測與修補結果

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計畫成自評

在老舊影片中可能存在著不同類型的雜訊，本研究針對於汙點及直線這兩種類型雜訊修復提出了新的演算法。對於汙點雜訊利用到動量估測的方法針對在時域上的變化進行估測後，再以 reconstruction by erosion 等方法。直線雜訊偵測利用亮度差異可分類出”非雜訊”、”可能的雜訊”與”雜訊”以及權重計算等方法，經由以上的程序可明確的把存在老舊影片中的雜訊標示出來。在本研究提出不考慮在常見修補方法中注重的優先順序的方法之下，相對排除掉排列修補優先序的程序來減少整體修補時間。除此之外，在本研究中利用的影片連續的特性，可以在連續的影格中搜尋最佳的修補資訊來進行破損修補，相對在實驗結果中也得到不錯的結果。

與會心得

98 年 6 月 18 日

報告人姓名	王駿瑋	就讀系所及年級	淡江大學資訊工程系博三

與會心得：

這一次到日本，看了很多，學了很多，當然也欣賞了不少美景，適逢現在是日本櫻花盛開的季節，所以在還沒去日本前就幻想著滿滿的櫻花景像，到了當地，由於氣溫不高，又下點雨，就在我們覺得掃興之餘，除了第一天下雨外，其它天的天氣都相當不錯，我們也就可以在參加會議之餘欣賞日本櫻花美景。

在參加會議的幾天中，印像最深刻的是在 3/23 那天，在 Content-based Multimedia Information Retrieval Tools 的 Section 中，有一個日本學者在報告過程中所講的英文讓我第一次真正體驗到日本人講英文的特殊腔調，整個報告過程，幾乎沒有幾個字聽的懂，最後，在看到 Conclusion 這張投影片後，與會學者提出了一些問題(英文還講的蠻標準的)，結果，報告者竟然無法聽懂，也就在台上摸摸頭，一臉苦笑，實在尷尬。此時心情也就緊張起來，因為接下來就是我要上台報告，很怕會像這一學者的情況，就在戰戰兢兢的情況及學者提出問題下，順利的結束報告。

以前在國內參加會議，大家都是講中文，從不知道英文報告的困難，經過了這一次會議，深深知道將來參加國際會議的機會會愈來愈多，因此，加強自已的英文是跨入國際舞台的第一步，也期許自已在未來的報告中能更加順暢。

這次能來日本參加國際性會議，真的讓我受益良多，除了能讓我看到世界上其學者在電腦領域努力，知道要更加把勁在自已的岡位上盡職，以及真切體驗到英文的重要性，除此之外，也讓我見識到日本都市的繁榮，在這個城市裡，每個人都兢兢業業的克守自已的本份，即使自已只是一個工讀生也都努力扮演好自已的角色，因此，日本在二次世界大戰後能迅速的回復不是沒有原因的。希望我也能學習日本人的這份精神，盡心盡力的努力、加油。

註：請以 12 字大小繕打

參加會議經過

98 年 6 月 18 日

報告人姓名	王駿瑋	就讀系所及年級	淡江大學資訊工程系博三

參加會議經過：

此次在杭州參加由 WSEAS 主辦的 2009 國際科學與工程協會(WSEAS)國際會議，我在會議前一天即搭乘國泰航空的早班飛機前往香港，再轉機到杭州蕭山機場。由於會議在飯店舉行，很方便。而本次的旅程為 5 日 4 夜，扣掉出發與離開，在杭州的時間為 3 天，正好是會議舉行的 3 天。第 1 天除了領取註冊收據之外，還參加了 2 場 seesion，雖英文聽力沒有很好，但勉強聽得懂。第 2 天早上專心準備下午的報告，當天也就只參加這麼一場 session，第 3 天，也是這次杭州之旅的最後一天，我到了西湖走走，西湖景色幽美，令人流連忘返。隔天便搭機回到台灣。此次參與國際性的研討會，讓我體驗了杭州的國際化;此外發表論文過程順利，並獲得一些寶貴意見以供未來研究之用。

註：請以 12 字大小繕打

An Efficient Method for Copy-Move Forgery Detection

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Abstract: - This paper proposes a method for detecting copy-move forgery over images tampered by copying some regions and pasting them onto other regions. To detect those forgeries, we divide the given image into overlapping blocks, extract feature for each blocks, and sort the extracted feature vectors by radix sort. The difference (shift vector) of the coordinates of every pair of adjacent vectors in the sorting list is computed. The accumulated number of each of the shift vectors is evaluated. Finally, the medium filtering and connected component analysis are performed to obtain the detected result. Compared with other methods, employing the radix sort makes the detection much more efficient without degradation of detection quality.

Key-Words: - forgery detection, copy-move, radix sort, connected component analysis, medium filtering.

1 Introduction

With the development of Internet and image processing techniques, images can be easily acquired through internet and tampered using some commonly available software, such as Photoshop and Photoimpact. As shown in Fig. 1, the forged image "*Fonda Speak To Veitnam Veterans At Anti-War Rally*" in Fig. 1(a) was synthesized using the images shown in Fig.s 1(b) and 1(c). For protecting the copyright and preventing forgery with a bad intention, methods for forgery detection have become more and more important.

Recently, many methods for detecting forged images have been proposed. Popescu [8] detected forgeries with linear interpolation, scaling or rotation based on the relationship between each pixel and its neighbors. Nillius et al. [2] and Johnson et al. [7] used light source consistency to detect forged images. Li et al. [10] detected tampered watermarked images with the embedded information and then recover the images.

Defects of cameras such as chromatic aberration and sensor pattern noise, and the color filter arrays the cameras use for interpolating colors can be used to detect forgeries [4][9][12]. Copy-move images are easily made by copying certain regions and pasting them on some other regions. The existing methods [1][5][6][11] for detecting such kind of forgeries are all time- consuming. In this paper, we shall propose a simple and fast method to detect copy-move forgeries. Compared with other methods, our algorithm is more efficient without degradation of detection rates. The rest of this paper is organized as follows. Related work is discussed in Section 2. In section 3, the proposed method is described in details. In Sections 4 and 5, we show some experimental results and make a conclusion for this paper.

(a) (b) (c)

Fig. 1 (a). A synthesized image "*Fonda Speak To Veitnam Veterans At Anti-War Rally*", (b)&(c). original images.

2 Related Work

In most methods of copy-move forgery detection, the detected image is divided into overlapping blocks, which are then represented as vectors, which are then lexicographically sorted for later detection. Suppose a detected image of size $N \times N$ is divided into $(N-b+1)^2$ overlapping blocks of size $b \times b$, which are represented as vectors of b^2 dimension, and sorted in a lexicographical order. Vectors corresponding to blocks of similar content would be close to each other in the list, so that identical regions could be easily detected. The image given in Figure 2(a) was tampered by copy-move forgery, as shown in Figure 2(b), in which block B_1, B_2, and block B_3 are copies of blocks A_1, A_2, and block A_3, respectively, and thus $V_{A1} = V_{B1}$, $V_{A2} = V_{B2}$, and $V_{A3} = V_{B3}$, where V_X denotes the vector corresponding to block X. As shown in Figure 2(c), identical vectors are adjacent in the sorted list, from which the copy-move regions could be easily detected. In the previously mentioned methods, the vectors were sorted by the lexicographical sort, which took $O(k \lg k)$ time to sort on each entry in the vectors, where $k = (N-b+1)^2$. The time complexity of lexicographical sorting on theses vectors is $O(b^2 k \lg k)$ when the vectors are of b^2. Farid et al. [6] reduced the time complexity to $O(32 \times k \lg k)$ by using PCA (principle component analysis).

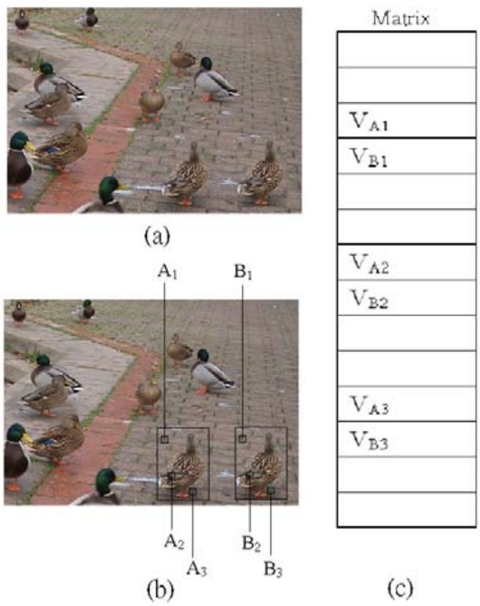


Fig. 2 (a). An original image, (b). Three pairs of identical blocks are marked by squares, (c). feature vectors corresponding to the divided blocks are sorting in a list.

The time complexity of the method proposed by G. Li et al. [1] was reduced to $O(8 \times k \lg k)$ by using SVD. W. Luo et al. [11] defined a feature vector of 7-dimension to represent blocks so as the time complexity is reduced to $O(7 \times k \lg k)$. In this paper, we shall propose a further efficient method for copy-move forgery detection.

3 The Propose Method

For resistance against various modifications and improving the sorting time, we represent each block B by a 9-dimensional feature vector $v_B = (x_1, x_2, \ldots, x_9)$, which is defined as follows. Firstly, the block B is divided into four equal-sized sub-blocks, S_1, S_2, S_3, and S_4, as shown in Fig. 3 and let *Ave*(.) denote the average intensity function. Then as described in (1), f_1 denotes the average intensity of the block B, the entries f_2, f_3, f_4, and f_5 denote the ratios of the average intensities of the blocks S_1, S_2, S_3, and S_4 to f_1, respectively, and f_6, f_7, f_8, and f_9 stand for the differences of the average intensities of the blocks S_1, S_2, S_3, and S_4 from f_1, respectively. Finally, entries f_i's are normalized to integers x_i's ranging from 0 to 255, as described in (2). Although these 9 entities contain duplicated information, they together possess higher capability for modification resistance, such as JPEG compression and Gaussian noise.

S_1	S_2
S_3	S_4

Fig. 3 A block is divided into four equal-sized sub-blocks.

$$f_i = \begin{cases} f_i = Ave(S) & \text{if } i = 1, \\ Ave(S_{i-1}) / (4\,Ave(S) + \varepsilon_1) & \text{if } 2 \le i \le 5, \\ f_i = Ave(S_{i-5}) - Ave(S) & \text{if } 6 \le i \le 9. \end{cases} \quad (1)$$

$$x_i = \begin{cases} \lfloor f_i \rfloor & \text{if } i = 1, \\ \lfloor 255 \times f_i \rfloor & \text{if } 2 \le i \le 5, \\ \left\lfloor 255 \times \dfrac{f_i - m_2}{m_1 - m_2 + \varepsilon_2} \right\rfloor & \text{if } 6 \le i \le 9, \end{cases} \quad (2)$$

where $m_1 = \max_{6 \le i \le 9} \{f_i\}$ and $m_2 = \min_{6 \le i \le 9} \{f_i\}$.

Unlike the matrix constructed by Farid et al. [6], which stores floating numbers (the PCA coefficients), the feature vectors we extract store integers. As a result, we may use the efficient radix sort algorithm to perform lexicographical sorting over those vectors. If the given image of size $N \times N$ is divided into overlapping blocks of size $b \times b$, then there are totally k blocks, where $k = (N-b+1)^2$. Let $v_1, v_2, \ldots, v_k$ be the feature vectors corresponding to these k blocks. To perform radix sort on these vectors of 9 dimensions, we regard each of them as a 9-digit number with each digit ranging from 0 to 255. The sorting algorithm is given in the following, where the input array A stores these vectors; that is, $A[i] = v_i, 1 \le i \le k$, and $d = 9$.

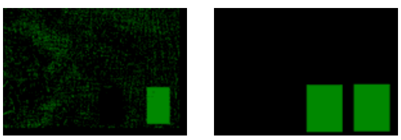
RADIX-SORT(A,d)
  for $i \leftarrow 1$ **to** d
    do use a stable sort to sort array A on digit i

Since each digit is in the range 0 to 255, which is not large, counting sort is chosen as the stable sort used in our radix sort. Each pass over k numbers then takes time O(256+k). There are 9 passes, so the total time for sorting the feature vectors is O(9(256+k)) = O(9k) since 256 << k.

The position of the top-left corner point of each block B is recorded in $P(v_B)$ for later use. From the sorted list of the feature vectors, we detect the copy-move regions by examining the accumulated number of each shift vector. A shift vector is defined as the difference of two adjacent feature vectors in the sorted list as shown in (3).

$$u(i) = P(v_{i+1}) - P(v_i) \tag{3}$$

For the number of a shift vector greater than a given threshold T_1, the top-left points of all the corresponding blocks are marked. For example, if the accumulated number of a shift vector u_0 is greater than T_1, then for each i, the top-left points of the respective blocks corresponding to v_i and v_{i+1} are marked if $u(i) = u_0$. Fig. 4(a) shows the result of marked points for Fig. 2(b). To reduce the false alarms, we delete the shift vectors with a small accumulated amount (less than a threshold T_2). Finally, the medium filtering is performed to remove noises and the connected component analysis is applied to obtain the final detected result as given in Fig. 4(b)



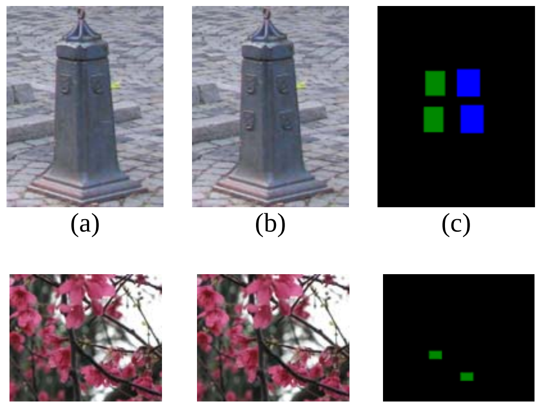
(a) (b)

Fig. 4 (a). Corner points of some blocks are marked according to the accumulated numbers of shift vectors for the tampered image given in Fig. 2(b), (b). final detected result.

4 The Experimental Results

The proposed method was implemented on a computer of CPU 3.0GHz with memory 1GB. The test images were cropped from 50 natural images. We tested over 50 tampered images, 150 compressed tampered images, and 150 tampered images with Gaussian noise. For detecting on color images, only the green channel is used since the human eyes are most sensitive to the green color. For parameter setting, we set b = 16, T_1 = 100, and T_2 = 10.

More detected results over tampered images are shown in Fig. 5. Fig. 6 shows the detected results over compressed tampered images with various quality factors. Fig. 7 shows the detected results over some images with Gaussian noise at various SNRs (signal to noise ratios). Detection rates for some datasets of copy-move images under various modifications are shown in Table 1.



(a) (b) (c)

(d) (e) (f)

Fig. 5 Detected results over tampered images: (a) & (d). original images, (b) & (e). tampered images, (c) & (f). detected results.

(a) (b) (c)

Fig. 6 Detected results over compressed versions of the image given in Fig. (2a), with various quality factors (QFs): (a). QF = 90, (b). QF = 70, (c). QF = 50.

(a) (b) (c)

Fig. 7 Detected results for the image given in Fig. (2a) with Gaussian noise at various SNRs: (a). SNR=10db, (b). SNR=20db, (c). SNR=35db.

Data sets of Copy-move images	No. of images	Detection rate (%)
without midification	50	98
JPEG compression QF = 100	50	98
JPEG compression QF = 90	50	98
JPEG compression QF = 80	50	96
Gaussian noise SNR = 10	50	98
Gaussian noise SNR = 20	50	98
Gaussian noise SNR = 35	50	94

Table 1 Detection rates for datasets of copy-move images.

4 Conclusion

In this paper, we propose an efficient method for copy-move forgery detection. Using of radix sort dramatically improves the time complexity and the adopted features enhance the capability of resisting of various attacks such as JPEG compression and Gaussian noise. Both efficiency and high detection rates have been demonstrated in our experimental results. However, a few small copied regions were not successfully detected. In the future, we would like to extend our work to video images.

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與會心得

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參加會議經過

98 年 6 月 18 日

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參加會議經過：

此次在杭州參加由 WSEAS 主辦的 2009 國際科學與工程協會(WSEAS)國際會議，我在會議前一天即搭乘國泰航空的早班飛機前往香港，再轉機到杭州蕭山機場。由於會議在飯店舉行，很方便。而本次的旅程為 5 日 4 夜，扣掉出發與離開，在杭州的時間為 3 天，正好是會議舉行的 3 天。第 1 天除了領取註冊收據之外，還參加了 2 場 seesion，雖英文聽力沒有很好，但勉強聽得懂。第 2 天早上專心準備下午的報告，當天也就只參加這麼一場 session，第 3 天，也是這次杭州之旅的最後一天，我到了西湖走走，西湖景色幽美，令人流連忘返。隔天便搭機回到台灣。此次參與國際性的研討會，讓我體驗了杭州的國際化;此外發表論文過程順利，並獲得一些寶貴意見以供未來研究之用。

註：請以 12 字大小繕打

An Efficient Method for Copy-Move Forgery Detection

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Abstract: - This paper proposes a method for detecting copy-move forgery over images tampered by copying some regions and pasting them onto other regions. To detect those forgeries, we divide the given image into overlapping blocks, extract feature for each blocks, and sort the extracted feature vectors by radix sort. The difference (shift vector) of the coordinates of every pair of adjacent vectors in the sorting list is computed. The accumulated number of each of the shift vectors is evaluated. Finally, the medium filtering and connected component analysis are performed to obtain the detected result. Compared with other methods, employing the radix sort makes the detection much more efficient without degradation of detection quality.

Key-Words: - forgery detection, copy-move, radix sort, connected component analysis, medium filtering.

1 Introduction

With the development of Internet and image processing techniques, images can be easily acquired through internet and tampered using some commonly available software, such as Photoshop and Photoimpact. As shown in Fig. 1, the forged image "*Fonda Speak To Veitnam Veterans At Anti-War Rally*" in Fig. 1(a) was synthesized using the images shown in Fig.s 1(b) and 1(c). For protecting the copyright and preventing forgery with a bad intention, methods for forgery detection have become more and more important.

Recently, many methods for detecting forged images have been proposed. Popescu [8] detected forgeries with linear interpolation, scaling or rotation based on the relationship between each pixel and its neighbors. Nillius et al. [2] and Johnson et al. [7] used light source consistency to detect forged images. Li et al. [10] detected tampered watermarked images with the embedded information and then recover the images.

Defects of cameras such as chromatic aberration and sensor pattern noise, and the color filter arrays the cameras use for interpolating colors can be used to detect forgeries [4][9][12]. Copy-move images are easily made by copying certain regions and pasting them on some other regions. The existing methods [1][5][6][11] for detecting such kind of forgeries are all time- consuming. In this paper, we shall propose a simple and fast method to detect copy-move forgeries. Compared with other methods, our algorithm is more efficient without degradation of detection rates. The rest of this paper is organized as follows. Related work is discussed in Section 2. In section 3, the proposed method is described in details. In Sections 4 and 5, we show some experimental results and make a conclusion for this paper.

(a) (b) (c)

Fig. 1 (a). A synthesized image "*Fonda Speak To Veitnam Veterans At Anti-War Rally*", (b)&(c). original images.

2 Related Work

In most methods of copy-move forgery detection, the detected image is divided into overlapping blocks, which are then represented as vectors, which are then lexicographically sorted for later detection. Suppose a detected image of size $N \times N$ is divided into $(N-b+1)^2$ overlapping blocks of size $b \times b$, which are represented as vectors of b^2 dimension, and sorted in a lexicographical order. Vectors corresponding to blocks of similar content would be close to each other in the list, so that identical regions could be easily detected. The image given in Figure 2(a) was tampered by copy-move forgery, as shown in Figure 2(b), in which block B_1, B_2, and block B_3 are copies of blocks A_1, A_2, and block A_3, respectively, and thus $V_{A1} = V_{B1}$, $V_{A2} = V_{B2}$, and $V_{A3} = V_{B3}$, where V_X denotes the vector corresponding to block X. As shown in Figure 2(c), identical vectors are adjacent in the sorted list, from which the copy-move regions could be easily detected. In the previously mentioned methods, the vectors were sorted by the lexicographical sort, which took $O(k \lg k)$ time to sort on each entry in the vectors, where $k = (N-b+1)^2$. The time complexity of lexicographical sorting on theses vectors is $O(b^2 k \lg k)$ when the vectors are of b^2. Farid et al. [6] reduced the time complexity to $O(32 \times k \lg k)$ by using PCA (principle component analysis).

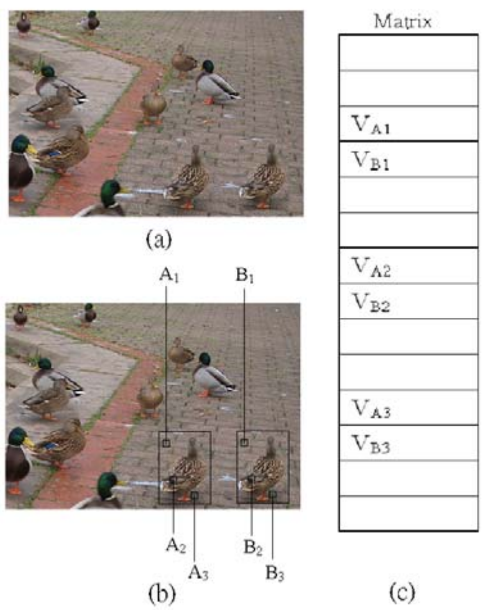


Fig. 2 (a). An original image, (b). Three pairs of identical blocks are marked by squares, (c). feature vectors corresponding to the divided blocks are sorting in a list.

The time complexity of the method proposed by G. Li et al. [1] was reduced to $O(8 \times k \lg k)$ by using SVD. W. Luo et al. [11] defined a feature vector of 7-dimension to represent blocks so as the time complexity is reduced to $O(7 \times k \lg k)$. In this paper, we shall propose a further efficient method for copy-move forgery detection.

3 The Propose Method

For resistance against various modifications and improving the sorting time, we represent each block B by a 9-dimensional feature vector $v_B = (x_1, x_2, \ldots, x_9)$, which is defined as follows. Firstly, the block B is divided into four equal-sized sub-blocks, S_1, S_2, S_3, and S_4, as shown in Fig. 3 and let *Ave*(.) denote the average intensity function. Then as described in (1), f_1 denotes the average intensity of the block B, the entries f_2, f_3, f_4, and f_5 denote the ratios of the average intensities of the blocks S_1, S_2, S_3, and S_4 to f_1, respectively, and f_6, f_7, f_8, and f_9 stand for the differences of the average intensities of the blocks S_1, S_2, S_3, and S_4 from f_1, respectively. Finally, entries f_i's are normalized to integers x_i's ranging from 0 to 255, as described in (2). Although these 9 entities contain duplicated information, they together possess higher capability for modification resistance, such as JPEG compression and Gaussian noise.

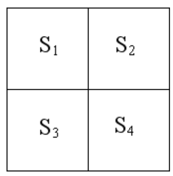


Fig. 3 A block is divided into four equal-sized sub-blocks.

$$f_i = \begin{cases} f_i = Ave(S) & \text{if } i = 1, \\ Ave(S_{i-1})/(4Ave(S) + \varepsilon_1) & \text{if } 2 \le i \le 5, \\ f_i = Ave(S_{i-5}) - Ave(S) & \text{if } 6 \le i \le 9. \end{cases} \quad (1)$$

$$x_i = \begin{cases} \lfloor f_i \rfloor & \text{if } i = 1, \\ \lfloor 255 \times f_i \rfloor & \text{if } 2 \le i \le 5, \\ \left\lfloor 255 \times \dfrac{f_i - m_2}{m_1 - m_2 + \varepsilon_2} \right\rfloor & \text{if } 6 \le i \le 9, \end{cases} \quad (2)$$

where $m_1 = \max_{6 \le i \le 9} \{f_i\}$ and $m_2 = \min_{6 \le i \le 9} \{f_i\}$.

Unlike the matrix constructed by Farid et al. [6], which stores floating numbers (the PCA coefficients), the feature vectors we extract store integers. As a result, we may use the efficient radix sort algorithm to perform lexicographical sorting over those vectors. If the given image of size $N \times N$ is divided into overlapping blocks of size $b \times b$, then there are totally k blocks, where $k = (N-b+1)^2$. Let v_1, v_2,…,v_k be the feature vectors corresponding to these k blocks. To perform radix sort on these vectors of 9 dimensions, we regard each of them as a 9-digit number with each digit ranging from 0 to 255. The sorting algorithm is given in the following, where the input array A stores these vectors; that is, $A[i] = v_i, 1 \le i \le k$, and d = 9.

RADIX-SORT(A,d)
    for $i \leftarrow 1$ **to** d
        do use a stable sort to sort array A on digit i

Since each digit is in the range 0 to 255, which is not large, counting sort is chosen as the stable sort used in our radix sort. Each pass over k numbers then takes time O(256+k). There are 9 passes, so the total time for sorting the feature vectors is O(9(256+k)) = O(9k) since 256 << k.

The position of the top-left corner point of each block B is recorded in $P(v_B)$ for later use. From the sorted list of the feature vectors, we detect the copy-move regions by examining the accumulated number of each shift vector. A shift vector is defined as the difference of two adjacent feature vectors in the sorted list as shown in (3).

$$u(i) = P(v_{i+1}) - P(v_i) \qquad (3)$$

For the number of a shift vector greater than a given threshold T_1, the top-left points of all the corresponding blocks are marked. For example, if the accumulated number of a shift vector u_0 is greater than T_1, then for each i, the top-left points of the respective blocks corresponding to v_i and v_{i+1} are marked if $u(i) = u_0$. Fig. 4(a) shows the result of marked points for Fig. 2(b). To reduce the false alarms, we delete the shift vectors with a small accumulated amount (less than a threshold T_2). Finally, the medium filtering is performed to remove noises and the connected component analysis is applied to obtain the final detected result as given in Fig. 4(b)

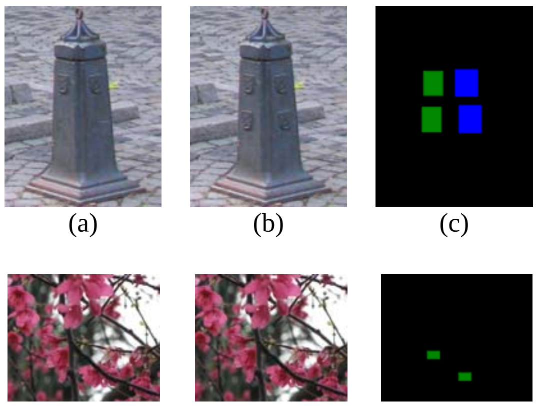
(a) (b)

Fig. 4 (a). Corner points of some blocks are marked according to the accumulated numbers of shift vectors for the tampered image given in Fig. 2(b), (b). final detected result.

4 The Experimental Results

The proposed method was implemented on a computer of CPU 3.0GHz with memory 1GB. The test images were cropped from 50 natural images. We tested over 50 tampered images, 150 compressed tampered images, and 150 tampered images with Gaussian noise. For detecting on color images, only the green channel is used since the human eyes are most sensitive to the green color. For parameter setting, we set b = 16, T_1 = 100, and T_2 = 10.

More detected results over tampered images are shown in Fig. 5. Fig. 6 shows the detected results over compressed tampered images with various quality factors. Fig. 7 shows the detected results over some images with Gaussian noise at various SNRs (signal to noise ratios). Detection rates for some datasets of copy-move images under various modifications are shown in Table 1.



(a) (b) (c)

(d) (e) (f)

Fig. 5 Detected results over tampered images: (a) & (d). original images, (b) & (e). tampered images, (c) & (f). detected results.

(a) (b) (c)

Fig. 6 Detected results over compressed versions of the image given in Fig. (2a), with various quality factors (QFs): (a). QF = 90, (b). QF = 70, (c). QF = 50.

(a) (b) (c)

Fig. 7 Detected results for the image given in Fig. (2a) with Gaussian noise at various SNRs: (a). SNR=10db, (b). SNR=20db, (c). SNR=35db.

Data sets of Copy-move images	No. of images	Detection rate (%)
without midification	50	98
JPEG compression QF = 100	50	98
JPEG compression QF = 90	50	98
JPEG compression QF = 80	50	96
Gaussian noise SNR = 10	50	98
Gaussian noise SNR = 20	50	98
Gaussian noise SNR = 35	50	94

Table 1 Detection rates for datasets of copy-move images.

4 Conclusion

In this paper, we propose an efficient method for copy-move forgery detection. Using of radix sort dramatically improves the time complexity and the adopted features enhance the capability of resisting of various attacks such as JPEG compression and Gaussian noise. Both efficiency and high detection rates have been demonstrated in our experimental results. However, a few small copied regions were not successfully detected. In the future, we would like to extend our work to video images.

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