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研究課題名（和文）Modeling the Perceptual Underpinnings for Quality Assessment of Restored Textures

研究課題名（英文）Modeling the Perceptual Underpinnings for Quality Assessment of Restored Textures

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研究成果の概要（和文）：画像において失われた視覚的細部を判定し、復元するためのアルゴリズムを開発することを、本研究の目的とした。研究代表者らは、テクスチャが元の画像の統計に基づいて生成され、そしてこれらが復元を実行するために画像に追加され得ることを見出した。ただし、品質にプラスの影響を与えるには、テクスチャを適切に調整する必要がある。各テクスチャの最適コントラストはそのテクスチャの視認性やどれだけ元の画像と一致するかに関連することを見出した。さらに、同じカテゴリーの異なる画像からのテクスチャは、テクスチャ作成時の適切なソース統計として役立つことが分かった。以上により画像の品質評価を行うためのアルゴリズムを開発した。

研究成果の学術的意義や社会的意義
Image restoration and enhancement have largely focused on removing artifacts and/or enhancing sharpness/contrast/colorfulness. We took a radically new approach by adding more noise. We demonstrated that adding shaped noise (matched random textures) can increase sharpness while hiding artifacts.

研究成果の概要（英文）：Images and video can suffer a loss in visual quality due to processing, transmission, and archiving. In this project, we aimed to research and develop computer algorithms for judging and restoring the lost visual details in such images. We found that textures can be created based on the statistics of the original images, and then these textures can be added to the images to perform the restoration. However, the textures must be properly adjusted in contrast to have a positive effect on quality. Via a series of visual experiments, we found that these optimal contrast adjustment factors are related to the visibility of each texture and how well the texture matches the image. We further found that textures from different images, but from the same image category, can serve as suitable source statistics for the creation of the textures. In addition, based in part on these findings, we developed two computer algorithms for performing quality assessment of distorted images.

研究分野：perceptual image processing

キーワード：quality assessment　image restoration　image enhancement　visual detection

１．研究開始当初の背景

This final report documents the work performed for Kakenhi Award 17K00232, "Modeling the Perceptual Underpinnings for Quality Assessment of Restored Textures," during the three-year period of the project from 2017 through 2019. Images and videos are subject to many forms of manipulation during their lifecycles, and thus the field of image and video quality assessment (QA), which deals with automated techniques for predicting visual quality, has emerged as an important research topic. However, traditional QA research deals only with quality degradations, whereas many applications give rise to quality improvements. In this project, we investigated a new area in QA research focused on assessing the qualities of images and videos which have undergone restoration.

２．研究の目的

Specifically, we researched and developed algorithms for judging and restoring the lost visual details in images' textures resulting from lossy compression. We found that restorative patterns can be created based on the statistics of the original image's textures, and then these patterns can be added to the image to perform the restoration. However, the restorative patterns must be properly adjusted in contrast to have a positive effect on quality. Via a series of visual experiments, we found that these optimal contrast adjustment factors are related to the visibility of each pattern and how well the pattern matches the underlying texture. We further found that textures from different images, but from the same image category, can serve as suitable source statistics for the creation of the patterns. In addition, based in part on these findings, we developed two algorithms for performing quality assessment of multiply distorted images.

３．研究の方法

3.1. *Restored Texture Quality Database*

During the period covered by this project, we created a first-of-its-kind database containing quality scores for compression-degraded textures (within images) and various restored versions of those textures.

The textures were obtained from both the McGill calibrated image database and our own custom images captured from within Japan. The images were hand-segmented, and then distorted versions of the textures were created by using HEVC-based image compression at rates corresponding to medium and low quality. From each original texture segment, restorative patterns were synthesized by using a modified parametric texture-synthesis algorithm. Restored versions of the textures were then created by adding the restorative patterns to the degraded textures. Finally, optimal contrast scaling factors for the restorative patterns and quality ratings for the restored/enhanced textures relative to the distorted textures were then measured.

3.2. *Visibility Thresholds for Predicting Optimal Contrasts*

Our synthesized-texture-based restoration/enhancement technique, which serves as the core theme of this research project, employs perceptually shaped noise patterns. However, as mentioned in Section 1, although this technique is quite effective, the contrasts of the patterns must be properly scaled, thus necessitating an algorithm that can automatically predict these scaling factors.

During the period covered by this project, we researched and developed techniques for automatically predicting the optimal contrast scaling factors needed for our texture-based restoration. As mentioned, in order for the proposed enhancement method to be effective, the shaped-noise patterns must be applied in the proper amounts. If the contrast of the pattern is set too high, the result appears artificial. Conversely, if the contrast of the pattern is set too low, the improvements cannot be seen. Thus, there is a need to automatically predict the optimal contrast scaling factor on a per-texture basis. We hypothesized that one determining factor is the visibility of the pattern when viewed within the distorted texture. To test this hypothesis, we conducted a psychophysical experiment to measure contrast thresholds for detecting the restorative patterns shown within their respective blurred textures. (The contrast detection threshold for a given pattern is defined as the minimum contrast required for the pattern to be visible.) Our specific aim was to investigate if there exists a relationship between the restorative patterns' optimal contrast scaling factors and the restorative patterns' contrast detection thresholds.

3.3. *Blind QA of Multiply Distorted Images*

Inspired by the findings from our database that noise can hide blur and blur-based compression artifacts, we asked whether it is possible to leverage this knowledge to develop a quality assessment (QA) algorithm that can predict the qualities of images simultaneously distorted by noise, blur, and compression.

During the period covered by this project, we specifically addressed the task of blind/no-reference (NR) QA of both multiply and singly distorted images, in which three common distortions types are considered: Gaussian blur, JPEG compression, and white noise. Although previous NR-QA research on each of the three individual distortion types has yielded excellent performance, blind quality assessment of images that simultaneously contain more than one of these three distortion types still remains extremely challenging. To address this challenge, we developed an NR algorithm for QA of multiply and singly distorted images based on distortion parameter estimation. Our method, called MUSIQUE, operates under the principle that decoupling the parameter estimation and QA tasks can enable opinion-unaware learning, and thereby lead to improved estimates of quality. To this end, MUSIQUE operates via three main stages: (1) distortion identification; (2) distortion parameter estimation; and (3) quality mapping and combination. The former two stages estimate the values of three assumed distortion parameters based on several classification and regression models, each of which is trained on regenerated datasets by using specific distortion-sensitive features. The final third stage maps and combines the three estimated distortion parameters to associated quality scores based on three polynomial-fitting models and the most-apparent-distortion strategy.

In the following year, we extended MUSIQUE to MUSIQUE-II, which for the first time, blindly assesses the quality of images corrupted by five distortion types (white noise, Gaussian blur, JPEG compression, JPEG2000 compression, and contrast change) and their combinations. MUSIQUE-II employs an expanded classification model with more features, trained on much more data, and an adaptive final combination stage, all of which are needed to deal with the numerous combinations of distortions.

3.4. *Texture Restoration Using a Different Image*

One major practical limitation of the central texture-based restoration/enhancement technique researched in this project is the fact that statistics of the original (pre-compressed) image's textures are required in order to synthesize the restorative textures. Another major drawback is that manual segmentation is required to isolate the to-be-restored textures. To overcome these limitations, we investigated whether it is possible to use machine-learning to: (1) discover a distorted image's objects' categories, and then to use other images from the same categories to generate the restorative textures; and (2) automatically perform the segmentation.

During the period covered by this project, we specifically researched and developed a prototype algorithm for automating the image restoration using other synthetic textures. In order to remove the requirement of having information from the original image, the restorative texture was generated by using statistics from the texture of another image of the same category, and the mask image was automatically generated from the distorted image. These objectives were achieved by using machine-learning frameworks.

４．研究成果

4.1. *Restored Texture Quality Database*

This database provides important training and testing data to help link measurable texture properties and the perception of restorative quality. Our results indicate that the addition of the shaped noise can provide markedly greater quality improvements compared to white noise, a finding which cannot be explained by the mere presence of high-frequency content. The average optimal contrast factors differed from texture to texture, due to the different perceived contrasts of the synthesized textures, and due to the masking capabilities of the source textures. For the quality improvement ratings, the highest per-texture quality improvements relative to the distorted textures were observed for very stochastic textures (e.g., rocks and carpet/synthetic fur). The lowest per-texture quality improvements relative to the distorted textures were observed for the highly regular textures (textures which the synthesis algorithm could not yield what would generally be considered a visually faithful representation of the source texture).

Nonetheless, the contrast scaling factors were always greater than zero, and always resulted in a visually detectable positive change in quality, suggesting that even minor improvements are possible.

The database will be made available at http://vision.eng.shizuoka.ac.jp after our latest paper submissions have been completed.

4.2. *Visibility Thresholds for Predicting Optimal Contrasts*

The results of this study support the hypothesis that low contrast threshold implies low contrast scaling factor, and vice-versa, but only for those patterns which could markedly improve the visual quality. This finding suggests that a future algorithm designed to predict the optimal contrast scaling factors for a given texture should take into account both the quality-improvement potential of the pattern (e.g., the degree to which it visually matches the texture) and the visibility of that pattern when it is applied to the texture.

This work was presented at the INTER-ACADEMIA 2018 conference and published in the conference proceedings.

4.3. *Blind QA of Multiply Distorted Images*

Experimental results on various multiply and singly distorted image quality databases demonstrate that the proposed MUSIQUE algorithm not only outperforms/challenges many state-of-the-art QA algorithms, but also reflects a degree of adaptiveness to images corrupted by different types of noise.

Experimental results on various multiply and singly distorted image quality databases demonstrate that the proposed MUSIQUE-II algorithm not only outperforms its predecessor, but also challenges many state-of-the-art QA algorithms.

The MUSIQUE algorithm was published in the IEEE Transactions on Image Processing in 2018. The MUSIQUE-II algorithm was published in the IEEE Transactions on Image Processing in 2019.

4.4. *Texture Restoration Using a Different Image*

Mask R-CNN and a texture database were used. Mask R-CNN is a convolutional neural network which can output the detected position of an object within an image, a label of the detected object, and a mask image of the object. An object label is used to select a same-category texture from our texture database, and the mask image from Mask R-CNN is used as the texture mask. Our results demonstrated that this technique can lead to visual improvements which are nearly as good as using restorative patterns from the original texture. However, incorrect segmentations, and issue with texture scale, can sometimes lead to unacceptable results. This is an issue that needs further future research.

This work was presented at the PCSJ/IMPS 2019 conference and published in the conference proceedings. The key findings from this effort (and also the project as a whole) were presented by Chandler in a keynote talk at the same conference.

4.5. *Training and Collaboration*

The educational efforts related to this project have included the training and mentoring of one undergraduate student and one M.S. student. Parts of this project were performed with collaboration with a former postdoc.

From 2017 through 2018, one undergraduate student conducted his thesis research on the database aspect of this project. The student specifically performed the efforts described in Sections 3.1/4.1 of this report.

From 2017 through 2019, one M.S. student performed his Master's thesis research on the vision-modeling and final restoration/enhancement algorithm aspects of this project. The student specifically performed the efforts described in Sections 3.2/4.2 and 3.4/4.4 of this report.

From 2017 through 2019, one former postdoc, Prof. Yi Zhang, who is now at Xi'an Jiaotong University, collaborated on the quality assessment algorithms aspect of this project. Prof. Zhang specifically led the QA efforts described in this report.

５．主な発表論文等

〔雑誌論文〕　計4件（うち査読付論文　4件／うち国際共著　4件／うちオープンアクセス　0件）

１．著者名 K. Kawai, D. M. Chandler, and G. Ohashi	４．巻 53
２．論文標題 On the Role of Shaped-Noise Visibility for Post-Compression Image Enhancement	５．発行年 2018年
３．雑誌名 Recent Advances in Technology Research and Education. INTER-ACADEMIA 2018. Lecture Notes in Networks and Systems	６．最初と最後の頁 195 - 203
掲載論文のDOI（デジタルオブジェクト識別子） 10.1007/978-3-319-99834-3_26	査読の有無 有
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 該当する

１．著者名 Y. Zhang and D. M. Chandler	４．巻 27
２．論文標題 Opinion-Unaware Blind Quality Assessment of Multiply and Singly Distorted Images via Distortion Parameter Estimation	５．発行年 2018年
３．雑誌名 IEEE Transactions on Image Processing	６．最初と最後の頁 5433 - 5448
掲載論文のDOI（デジタルオブジェクト識別子） 10.1109/TIP.2018.2857413	査読の有無 有
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 該当する

１．著者名 R. Allison, K. Brunnstrom, D. M. Chandler, H. Colett, P. Corriveau, S. Daly, J. Goel, J. Long, L. Wilcox, Y. Yaacob, S. Yang, Y. Zhang	４．巻 27
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３．雑誌名 Journal of Electronic Imaging	６．最初と最後の頁 1-23
掲載論文のDOI（デジタルオブジェクト識別子） 10.1117/1.JEI.27.5.053035	査読の有無 有
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１．著者名 Y. Zhang, X. Mou, and D. M. Chandler	４．巻 29
２．論文標題 Learning No-Reference Quality Assessment of Multiply and Singly Distorted Images With Big Data	５．発行年 2020年
３．雑誌名 IEEE Transactions on Image Processing	６．最初と最後の頁 2676～2691
掲載論文のDOI（デジタルオブジェクト識別子） 10.1109/TIP.2019.2952010	査読の有無 有
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 該当する

〔学会発表〕　計3件（うち招待講演　1件／うち国際学会　1件）

1．発表者名 K. Kawai, D. M. Chandler, and G. Ohashi
2．発表標題 On the Role of Shaped-Noise Visibility for Post-Compression Image Enhancement
3．学会等名 International Conference on Global Research and Education（国際学会）
4．発表年 2018年

1．発表者名 D. M. Chandler
2．発表標題 特別講演: Adapting Low-Level Perceptual Models for Higher-Level Analysis and Processing
3．学会等名 画像符号化シンポジウム(PCSJ)／映像メディア処理シンポジウム(IMPS)（招待講演）
4．発表年 2019年

1．発表者名 K. Kawai, D. M. Chandler, and G. Ohashi
2．発表標題 圧縮画像改善のための知覚テクスチャ類似性因子
3．学会等名 画像符号化シンポジウム(PCSJ)／映像メディア処理シンポジウム(IMPS)
4．発表年 2019年

〔図書〕　計0件

〔産業財産権〕

〔その他〕

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6．研究組織

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