

University of Groningen

Leveraging image noise: source camera identification and increased robustness of convolutional neural networks

Bennabhaktula, Guru Swaroop

DOI:

[10.33612/diss.843513794](https://doi.org/10.33612/diss.843513794)

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version

Publisher's PDF, also known as Version of record

Publication date:

2023

[Link to publication in University of Groningen/UMCG research database](#)

Citation for published version (APA):

Bennabhaktula, G. S. (2023). *Leveraging image noise: source camera identification and increased robustness of convolutional neural networks*. [Thesis fully internal (DIV), University of Groningen]. University of Groningen. <https://doi.org/10.33612/diss.843513794>

Copyright

Other than for strictly personal use, it is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license (like Creative Commons).

The publication may also be distributed here under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license. More information can be found on the University of Groningen website: <https://www.rug.nl/library/open-access/self-archiving-pure/taverne-amendment>.

Take-down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from the University of Groningen/UMCG research database (Pure): <http://www.rug.nl/research/portal>. For technical reasons the number of authors shown on this cover page is limited to 10 maximum.

Bibliography

- Akbari, Y., Al-maadeed, S., Almaadeed, N., Al-ali, A., Khelifi, F., Lawgaly, A., et al. A new forensic video database for source smartphone identification: Description and analysis. *IEEE Access*, 2022.
- Alles, E. J., Geradts, Z. J., and Veenman, C. J. Source camera identification for heavily JPEG compressed low resolution still images. *Journal of forensic sciences*, 54(3):628–638, 2009.
- Araujo, A., Norris, W., and Sim, J. Computing receptive fields of convolutional neural networks. *Distill*, 2019. doi: 10.23915/distill.00021. <https://distill.pub/2019/computing-receptive-fields>.
- Azzopardi, G. and Petkov, N. A CORF computational model of a simple cell that relies on LGN input outperforms the Gabor function model. *Biological cybernetics*, 106(3):177–189, 2012.
- Azzopardi, G. and Petkov, N. Trainable cosfire filters for keypoint detection and pattern recognition. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 35(2):490–503, 2013. doi: 10.1109/TPAMI.2012.106.
- Azzopardi, G., Rodríguez-Sánchez, A., Piater, J., and Petkov, N. A push-pull CORF model of a simple cell with antiphase inhibition improves SNR and contour detection. *PLoS One*, 9(7):e98424, 2014.
- Babaiee, Z., Hasani, R., Lechner, M., Rus, D., and Grosu, R. On-off center-surround receptive fields for accurate and robust image classification. In *International Conference on Machine Learning*, pages 478–489. PMLR, 2021.
- Barni, M., Chen, Z., and Tondi, B. Adversary-aware, data-driven detection of double JPEG compression: How to make counter-forensics harder. In *2016 IEEE international workshop on information forensics and security (WIFS)*, pages 1–6. IEEE, 2016.

- Barni, M., Bondi, L., Bonettini, N., Bestagini, P., Costanzo, A., Maggini, M., Tondi, B., and Tubaro, S. Aligned and non-aligned double JPEG detection using convolutional neural networks. *Journal of Visual Communication and Image Representation*, 49:153–163, 2017.
- Bayar, B. and Stamm, M. Constrained convolutional neural networks: A new approach towards general purpose image manipulation detection. *IEEE Transactions on Information Forensics and Security*, 13(11):2691–2706, 2018a.
- Bayar, B. and Stamm, M. C. A deep learning approach to universal image manipulation detection using a new convolutional layer. In *Proceedings of the 4th ACM Workshop on Information Hiding and Multimedia Security*, pages 5–10. ACM, 2016.
- Bayar, B. and Stamm, M. C. Design principles of convolutional neural networks for multimedia forensics. *Electronic Imaging*, 2017(7):77–86, 2017a.
- Bayar, B. and Stamm, M. C. On the robustness of constrained convolutional neural networks to jpeg post-compression for image resampling detection. In *2017 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, pages 2152–2156. IEEE, 2017b.
- Bayar, B. and Stamm, M. C. Towards open set camera model identification using a deep learning framework. In *2018 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, pages 2007–2011. IEEE, 2018b.
- Bayer, B. E. Color imaging array. *United States Patent 3,971,065*, 1976.
- Bayram, S., Sencar, H., Memon, N., and Avciabas, I. Source camera identification based on cfa interpolation. In *IEEE International Conference on Image Processing 2005*, volume 3, pages III–69. IEEE, 2005.
- Bennabhaktula, G. S., Alegre, E., Karastoyanova, D., and Azzopardi, G. Device-based image matching with similarity learning by convolutional neural networks that exploit the underlying camera sensor pattern noise. In *Proceedings of the 9th International Conference on Pattern Recognition Applications and Methods: ICPRAM*, volume 1, pages 578–584, 2020. doi: 10.5220/0009155505780584.
- Bennabhaktula, G. S., Alegre, E., Karastoyanova, D., and Azzopardi, G. Device-based image matching with similarity learning by convolutional neural networks that exploit the underlying camera sensor pattern noise. In *Proceedings of the 9th International Conference on Pattern Recognition Applications and Methods - Volume 1: ICPRAM*, pages 578–584. INSTICC, SciTePress, 2020. ISBN 978-989-758-397-1. doi: 10.5220/0009155505780584.
- Bennabhaktula, S., Alegre, E., Karastoyanova, D., and Azzopardi, G. Device-based image matching with similarity learning by convolutional neural networks that exploit the underlying camera sensor pattern noise. In *In Proceedings of the 9th International Conference on Pattern Recognition Applications and Methods - ICPRAM*, pages 578–584, 2020. doi: 10.5220/0009155505780584.

- Boncellet, C. Image noise models. In *The essential guide to image processing*, pages 143–167. Elsevier, 2009.
- Bondi, L., Baroffio, L., Güera, D., Bestagini, P., Delp, E. J., and Tubaro, S. First steps toward camera model identification with convolutional neural networks. *IEEE Signal Processing Letters*, 24(3):259–263, 2016.
- Bondi, L., Lameri, S., Güera, D., Bestagini, P., Delp, E. J., and Tubaro, S. Tampering detection and localization through clustering of camera-based CNN features. In *2017 IEEE Conference on Computer Vision and Pattern Recognition Workshops (CVPRW)*, pages 1855–1864. IEEE, 2017.
- Borg-Graham, L. J., Monier, C., and Fregnac, Y. Visual input evokes transient and strong shunting inhibition in visual cortical neurons. *Nature*, 393(6683):369–373, 1998.
- Bunk, J., Bappy, J. H., Mohammed, T. M., Nataraj, L., Flenner, A., Manjunath, B., Chandrasekaran, S., Roy-Chowdhury, A. K., and Peterson, L. Detection and localization of image forgeries using resampling features and deep learning. In *2017 IEEE Conference on Computer Vision and Pattern Recognition Workshops (CVPRW)*, pages 1881–1889. IEEE, 2017.
- Caldell, R., Amerini, I., Picchioni, F., De Rosa, A., and Uccheddu, F. Multimedia forensic techniques for acquisition device identification and digital image authentication. In *Handbook of Research on Computational Forensics, Digital Crime, and Investigation: Methods and Solutions*, pages 130–154. IGI Global, 2010.
- Cao, H. and Kot, A. C. Accurate detection of demosaicing regularity for digital image forensics. *IEEE Transactions on Information Forensics and Security*, 4(4):899–910, 2009.
- Carlini, N. and Wagner, D. Defensive distillation is not robust to adversarial examples. *arXiv preprint arXiv:1607.04311*, 2016.
- Carlini, N. and Wagner, D. Adversarial examples are not easily detected: Bypassing ten detection methods. In *Proceedings of the 10th ACM workshop on artificial intelligence and security*, pages 3–14, 2017a.
- Carlini, N. and Wagner, D. Towards evaluating the robustness of neural networks. In *2017 IEEE Symposium on Security and Privacy (SP)*, pages 39–57. Ieee, 2017b.
- Chang, C.-C. and Lin, C.-J. Libsvm: a library for support vector machines. *ACM transactions on intelligent systems and technology (TIST)*, 2(3):27, 2011.
- Chen, C. and Stamm, M. C. Camera model identification framework using an ensemble of demosaicing features. In *2015 IEEE International Workshop on Information Forensics and Security (WIFS)*, pages 1–6. IEEE, 2015.
- Chen, J., Kang, X., Liu, Y., and Wang, Z. J. Median filtering forensics based on convolutional neural networks. *IEEE Signal Processing Letters*, 22(11):1849–1853, 2015.

- Chen, M., Fridrich, J., Goljan, M., and Lukás, J. Determining image origin and integrity using sensor noise. *IEEE Transactions on information forensics and security*, 3(1):74–90, 2008.
- Chuang, W.-H., Su, H., and Wu, M. Exploring compression effects for improved source camera identification using strongly compressed video. In *2011 18th IEEE International Conference on Image Processing*, pages 1953–1956. IEEE, 2011.
- Cozzolino, D. and Verdoliva, L. Noiseprint: a cnn-based camera model fingerprint. *IEEE Transactions on Information Forensics and Security*, 2019.
- Cubuk, E. D., Zoph, B., Mane, D., Vasudevan, V., and Le, Q. V. Autoaugment: Learning augmentation strategies from data. In *CVPR*, June 2019.
- da Costa, G. B. P., Contato, W. A., Nazare, T. S., Neto, J. E., and Ponti, M. An empirical study on the effects of different types of noise in image classification tasks. *arXiv preprint arXiv:1609.02781*, 2016.
- Dal Cortivo, D., Mandelli, S., Bestagini, P., and Tubaro, S. CNN-based multi-modal camera model identification on video sequences. *Journal of Imaging*, 7(8):135, 2021.
- Deng, J., Dong, W., Socher, R., Li, L.-J., Li, K., and Fei-Fei, L. Imagenet: A large-scale hierarchical image database. In *2009 IEEE conference on computer vision and pattern recognition*, pages 248–255. Ieee, 2009.
- Dirik, A. E., Sencar, H. T., and Memon, N. Digital single lens reflex camera identification from traces of sensor dust. *IEEE Transactions on Information Forensics and Security*, 3(3):539–552, 2008.
- Dodge, S. and Karam, L. Understanding how image quality affects deep neural networks. In *2016 eighth international conference on quality of multimedia experience (QoMEX)*, pages 1–6. IEEE, 2016.
- Fan, W., Wang, K., and Cayre, F. General-purpose image forensics using patch likelihood under image statistical models. In *2015 IEEE International Workshop on Information Forensics and Security (WIFS)*, pages 1–6. IEEE, 2015.
- Ferster, D. Spatially opponent excitation and inhibition in simple cells of the cat visual cortex. *Journal of Neuroscience*, 8(4):1172–1180, 1988.
- Geirhos, R., Rubisch, P., Michaelis, C., Bethge, M., Wichmann, F. A., and Brendel, W. Imagenet-trained cnns are biased towards texture; increasing shape bias improves accuracy and robustness. *arXiv preprint arXiv:1811.12231*, 2018.
- Geradts, Z. J., Bijhold, J., Kieft, M., Kurosawa, K., Kuroki, K., and Saitoh, N. Methods for identification of images acquired with digital cameras. In *Enabling technologies for law enforcement and security*, volume 4232, pages 505–513. International Society for Optics and Photonics, 2001.

- Gloe, T. and Böhme, R. The dresden image database for benchmarking digital image forensics. In *Proceedings of the 2010 ACM Symposium on Applied Computing*, pages 1584–1590. Acm, 2010.
- Glorot, X. and Bengio, Y. Understanding the difficulty of training deep feedforward neural networks. In *Proceedings of the thirteenth international conference on artificial intelligence and statistics*, pages 249–256. JMLR Workshop and Conference Proceedings, 2010.
- Goljan, M. Digital camera identification from images—estimating false acceptance probability. In *International workshop on digital watermarking*, pages 454–468. Springer, 2008.
- Goljan, M., Fridrich, J., and Filler, T. Large scale test of sensor fingerprint camera identification. In *Media forensics and security*, volume 7254, page 72540I. International Society for Optics and Photonics, 2009.
- Goodfellow, I. J., Shlens, J., and Szegedy, C. Explaining and harnessing adversarial examples. *arXiv preprint arXiv:1412.6572*, 2014.
- Gu, K., Lin, W., Zhai, G., Yang, X., Zhang, W., and Chen, C. W. No-reference quality metric of contrast-distorted images based on information maximization. *IEEE transactions on cybernetics*, 47(12):4559–4565, 2016.
- Gu, K., Jakhetiya, V., Qiao, J.-F., Li, X., Lin, W., and Thalmann, D. Model-based referenceless quality metric of 3d synthesized images using local image description. *IEEE Transactions on Image Processing*, 27(1):394–405, 2017a.
- Gu, K., Li, L., Lu, H., Min, X., and Lin, W. A fast reliable image quality predictor by fusing micro-and macro-structures. *IEEE Transactions on Industrial Electronics*, 64(5):3903–3912, 2017b.
- Gu, K., Zhou, J., Qiao, J.-F., Zhai, G., Lin, W., and Bovik, A. C. No-reference quality assessment of screen content pictures. *IEEE Transactions on Image Processing*, 26(8):4005–4018, 2017c.
- Guo, J., Shi, C., Azzopardi, G., and Petkov, N. Recognition of architectural and electrical symbols by cosfire filters with inhibition. In Azzopardi, G. and Petkov, N., editors, *Computer Analysis of Images and Patterns*, pages 348–358, Cham, 2015. Springer International Publishing. ISBN 978-3-319-23117-4.
- Haralick, R. M., Shanmugam, K., and Dinstein, I. H. Textural features for image classification. *IEEE Transactions on systems, man, and cybernetics*, 3(6):610–621, 1973.
- He, K., Zhang, X., Ren, S., and Sun, J. Deep residual learning for image recognition. In *Proceedings of the IEEE conference on computer vision and pattern recognition*, pages 770–778, 2016a.
- He, K., Zhang, X., Ren, S., and Sun, J. Identity mappings in deep residual networks. In *European conference on computer vision*, pages 630–645. Springer, 2016b.

- Hendrycks, D. and Dietterich, T. Benchmarking neural network robustness to common corruptions and perturbations. *ICLR*, 2019.
- Hendrycks, D., Lee, K., and Mazeika, M. Using pre-training can improve model robustness and uncertainty. In *International Conference on Machine Learning*, pages 2712–2721. PMLR, 2019a.
- Hendrycks, D., Mu, N., Cubuk, E. D., Zoph, B., Gilmer, J., and Lakshminarayanan, B. Augmix: A simple data processing method to improve robustness and uncertainty. In *International Conference on Learning Representations*, 2019b.
- Hendrycks, D., Basart, S., Mu, N., Kadavath, S., Wang, F., Dorundo, E., Desai, R., Zhu, T., Parajuli, S., Guo, M., et al. The many faces of robustness: A critical analysis of out-of-distribution generalization. In *Proceedings of the IEEE/CVF International Conference on Computer Vision*, pages 8340–8349, 2021.
- Hirsch, J. A., Alonso, J.-M., Reid, R. C., and Martinez, L. M. Synaptic integration in striate cortical simple cells. *Journal of neuroscience*, 18(22):9517–9528, 1998.
- Holst, G. *CCD arrays, cameras, and displays*. JCD Publishing, 1998. ISBN 9780964000049. URL <https://books.google.co.in/books?id=QyVLAQAIAAJ>.
- Hosler, B., Mayer, O., Bayar, B., Zhao, X., Chen, C., Shackleford, J. A., and Stamm, M. C. A video camera model identification system using deep learning and fusion. In *ICASSP 2019-2019 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, pages 8271–8275. IEEE, 2019.
- Howard, A., Sandler, M., Chu, G., Chen, L.-C., Chen, B., Tan, M., Wang, W., Zhu, Y., Pang, R., Vasudevan, V., et al. Searching for mobilenetv3. In *Proceedings of the IEEE/CVF International Conference on Computer Vision*, pages 1314–1324, 2019.
- Howard, A. G., Zhu, M., Chen, B., Kalenichenko, D., Wang, W., Weyand, T., Andreetto, M., and Adam, H. Mobilenets: Efficient convolutional neural networks for mobile vision applications. *arXiv preprint arXiv:1704.04861*, 2017.
- Hu, J., Shen, L., and Sun, G. Squeeze-and-excitation networks. In *Proceedings of the IEEE conference on computer vision and pattern recognition*, pages 7132–7141, 2018.
- Hubel, D. H. and Wiesel, T. N. Receptive fields, binocular interaction and functional architecture in the cat’s visual cortex. *The Journal of physiology*, 160(1):106, 1962.
- Hubel, D. H. and Wiesel, T. N. Brain mechanisms of vision. *Scientific American*, 241(3):150–163, 1979.
- Hubel, D. H. and Wiesel, T. N. 8. receptive fields of single neurones in the cat’s striate cortex. In *Brain Physiology and Psychology*, pages 129–150. University of California Press, 2020.

- Ioffe, S. and Szegedy, C. Batch normalization: Accelerating deep network training by reducing internal covariate shift. In *International conference on machine learning*, pages 448–456. PMLR, 2015.
- Iuliani, M., Fontani, M., Shullani, D., and Piva, A. Hybrid reference-based video source identification. *Sensors*, 19(3):649, 2019.
- Kang, X. and Wei, S. Identifying tampered regions using singular value decomposition in digital image forensics. In *2008 International conference on computer science and software engineering*, volume 3, pages 926–930. IEEE, 2008.
- Kang, X., Stamm, M. C., Peng, A., and Liu, K. R. Robust median filtering forensics using an autoregressive model. *IEEE Transactions on Information Forensics and Security*, 8(9):1456–1468, 2013.
- Karras, T., Laine, S., Aittala, M., Hellsten, J., Lehtinen, J., and Aila, T. Analyzing and improving the image quality of stylegan. In *Proceedings of the IEEE/CVF conference on computer vision and pattern recognition*, pages 8110–8119, 2020.
- Kharrazi, M., Sencar, H. T., and Memon, N. Blind source camera identification. In *2004 International Conference on Image Processing, 2004. ICIP'04.*, volume 1, pages 709–712. IEEE, 2004.
- Kirchner, M. and Fridrich, J. On detection of median filtering in digital images. In *Media forensics and security II*, volume 7541, page 754110. International Society for Optics and Photonics, 2010.
- Kirchner, M. and Gloe, T. Forensic camera model identification. *Handbook of Digital Forensics of Multimedia Data and Devices*, pages 329–374, 2015.
- Krizhevsky, A., Hinton, G., et al. Learning multiple layers of features from tiny images. *Master's thesis, University of Tront*, 2009.
- Krizhevsky, A., Sutskever, I., and Hinton, G. E. Imagenet classification with deep convolutional neural networks. *Advances in neural information processing systems*, 25:1097–1105, 2012.
- Kurosawa, K., Kuroki, K., and Saitoh, N. Basic study on identification of video camera models by videotaped images. In *Proceedings of 6th Indo Pacific Congress on Legal Medicine and Forensic Sciences*, pages 26–30, 1998.
- Kurosawa, K., Kuroki, K., and Saitoh, N. Ccd fingerprint method-identification of a video camera from videotaped images. In *Proceedings 1999 International Conference on Image Processing (Cat. 99CH36348)*, volume 3, pages 537–540. IEEE, 1999.
- Li, C.-T. Source camera identification using enhanced sensor pattern noise. *IEEE Transactions on Information Forensics and Security*, 5(2):280–287, 2010.

- Li, C.-T., Chang, C.-Y., and Li, Y. On the repudiability of device identification and image integrity verification using sensor pattern noise. In *International Conference on Information Security and Digital Forensics*, pages 19–25. Springer, 2009.
- Li, J., Li, X., Yang, B., and Sun, X. Segmentation-based image copy-move forgery detection scheme. *IEEE transactions on information forensics and security*, 10(3):507–518, 2014.
- Lin, X. and Li, C.-T. Preprocessing reference sensor pattern noise via spectrum equalization. *IEEE Transactions on Information Forensics and Security*, 11(1):126–140, 2015.
- Liu, H., Wu, H., Xie, W., Liu, F., and Shen, L. Group-wise inhibition based feature regularization for robust classification. In *Proceedings of the IEEE/CVF International Conference on Computer Vision*, pages 478–486, 2021.
- Loshchilov, I. and Hutter, F. SGDR: Stochastic gradient descent with warm restarts. *arXiv preprint arXiv:1608.03983*, 2016.
- Lukas, J., Fridrich, J., and Goljan, M. Digital camera identification from sensor pattern noise. *IEEE Transactions on Information Forensics and Security*, 1(2):205–214, 2006a.
- Lukas, J., Fridrich, J., and Goljan, M. Detecting digital image forgeries using sensor pattern noise. In *Security, Steganography, and Watermarking of Multimedia Contents VIII*, volume 6072, page 60720Y. International Society for Optics and Photonics, 2006b.
- Luo, W., Huang, J., and Qiu, G. JPEG error analysis and its applications to digital image forensics. *IEEE Transactions on Information Forensics and Security*, 5(3):480–491, 2010.
- Mandelli, S., Bestagini, P., Verdoliva, L., and Tubaro, S. Facing device attribution problem for stabilized video sequences. *IEEE Transactions on Information Forensics and Security*, 15: 14–27, 2019.
- Marra, F., Poggi, G., Sansone, C., and Verdoliva, L. A study of co-occurrence based local features for camera model identification. *Multimedia Tools and Applications*, 76(4):4765–4781, 2017.
- Marra, F., Gragnaniello, D., and Verdoliva, L. On the vulnerability of deep learning to adversarial attacks for camera model identification. *Signal Processing: Image Communication*, 65:240–248, 2018.
- Martinez, L. M., Wang, Q., Reid, R. C., Pillai, C., Alonso, J.-M., Sommer, F. T., and Hirsch, J. A. Receptive field structure varies with layer in the primary visual cortex. *Nature neuroscience*, 8(3):372–379, 2005.
- Mayer, O. and Stamm, M. C. Learned forensic source similarity for unknown camera models. In *2018 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, pages 2012–2016. IEEE, 2018.

- Mayer, O. and Stamm, M. C. Forensic similarity for digital images. *arXiv preprint arXiv:1902.04684*, 2019.
- Mayer, O., Bayar, B., and Stamm, M. C. Learning unified deep-features for multiple forensic tasks. In *Proceedings of the 6th ACM workshop on information hiding and multimedia security*, pages 79–84, 2018.
- Melotti, D., Heimbach, K., Rodríguez-Sánchez, A., Strisciuglio, N., and Azzopardi, G. A robust contour detection operator with combined push-pull inhibition and surround suppression. *Information Sciences*, 524:229–240, 2020.
- Metzen, J. H., Genewein, T., Fischer, V., and Bischoff, B. On detecting adversarial perturbations. *arXiv preprint arXiv:1702.04267*, 2017.
- Milani, S., Fontani, M., Bestagini, P., Barni, M., Piva, A., Tagliasacchi, M., and Tubaro, S. An overview on video forensics. *APSIPA Transactions on Signal and Information Processing*, 1, 2012.
- Milani, S., Bestagini, P., Tagliasacchi, M., and Tubaro, S. Demosaicing strategy identification via eigenalgorithms. In *2014 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, pages 2659–2663. IEEE, 2014.
- Mittal, A., Moorthy, A. K., and Bovik, A. C. No-reference image quality assessment in the spatial domain. *IEEE Transactions on image processing*, 21(12):4695–4708, 2012a.
- Mittal, A., Soundararajan, R., and Bovik, A. C. Making a “completely blind” image quality analyzer. *IEEE Signal processing letters*, 20(3):209–212, 2012b.
- Nazaré, T. S., da Costa, G. B. P., Contato, W. A., and Ponti, M. Deep convolutional neural networks and noisy images. In *Iberoamerican Congress on Pattern Recognition*, pages 416–424. Springer, 2017.
- Neocleous, A., Azzopardi, G., Schizas, C. N., and Petkov, N. Filter-based approach for ornamentation detection and recognition in singing folk music. In Azzopardi, G. and Petkov, N., editors, *Computer Analysis of Images and Patterns*, pages 558–569, Cham, 2015. Springer International Publishing. ISBN 978-3-319-23192-1.
- Ng, A. Y. Feature selection, l_1 vs. l_2 regularization, and rotational invariance. In *Proceedings of the twenty-first international conference on Machine learning*, page 78, 2004.
- Papernot, N., McDaniel, P., Wu, X., Jha, S., and Swami, A. Distillation as a defense to adversarial perturbations against deep neural networks. In *2016 IEEE symposium on security and privacy (SP)*, pages 582–597. IEEE, 2016.
- Pibre, L., Pasquet, J., Ienco, D., and Chaumont, M. Deep learning is a good steganalysis tool when embedding key is reused for different images, even if there is a cover source mismatch. *Electronic Imaging*, 2016(8):1–11, 2016.

- Qian, Y., Dong, J., Wang, W., and Tan, T. Deep learning for steganalysis via convolutional neural networks. In *Media Watermarking, Security, and Forensics 2015*, volume 9409, page 94090J. International Society for Optics and Photonics, 2015.
- Qiu, X., Li, H., Luo, W., and Huang, J. A universal image forensic strategy based on steganalytic model. In *Proceedings of the 2nd ACM workshop on Information hiding and multimedia security*, pages 165–170, 2014.
- Rafi, A. M., Tonmoy, T. I., Kamal, U., Wu, Q. J., and Hasan, M. K. Remnet: remnant convolutional neural network for camera model identification. *Neural Computing and Applications*, pages 1–16, 2020a.
- Rafi, A. M., Wu, J., and Hasan, M. K. L2-constrained remnet for camera model identification and image manipulation detection. In *European Conference on Computer Vision*, pages 267–282. Springer, 2020b.
- Ramachandran, P., Zoph, B., and Le, Q. V. Searching for activation functions. *arXiv preprint arXiv:1710.05941*, 2017.
- Recht, B., Roelofs, R., Schmidt, L., and Shankar, V. Do cifar-10 classifiers generalize to cifar-10? *arXiv preprint arXiv:1806.00451*, 2018.
- Rosenfeld, K. and Sencar, H. T. A study of the robustness of PRNU-based camera identification. In *Media Forensics and Security*, volume 7254, page 72540M. International Society for Optics and Photonics, 2009.
- Russakovsky, O., Deng, J., Su, H., Krause, J., Satheesh, S., Ma, S., Huang, Z., Karpathy, A., Khosla, A., Bernstein, M., Berg C., A., and Fei-Fei, L. Imagenet large scale visual recognition challenge. *IJCV*, 115(3):211–252, 2015.
- Sandler, M., Howard, A., Zhu, M., Zhmoginov, A., and Chen, L.-C. Mobilenetv2: Inverted residuals and linear bottlenecks. In *Proceedings of the IEEE conference on computer vision and pattern recognition*, pages 4510–4520, 2018.
- Schmidt, L., Santurkar, S., Tsipras, D., Talwar, K., and Madry, A. Adversarially robust generalization requires more data. *Advances in neural information processing systems*, 31, 2018.
- Shamsabadi, A. S., Sanchez-Matilla, R., and Cavallaro, A. Colorfool: Semantic adversarial colorization. In *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR)*, June 2020.
- Shiva Kasiviswanathan, N. et al. Simple black-box adversarial attacks on deep neural networks. In *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition Workshops*, pages 6–14, 2017.

- Shullani, D., Fontani, M., Iuliani, M., Al Shaya, O., and Piva, A. Vision: a video and image dataset for source identification. *EURASIP Journal on Information Security*, 2017(1):15, 2017.
- Simonyan, K. and Zisserman, A. Very deep convolutional networks for large-scale image recognition. *arXiv preprint arXiv:1409.1556*, 2014.
- Smith, L. N. and Topin, N. Super-convergence: Very fast training of neural networks using large learning rates. In *Artificial intelligence and machine learning for multi-domain operations applications*, volume 11006, pages 369–386. SPIE, 2019.
- Srivastava, N., Hinton, G., Krizhevsky, A., Sutskever, I., and Salakhutdinov, R. Dropout: a simple way to prevent neural networks from overfitting. *The journal of machine learning research*, 15(1):1929–1958, 2014.
- Strisciuglio, N. and Azzopardi, G. Visual response inhibition for increased robustness of convolutional networks to distribution shifts. In *NeurIPS 2022 Workshop on Distribution Shifts: Connecting Methods and Applications*, 2022. URL <https://openreview.net/forum?id=enByqfq18t>.
- Strisciuglio, N., Azzopardi, G., and Petkov, N. Robust inhibition-augmented operator for delineation of curvilinear structures. *IEEE Transactions on Image Processing*, 28(12):5852–5866, 2019a. doi: 10.1109/TIP.2019.2922096.
- Strisciuglio, N., Azzopardi, G., and Petkov, N. Robust inhibition-augmented operator for delineation of curvilinear structures. *IEEE Transactions on Image Processing*, 28(12):5852–5866, 2019b.
- Strisciuglio, N., Lopez-Antequera, M., and Petkov, N. Enhanced robustness of convolutional networks with a push–pull inhibition layer. *Neural Computing and Applications*, pages 1–15, 2020.
- Swaminathan, A., Wu, M., and Liu, K. R. Nonintrusive component forensics of visual sensors using output images. *IEEE Transactions on Information Forensics and Security*, 2(1):91–106, 2007.
- Szegedy, C., Liu, W., Jia, Y., Sermanet, P., Reed, S., Anguelov, D., Erhan, D., Vanhoucke, V., and Rabinovich, A. Going deeper with convolutions. In *Proceedings of the IEEE conference on computer vision and pattern recognition*, pages 1–9, 2015.
- Tan, M. and Le, Q. Efficientnet: Rethinking model scaling for convolutional neural networks. In *International Conference on Machine Learning*, pages 6105–6114. PMLR, 2019.
- Tang, H., Ni, R., Zhao, Y., and Li, X. Median filtering detection of small-size image based on CNN. *Journal of Visual Communication and Image Representation*, 51:162–168, 2018.
- Taori, R., Dave, A., Shankar, V., Carlini, N., Recht, B., and Schmidt, L. When robustness doesn't promote robustness: Synthetic vs. natural distribution shifts on imagenet, 2020. URL <https://openreview.net/forum?id=HyxPIyrFvH>.

- Thai, T. H., Cogranne, R., and Retraint, F. Camera model identification based on the heteroscedastic noise model. *IEEE Transactions on Image Processing*, 23(1):250–263, 2013.
- Timmerman, D., Bennabhaktula, G. S., Alegre, E., and Azzopardi, G. Video camera identification from sensor pattern noise with a constrained convnet. In *ICPRAM 2021 Proceedings*. SciTePress, 2020. 10th International Conference on Pattern Recognition Applications and Methods ICPRAM 2021.
- Timmerman, D., Bennabhaktula, G., Alegre, E., and Azzopardi, G. Video camera identification from sensor pattern noise with a constrained ConvNet. In *Proceedings of the 10th International Conference on Pattern Recognition Applications and Methods - ICPRAM*, pages 417–425. INSTICC, SciTePress, 2021. ISBN 978-989-758-486-2. doi: 10.5220/0010246804170425.
- Tuama, A., Comby, F., and Chaumont, M. Camera model identification with the use of deep convolutional neural networks. In *2016 IEEE International workshop on information forensics and security (WIFS)*, pages 1–6. IEEE, 2016.
- Vasconcelos, C., Larochelle, H., Dumoulin, V., Roux, N. L., and Goroshin, R. An effective anti-aliasing approach for residual networks. *arXiv preprint arXiv:2011.10675*, 2020.
- Venkatanath, N., Praneeth, D., Bh, M. C., Channappayya, S. S., and Medasani, S. S. Blind image quality evaluation using perception based features. In *2015 Twenty First National Conference on Communications (NCC)*, pages 1–6. IEEE, 2015.
- Wang, J. and Zhang, H. Bilateral adversarial training: Towards fast training of more robust models against adversarial attacks. In *Proceedings of the IEEE/CVF International Conference on Computer Vision*, pages 6629–6638, 2019.
- Wang, Q. and Zhang, R. Double JPEG compression forensics based on a convolutional neural network. *EURASIP Journal on Information Security*, 2016(1):1–12, 2016.
- Wang, X., Wang, H., and Niu, S. An image forensic method for AI inpainting using faster R-CNN. In *International Conference on Artificial Intelligence and Security*, pages 476–487. Springer, 2019.
- Xiao, H., Rasul, K., and Vollgraf, R. Fashion-mnist: a novel image dataset for benchmarking machine learning algorithms. *arXiv preprint arXiv:1708.07747*, 2017.
- Xu, G. and Shi, Y. Q. Camera model identification using local binary patterns. In *2012 IEEE International Conference on Multimedia and Expo*, pages 392–397. IEEE, 2012.
- Yin, D., Gontijo Lopes, R., Shlens, J., Cubuk, E. D., and Gilmer, J. A fourier perspective on model robustness in computer vision. *Advances in Neural Information Processing Systems*, 32, 2019.

- Yuan, L., Wang, T., Zhang, X., Tay, F. E., Jie, Z., Liu, W., and Feng, J. Central similarity quantization for efficient image and video retrieval. In *CVPR*, pages 3083–3092, 2020.
- Yun, S., Han, D., Oh, S. J., Chun, S., Choe, J., and Yoo, Y. Cutmix: Regularization strategy to train strong classifiers with localizable features. In *ICCV*, pages 6023–6032, 2019.
- Zeiler, M. D. and Fergus, R. Visualizing and understanding convolutional networks. In *European conference on computer vision*, pages 818–833. Springer, 2014.
- Zhai, J., Shen, W., Singh, I., Wanyama, T., and Gao, Z. A review of the evolution of deep learning architectures and comparison of their performances for histopathologic cancer detection. *Procedia Manufacturing*, 46:683–689, 2020.
- Zhang, K., Zuo, W., Chen, Y., Meng, D., and Zhang, L. Beyond a gaussian denoiser: Residual learning of deep cnn for image denoising. *IEEE Transactions on Image Processing*, 26(7): 3142–3155, 2017.
- Zhang, R. Making convolutional networks shift-invariant again. In *International conference on machine learning*, pages 7324–7334. PMLR, 2019.
- Zhu, X., Qian, Y., Zhao, X., Sun, B., and Sun, Y. A deep learning approach to patch-based image inpainting forensics. *Signal Processing: Image Communication*, 67:90–99, 2018.

