Selective Concealment of Characters for Privacy Protection

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***Abstract*—A method of concealing characters is proposed for degrading legibility of privacy sensitive textual information in natural scene, such as car license plate numbers and name tags. An important property of the proposed method is that it realizes selective concealing of characters; that is, the proposed method degrades legibility of character regions without degrading the quality of non-character regions. This selective concealment is realized because characters have special concealment characteristics. Specifically, character legibility can be degraded by damaging stroke structure by using exemplar-based image inpainting, which does not affect non-character regions. Experimental results of qualitative and quantitative evaluations have proven that the selective concealment is practically possible. Furthermore, the quantitative evaluation through a subjective experiment revealed appropriate setups of image inpainting for maximizing selective concealment performance.**

I. Introduction

Natural images published on the Internet often infringe people's privacy, and we therefore need to conceal privacy sensitive information using some image processing. In fact, concealing sensitive information and privacy in images is an emerging hot topic [1]. Targets of the concealment are images which enable person identification, such as face [1]–[4] and entire body [4]. Other common targets are texts usable for identification, such as license plates [5] or name tags.

For concealing targets automatically, we need to realize two functions: (i) automatic target detection from the given images, and (ii) image processing of the detected part for degrading recognizability. For the first function, we can use traditional and/or state-of-the-art CV/PR techniques of target detection. For the second function, Gaussian blurring is a simple choice. Google StreetView, e.g., has employed Gaussian blurring [5]. In [2]–[4], several degradation strategies, such as blurring, blocking-out, pixelization, random sign inversion, and seam carving, are compared at their concealment performance.

Unfortunately, automatic target detection is still not perfect even by using state-of-the-art techniques and thus we have to make a trade-off between miss-detections and false alarms. For privacy preservation, we need to keep the false negatives as low as possible. This, in turn, leads to many false alarms. The false alarm regions are then degraded by, for example, blurring. Figure 1 is a snapshot from Google StreetView. As indicated by the red rectangles, several false alarm regions can be seen which are blurred unnecessarily.

[1]Recently, an IEEE journal (*IEEE Transactions on Information Forensics and Security*, vol.10, no.8, 2013) has published an special issue dedicated to "Intelligent Video Surveillance for Public Security and Personal Privacy."

The purpose of this paper is to introduce an image processing method for character concealment, which degrades character *legibility* without degrading the quality of false alarm, that is, non-character regions. To emphasize this useful property, we hereafter call the method *selective concealment*.

A clue to realize the selective concealment is the fact that characters have special concealment characteristics as follows. Figure 2 shows a digit pattern "4" with three different disturbances. Dot and line-segment noises are superimposed on "4" in (a) and (b), respectively, yet they cannot conceal the digit. These figures show that characters are designed to be robust against such additive noise disturbances. On the other hand, it is very difficult to find the "4" in Fig. 2 (c). (The crossing point indicated by an arrow is the crossing point of the hidden "4".) What sets (c) apart from (a) and (b) is that the disturbance is on the character stroke structure of "4" in

Fig. 1. A snapshot from Google StreetView.

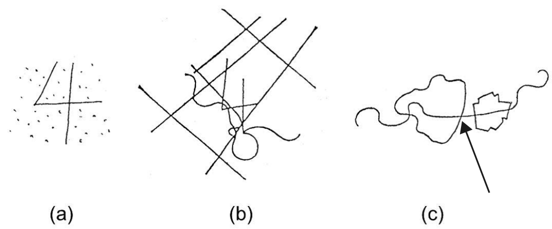

Fig. 2. Concealment characteristics of digit pattern "4". (Cited from [6] and modified.)

Fig. 3. "Guard Your ID Stamp Roller" (PLUS Corporation), which conceals privacy sensitive characters by superimposing characters.

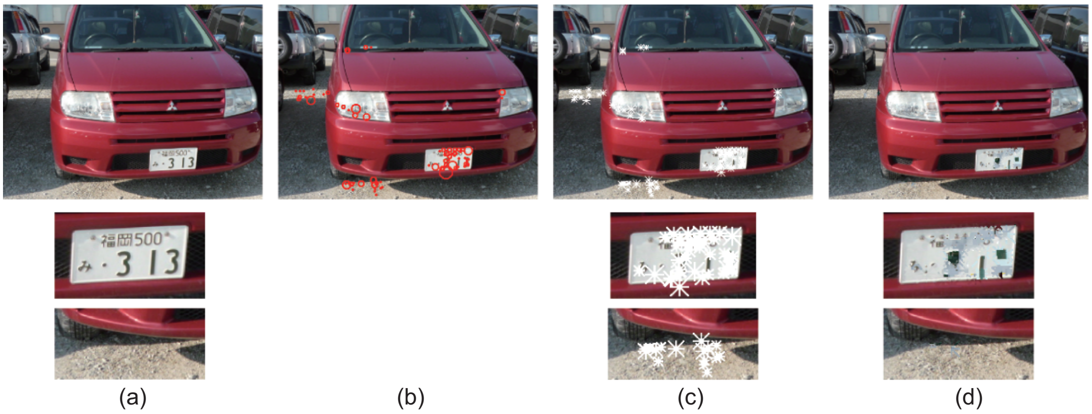

Fig. 4. The entire procedure of selective concealment. (a) Original image. (b) Detection of character candidate regions. (c) Created holes around the character candidate regions. A star-shaped hole is used here. (d) Selective concealment by image inpainting.

(c). In other words, character legibility is strongly degraded by damaging its stroke structure. Figure 3 shows a stamp to conceal privacy sensitive characters (such as address and name information on an envelope being disposed) by superimposing other character patterns.

For the selective concealment of characters, we employ an *image inpainting* technique [7], [8] in this paper. In general, image inpainting is a technique to fill missing regions, hereafter called *holes*, in an image. For example, the image inpainting technique in [8] fills each hole gradually from the outside of the hole by using similar regions in the image. We can expect a natural filled result when the hole is located in a uniform texture. (See example in Fig. 5(b).) An simple example is a regular mesh image – even if it has several holes, the original image can be recovered near-perfectly from the other region.

We can expect that image inpainting will damage the stroke structure of characters. That is, if we create artificial holes around character regions, image inpainting may not be able to recover the stroke structure of characters correctly. This is because characters are not a uniform texture and thus the recovered pattern will be different from the original pattern. As an example, consider a case where the upper part of "T" is missed. The legibility of "T" will be lost if it is recovered like an "Y" after image inpainting.

The outline of our selective concealment method based on image inpainting is as follows:

1) By using some technique, character candidate regions are detected from an input image (Figs. 4(a) and (b)). As an extreme case, we can even perform random detection, which just places the character candidate regions randomly and uniformly over the image.
2) A small hole is created at each detected region (Fig. 4(c)), by setting the pixel values in the detected region to "unknown".
3) Each hole is filled by an image inpainting technique (Fig. 4(d)).
4) We have the inpainting result where the stroke structure of characters is damaged and they will become not readable, whereas non-character regions will be recovered with their original appearance.

The contribution of this paper is threefold. First, to the authors' best knowledge, this is the first trial on concealing characters. Second, we reveal that image inpainting is effective for selective concealment, that is, for having not only sufficient concealment effect on character regions but also less side-effect on non-character regions. Third, we reveal the concealment characteristics of character patterns (i.e., the robustness of character patterns against damages on their stroke structure) through a subjective experiment on various setups of image inpainting.

Throughout the paper, we consider license plate images as the target of selective concealment of characters, unless otherwise mentioned. (Precisely speaking, we will conceal digit patterns on license plates.) Note that the proposed method will be used for concealing arbitrary characters in natural scene.

The rest of this paper is organized as follows. Section II reviews image inpainting techniques and details the entire procedure of selective character concealment. Section III reports experimental results of qualitative and quantitative evaluations of selective concealment performance. Since it is difficult to quantify the concealment performance by some objective evaluation, a subjective evaluation by multiple human subjects has been conducted. Section IV draws the conclusion and discusses future directions.

II. Selective Concealment of Characters by Image Inpainting

A. Image Inpainting Techniques

As noted before, image inpainting is a technique to fill holes in an image by using the remaining part of the image and/or other images. In this paper, image inpainting is utilized in a new way, based on the underlying assumption that inpaintings are unable to recover holes in character regions. Since characters are represented by neither some simple and uniform texture nor some simple edges, image inpainting will fail to reproduce the original entire character image from a character image with holes.

For the image inpainting techniques, two very different techniques are employed in this paper. One is a simple interpolation-based method [7] and the other is an exemplar-based method [8]. Note, that it is also possible to use other

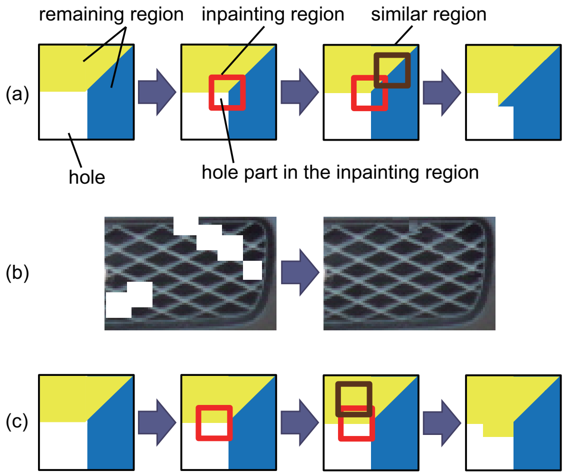

Fig. 5. Exemplar-based inpainting [8]. (a) Inpainting by finding a similar region. (b) A result of exemplar-based inpainting. (c) A failure inpainting result caused by disregarding the edge priority.

types of inpainting methods, such as texture synthesis [9], and is left for our future work.

1) Interpolation-based inpainting: The simplest image inpainting technique is image interpolation. This technique determines the pixel value of pixels in a hole by interpolating boundary pixels of the hole. From the various existing image interpolation techniques [10], we hereafter employ a popular Navier-Stokes interpolation [7]. Note that image interpolation usually produces reliable results only around boundary pixels and thus the filled result is unnatural especially when the hole is large. This is not crucial for degrading character legibility, but crucial for having reasonable recovery results in non-character regions.

2) Exemplar-based inpainting: Another more powerful inpainting technique is an exemplar-based inpainting. In [8], an exemplar-based inpainting technique has been proposed, where each hole is filled gradually from the outside of the hole by using similar regions. Figure 5 (a) illustrates the procedure of the exemplar-based inpainting. An inpainting region is first set around the hole boundary. This inpainting region should be overlapped with some undisturbed region (i.e., the non-hole region). Given this overlapped part, a similar region is then found within the remaining region. Finally copying this similar region to the inpainting region, the part of the inpainting region overlapping the hole is filled. This procedure is repeated until all hole region is filled.

The exemplar-based inpainting can fill a wider hole area than the interpolation-based inpainting. Additionally, it provides a very natural recovery result at holes in a uniform texture region. Figure 5 (b) shows an example of the exemplar-based inpainting result, where a mesh-texture is recovered almost completely.

Note that the order of the inpainting regions is important. Roughly speaking, a region with a strong edge will have a larger priority in the order. This edge priority is necessary to maintain edge direction correctly. In Fig. 5 (c), the edge between blue and yellow regions is disappeared by disregarding the edge priority.

Fig. 6. Part-based detection of characters on license plates. From left to right, an input image X, the local features extracted from X, the character candidate regions detected by using the nearest neighbor distance to the reference feature set.

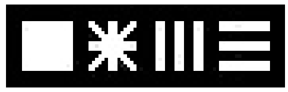

Fig. 7. Four types of hole shape.

3) An extended version of exemplar-based inpainting: For an image with holes, the original exemplar-based inpainting technique [8] uses similar regions within the same image, as shown in Fig. 5 (a). This process can be extended to use extra images; that is, for filling a hole in an image, we can use another image. For example, if we want to apply image inpainting to license plate images for hiding characters and digits on them we can use extra license plate images.

It should be noted that use of those extra images will have both of positive and negative effects. The positive effect is that we can have a larger collection of stroke parts and thus expect more confusing recovery results. The negative effect is that the risk of near-perfect recovery of the original stroke structure increases.

B. Detection of Character Candidate Regions

Before performing image inpainting, we need to create holes around character regions on the input image. Consequently, we first need to detect characters in the image. Note that character detection as well as other target detection tasks are still a difficult problem as discussed in Section I. In fact, the best f-value at the latest competition on scene character detection is reported as 76% [11].

In this paper, a simple part-based character detection method is used[2]. Before the detection, a training step is performed where SURF features $\{r_j^k\}$ are extracted from a set of manually segmented license plate images $\{R^k\}$ and then added to the reference set of license plate character features. Figure 6 shows the character candidate region detection step using this reference set. In the detection step, from an input image X, SURF features $\{x_i\}$ are extracted. Then, the nearest neighbor distance is evaluated between each SURF feature x_i and the reference set $\{r_j^k\}$. If the nearest neighbor distance is smaller than a threshold, the local area providing x_i is determined as a character candidate region.

[2]Of course, it is possible to use arbitrary license plate detection methods, such as [12]. In this paper, the part-based method is used because we do not need to detect the entire (rectangular) area of each license plate for privacy preservation. In addition, the part-based method has several merits, such as robustness against occlusion and perspective distortion. It can also reduce the false alarm rate because each individual detected region is very local. Note that a more sophisticated part-based character detection method has been proposed in [13].

Fig. 8. Results of the proposed selective concealment method with different hole shapes.

C. Design of Hole Shape and Size

A hole is created at each character candidate region detected by the above procedure. Figure 7 shows four examples of hole shape. The shape of the holes should be designed considering not only the legibility degradation, but also the image inpainting results at non-character regions. Consider for example the square hole. On the one hand, it is well suited to degrade character legibility. On the other hand, however, it will cause an unnatural inpainting result at non-character regions.

The remaining problem is how to set the size of each hole. For this problem, we utilize the fact that SURF provides scale information of the individual local part. Roughly speaking, the scale becomes larger at a larger corner in general. Consequently, we set the hole size relative to the scale by SURF since a larger character in the license plate will have a larger corner.

III. Experimental Evaluation

Two different experiments have been conducted to evaluate the performance of selective concealment; qualitative evaluation and quantitative evaluation. The qualitative evaluation explained in III-A was done to observe several concealment results on natural scene images. The quantitative evaluation explained in III-B was done to compare the concealment performance under different image inpainting setups.

A. Qualitative Evaluation of Selective Concealment

Figure 8 shows the results of selective concealment under different hole shapes. First, it is observed that non-character regions are naturally recovered by any image inpainting setup. Upon closer inspection, it is revealed that the square hole produces worse results, due to the fact that it has the widest gap out of all tested holes.

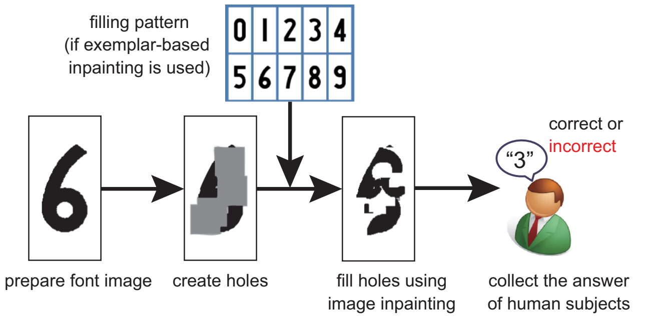

Fig. 9. Subjective evaluation of character concealment performance.

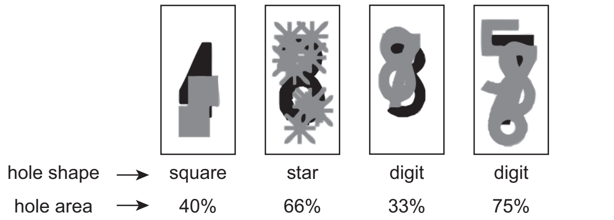

Fig. 10. Examples of digit patterns to be inpainted for the subjective experiment. Gray areas indicate holes.

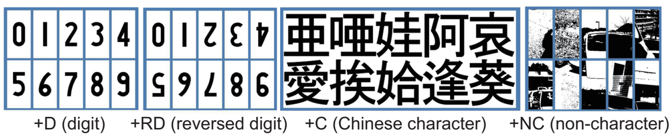

Fig. 11. Four patterns for filling holes in the exemplar-based inpainting.

Second, it can also be observed from Fig. 8 that character regions are damaged in most cases and the digit patterns lost their legibility *successfully*. Especially, the exemplar-based inpainting with extra images seems to be the most effective for losing the legibility. In contrast, from the results of the interpolation-based inpainting technique with linear hole shapes, it is sometimes possible to guess the original digit. The next section is devoted for quantifying how characters lost their legibility.

B. Quantitative Evaluation via Subjective Experiment

A quantitative evaluation of the performance of the proposed selective concealment method was conducted while focusing on how the proposed method degrades character legibility. This focus is reasonable because the qualitative evaluation in the previous section proved that the method can reproduce non-character regions by any image inpainting setup. Thus, the remaining evaluation problem is to quantify the best image inpainting setup for concealing character regions.

As shown in Fig. 9, the quantitative evaluation was done by showing inpainted digit images to 19 human subjects and evaluating whether they can provide correct answers about the original class of the inpainted digit images. If the correct answer rate is low under a specific setup of image inpainting, the setup can successfully degrade the legibility of digits. The digit images were not collected from natural camera-captured license plate images but instead generated by using digital font directly[3].

TABLE I. Correct answer rate (%) for various inpainting setups. NO: No inpaining. INT: interpolation-based inpainting. EXEM: exemplar-based inpainting. +D/+RD/+C/+NC: four patterns for filling holes in the exemplar-based inpainting. See Fig. 11.

hole shape	hole area(%)	NO	INT	EXEM +D	EXEM +RD	EXEM +C	EXEM +NC
square ■	33	97	100	93	93	93	97
	50	80	90	90	77	87	93
	66	53	77	90	50	33	57
	75	43	53	53	47	**23**	47
star *	33	100	100	100	90	100	93
	50	90	100	97	93	90	80
	66	97	100	90	73	70	80
	75	77	93	80	47	**23**	43
digit ‘0’-‘9’	33	97	100	97	93	87	90
	50	77	97	93	77	83	63
	66	63	87	77	60	47	60
	75	37	77	73	40	33	47

1) Preparation of concealed character patterns: Figure 10 shows several digit patterns to be inpainted for the subjective experiment. Gray areas indicate holes. As shown in this figure, three different hole shapes (square, star, and digit) and four different hole areas (33, 50, 66, and 75%) were used in the experiment. The hole area indicates the fraction of the black pixels in the original images that are erased to be holes. The digit-shape hole was employed for mimicking the stamp roller of Fig. 3, where characters are concealed by superimposing other characters.

The hole area was then filled by one of six image painting setups: no inpainting (“NO” in Table I), interpolation-based inpainting (“INT”), and four variations of exemplar-based inpainting (“EXEM”). The four variations were based on four different image patterns for filling holes. Those patterns are shown in Fig. 11. Three of four patterns were prepared as characters or digits. This is because the proposed concealment method expects that a character stroke structure is damaged by fusing other character stroke structures during the inpainting process.

Finally, we had 2 160 inpainted digit images, made up of 10 digits $\times$ 3 sizes $\times$ 3 hole shapes $\times$ 4 hole areas $\times$ 6 image inpainting setups. The digit patterns were scaled into 3 different sizes (80, 100, 120% of the original size) for making the class answering problem difficult. In other words, the problem is rather easy without this scaling because it is possible to guess the original class by finding some specific shape at a fixed location.

2) Subjective evaluation: As noted above, 19 human subjects have observed 2 160 inpainted digit images and provided their answer about the original digit class for each image. No time limit has been set. If a subject gave up to provide the answer, it was counted as an incorrect answer.

3) Result: Table I summarizes the correct answer rates for all image inpainting setups. From this table, we could reveal several concealment characteristics of character patterns as follows:

[3]This font for license plate is available at `http://minicarmuseum.com/platecreate.php`.

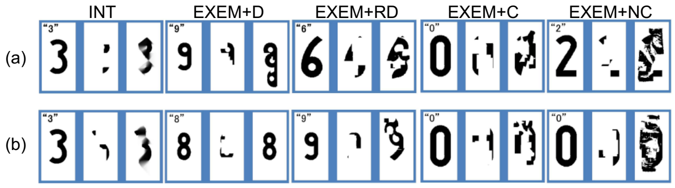

Fig. 12. Examples that image inpainting degrades legibility successfully (a) and increases legibility unsuccessfully (b). For each result, original digit image, image with holes, and final inpainted result are shown. The square hole shape (■) was used.

- The most important fact is that an appropriate exemplar-based inpainting technique is better than "no inpainting" in their performance of character concealment. For example, for the square hole shape and an hole area of 66%, the correct answer rate is reduced successfully to 33% from 53% by using the exemplar-based inpainting with the Chinese character filling pattern.
- As filling patterns, Chinese characters and reversed digits achieved better results than (upright) digits and non-character images. This suggests that characters can be concealed by strokes with different structures. This fact coincides with the observation of Fig. 2.
- As expected from the qualitative observation in III-A, exemplar-based inpainting outperformed interpolation-based inpainting largely.
- It was also revealed that characters have strong robustness to degradation. Even if we substitute 75% of the original stroke pixels with filling patterns, at least 33% of characters still keep their legibility. Since only 10 classes were given, which renders the task of identifying the correct class fairly easy, at least 50% of the stroke pixels should be removed for practical concealment.

Figures 12(a) and (b) show several examples whose legibility was degraded (successfully) and increased (unsuccessfully), respectively. In the successful examples of the exemplar-based inpainting, confusing stroke structures are fused from digit or Chinese character patterns. On the other hand, in the unsuccessful examples, the original stroke structure is recovered; especially, in the inpainting result of "8" by the exemplar-based inpainting with digit filling patterns ("EXEM+D"), the original structure is perfectly recovered from a small amount of survived pixels. This coincides with the above investigation about the robustness of characters.

IV. Conclusion

In this paper, we proposed a method of concealing characters in natural images. Its key idea is that legibility of characters can be damaged by adding structural deformation by an exemplar-based image inpainting technique. A promising property of this method is that the exemplar-based image inpainting technique does not badly affect non-character regions. Consequently, the exemplar-based image inpainting technique can successfully be used to realize a selective concealment method for characters.

This fact was proven through experiments using qualitative and quantitative evaluations of the performance of the proposed character concealment. Specifically, the observation of several inpainting results demonstrated that character regions lose their legibility by inpainting whereas non-character regions can mostly keep their original appearance. A quantitative evaluation based on subjective experiments also confirmed the fact. Furthermore, we showed that the exemplar-based image inpainting can degrade the legibility better than just creating holes around character regions. Another result is that fusing by different stroke structures is effective for degrading the legibility. For example, the stroke structure of Chinese characters is more effective than that of digits for degrading the legibility of digits.

Future work will focus on the use of another framework for damaging the stroke structure. As noted before, texture synthesis [9] is a possible alternative to image inpainting. It is also possible to specify the distribution of legible characters by using the knowledge given from character concealment researches. Given a perfect character concealment method, we can specify this distribution, which is crucial to discriminate between characters and non-characters.

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