Xintao DUAN, Chun LI, Bingxin WEI, Guoming WU, Chuan QIN, Haewoon NAM, 2025. SCFformer: a binary data hiding method against JPEG compression based on spatial channel fusion Transformer. *Frontiers of Information Technology & Electronic Engineering*, 26(5):728-741. https://doi.org/10.1631/FITEE.2300762

SCFformer: a binary data hiding method against JPEG compression based on spatial channel fusion Transformer

Front Inform Technol Electron Eng

Key words: Binary data hiding; Against JPEG compression; Discrete cosine transform quantization; SCFformer

Corresponding author: Xintao DUAN
E-mail: duanxintao@htu.edu.com
ORCID: https://orcid.org/0000-0001-8757-2447

Motivation

- Targeting the inadequacy of current data hiding algorithms, which exhibit significant extraction errors after low-quality-factor JPEG compression and demonstrate limited practical applicability, a novel anti-JPEG compression binary data hiding method based on spatial channel fusion Transformer (SCFformer) is proposed, which can recover secret information with high precision after image processing.

Front Inform Technol Electron Eng

Main idea

- A novel anti-JPEG compression binary data hiding method based on SCFformer is proposed, which can provide high-precision secret information recovery with a low quality factor.
- A discrete cosine transform (DCT) quantization truncation mechanism is proposed, which improves the anti-JPEG compression ability of stego images, improves the flexibility by using the scalable module, and realizes secret data hiding with variable capacity.
- An efficient fusion Transformer is proposed, which improves the ability of capturing the dimensional relationships of the entire space and channels while maintaining high efficiency, thereby achieving a lower secret data extraction error rate (ER) at the same capacity.

From Inform Technol Electron Eng

Method

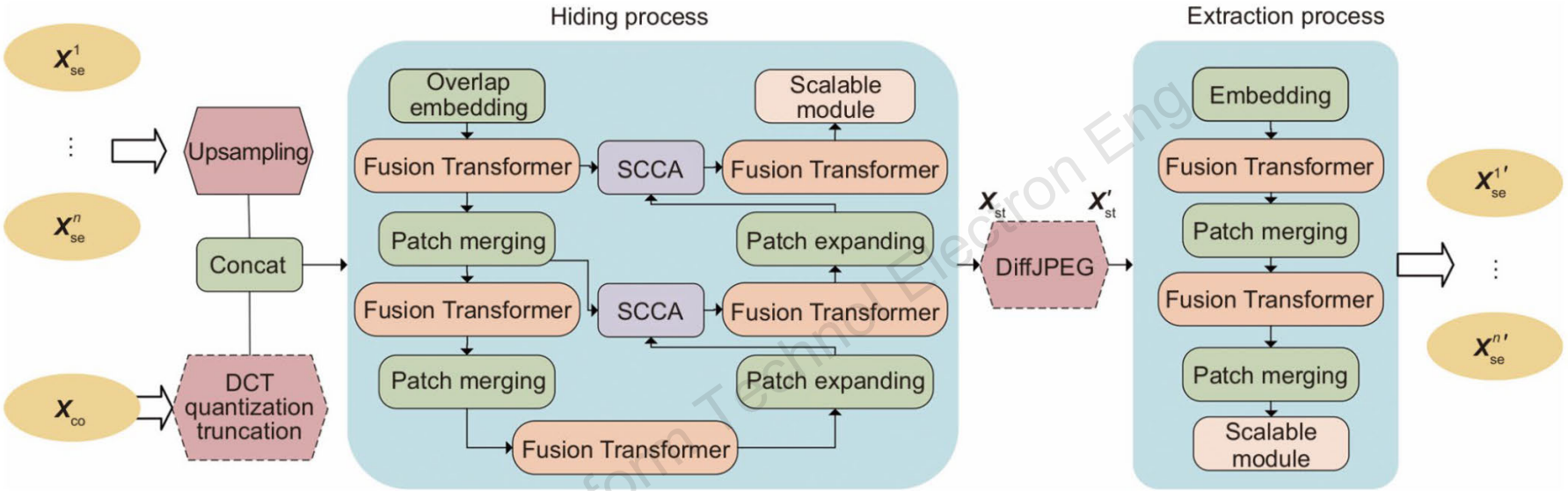


Fig. 1 The overall framework of SCFformer data hiding scheme including mainly two parts, hiding process and extraction process

Front Inform Technol Electron Eng

$$\begin{cases} \boldsymbol{T}(\boldsymbol{Q},\boldsymbol{K},\boldsymbol{V}) = \boldsymbol{V}\boldsymbol{C}_{\mathrm{T}}(\boldsymbol{K},\boldsymbol{Q}), \\ \boldsymbol{C}_{\mathrm{T}}(\boldsymbol{K},\boldsymbol{Q}) = \mathrm{Softmax}\left(\dfrac{\boldsymbol{K}^{\mathrm{T}}\boldsymbol{Q}}{\tau}\right), \end{cases}$$

Learning process can be described as

$$\begin{cases} \boldsymbol{E}_{\mathrm{block}}(\boldsymbol{X},\boldsymbol{Q}_1,\boldsymbol{K}_1,\boldsymbol{V}_1) = \boldsymbol{E}(\boldsymbol{Q}_1,\boldsymbol{K}_1,\boldsymbol{V}_1) + \boldsymbol{X}, \\ \mathrm{MF}_1(\boldsymbol{E}_{\mathrm{block}}) = \mathrm{MF}(\mathrm{LN}(\boldsymbol{E}_{\mathrm{block}})), \\ \boldsymbol{T}_{\mathrm{block}}(\boldsymbol{E}_{\mathrm{block}},\boldsymbol{Q}_2,\boldsymbol{K}_2,\boldsymbol{V}_2) \\ \quad = \boldsymbol{T}(\mathrm{MF}_1(\boldsymbol{E}_{\mathrm{block}}) + \boldsymbol{E}_{\mathrm{block}}) + \mathrm{MF}_1(\boldsymbol{E}_{\mathrm{block}}), \\ \mathrm{MF}_2(\boldsymbol{T}_{\mathrm{block}}) = \mathrm{MF}(\mathrm{LN}(\boldsymbol{T}_{\mathrm{block}})), \\ \mathrm{FT}(\boldsymbol{T}_{\mathrm{block}}) = \mathrm{MF}_2(\boldsymbol{T}_{\mathrm{block}}) + \boldsymbol{T}_{\mathrm{block}}. \end{cases} \tag{3}$$

Method

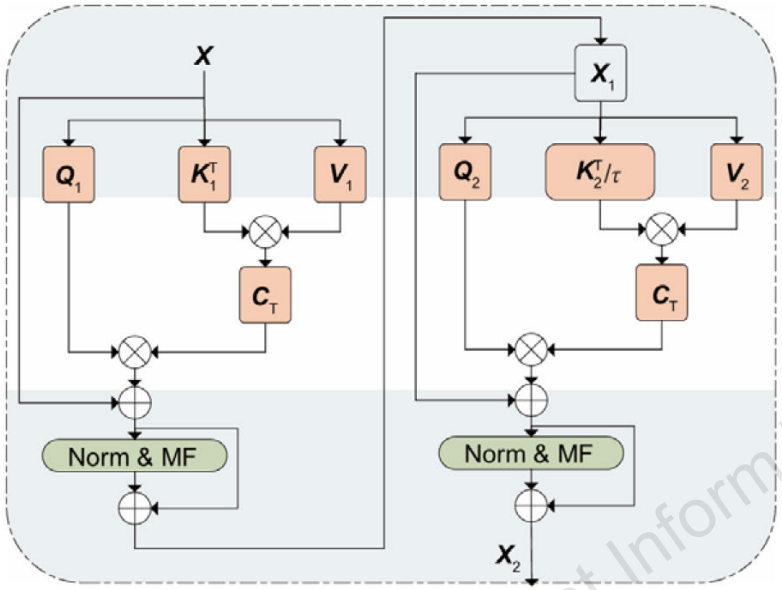


Fig. 2 Efficient fusion Transformer module including an efficient spatial attention block and a channel attention block, followed by a specification and mix-feedforward (MF) neural network

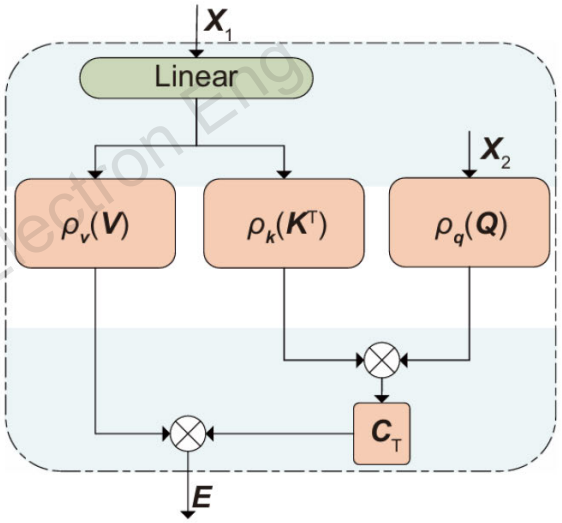


Fig. 3 The SCCA module containing a linear layer and an efficient attention module

Front Inform Technol Electron Eng

Results

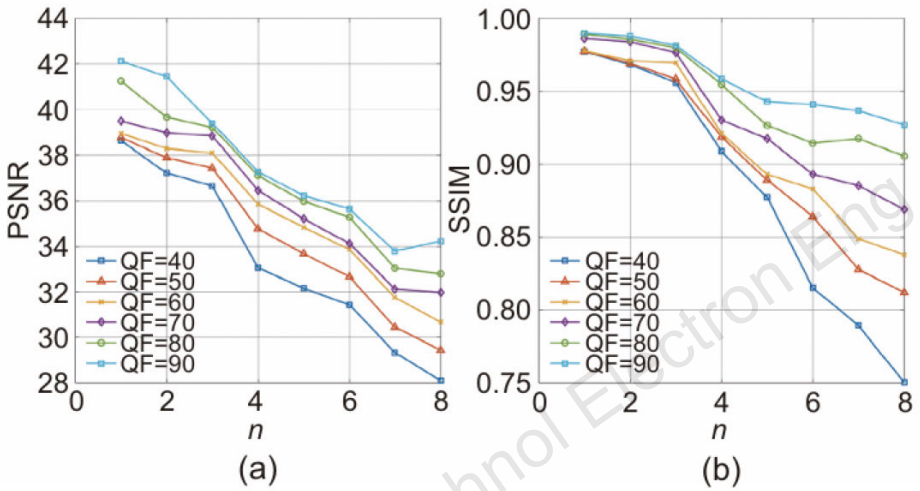


Fig. 8 PSNR (a) and SSIM (b)

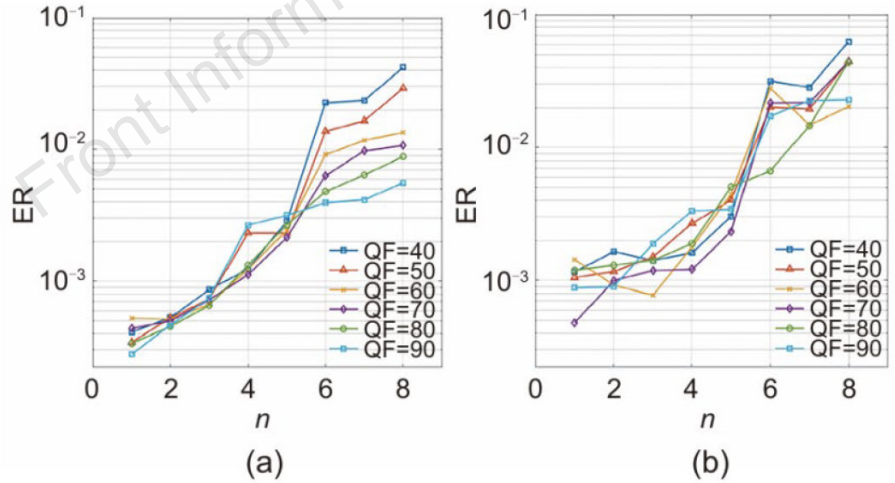


Fig. 9 Error rate (ER) under different n's using SCF-former (a) and U-Net (b)

Front Inform Technol Electron Eng

Results

Table 4 Generalization performance results in four datasets

Dataset	Type	MSE	ER	PSNR		SSIM	
				Max	Average	Max	Average
ImageNet1K	Variation *A*	0.000 180	0.000 721	45.77	38.85	0.990	0.976
	Variation *B*	0.000 195	0.000 972	43.29	38.12	0.986	0.967
	Variation *C*	0.000 572	0.001 216	41.33	33.61	0.978	0.928
CelebA	Variation *A*	**0.000 064**	**0.000 139**	**46.06**	**42.91**	0.990	**0.980**
	Variation *B*	0.000 090	0.000 140	43.68	41.12	0.983	0.968
	Variation *C*	0.000 198	0.000 420	42.33	37.98	0.974	0.954
DIV2K	Variation *A*	0.000 222	0.000 801	43.91	38.40	0.988	0.978
	Variation *B*	0.000 241	0.000 725	41.48	36.97	0.988	0.971
	Variation *C*	0.000 741	0.001 615	38.14	32.09	0.973	0.933
MS-coco	Variation *A*	0.000 172	0.000 801	45.58	39.35	**0.991**	0.977
	Variation *B*	0.000 194	0.000 537	42.98	38.23	0.987	0.967
	Variation *C*	0.000 540	0.001 154	41.23	33.64	0.931	0.977

The best results are in bold and the suboptimal results are underlined

From Harbin Institute of Electron Eng

Conclusions

In this work, we propose a novel anti-JPEG compression binary data hiding method based on spatial channel fusion Transformer (SCFformer), aiming to provide a large-capacity and secure data hiding method to achieve high-precision secret information recovery with a low quality factor. The design of SCFformer can provide some inspiration for further research on hiding a large amount of binary data in JPEG images.

Front Inform Technol Electron Eng



Xintao DUAN received the MS degree in computer application technology from Shanghai Normal University, in 2004, and the PhD degree in communication and information systems from Shanghai University, in 2011. His research interests include image encryption, information hiding, image forensics, and deep learning.



Chun LI received his BS degree from Zhengzhou University of Industrial Technology, China, in 2021. Currently, he is pursuing his MS degree. His research interests include image processing, deep learning, and data hiding.



Bingxin WEI received her MS degree in computer science and technology from Henan Normal University, China, in 2023, where she is currently pursuing her PhD degree at Hanyang University, Republic of Korea. Her research interests include deep learning and image steganography.

Front Inform Technol Electron Eng



Guoming WU received his BS degree in 2021 from Henan Normal University, China. Currently he is pursuing his MS degree. His research interests include image processing, deep learning, and image steganography.



Chuan QIN received the BS degree in electronic engineering and the MS degree in signal and information processing from Hefei University of Technology, Anhui, China, in 2002 and 2005, respectively, and the PhD degree in signal and information processing from Shanghai University, Shanghai, China, in 2008. Since 2008, he has been with the School of Optical-Electrical and Computer Engineering, University of Shanghai for Science and Technology, as a Faculty Member, where he is currently a professor. He was with Feng Chia University, Taiwan, China, as a Postdoctoral Researcher, from 2010 to 2012. He has published more than 110 articles in these research areas. His research interests include image processing and multimedia security.

Front Inform Technol Electron Eng



Haewoon NAM received the BS degree from Hanyang University, Republic of Korea, the MS degree from Seoul National University, and the PhD degree from the University of Texas at Austin, Austin, TX, USA. From 1999 to 2002, he was with Samsung Electronics, Suwon, Republic of Korea, where he was engaged in the design and development of code division multiple access and global system for mobile communications/general packet radio service baseband modem processors. In 2003, he was with IBM Thomas J. Watson Research Center, Yorktown Heights, NY, USA, where he performed extensive radio channel measurements and analysis at 60 GHz. In 2005, he was with the Wireless Mobile System Group, Freescale Semiconductor, Austin, where he was engaged in the design and test of the worldwide interoperability for microwave access medium access control layer. His industry experience also includes the work with the Samsung Advanced Institute of Technology, Kiheung, Republic of Korea, where he participated in the simulation of multi-input multi-output systems for the Third-Generation Partnership Project (3GPP) and Long-Term Evolution (LTE) standard. In 2006, he joined the Mobile Devices Technology Office, Motorola, Inc., Austin, where he was involved in algorithm design and development for the 3GPP LTE Mobile Systems, including modeling of 3GPP LTE modem processor. In 2010, he was with Apple, Inc., Cupertino, CA, USA, where he researched on the research and development of next-generation smart mobile systems. Since 2011, he has been with Hanyang University, Ansan, Republic of Korea, where he is currently an associate professor. He received the Korean Government overseas scholarship for his doctoral studies in the field of electrical engineering.

Front Inform Technol Electron Eng