

Imperial College London  
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# Automatic Cell Tracking in Noisy Images for Microscopic Image Analysis

by

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## 7 Conclusions and future work NEW

### 7.1 Conclusion NEW

- what this is
  - what were the main contributions
  - how were the results
  - what were the weak and which the strong points: it can work for any point objects

### 7.2 Future work NEW

image stabilization. problem and what would ipmrove

denoising process

skipping bad frames as a preprocessing step

outputs that analyse the data... but can be done with external software

tracker: experiment with multiclass classifier, taht is dependent on the distance of the closing gaps

windowed approach to be able to handle tens thousands of frames

# Appendices

# Bibliography

- [1] C. Arteta, V. Lempitsky, J. A. Noble, and A. Zisserman, “Learning to detect cells using non-extremal regions,” in *Proceedings of the 15th International Conference on Medical Image Computing and Computer-Assisted Intervention - Volume Part I*, MICCAI’12, (Berlin, Heidelberg), pp. 348–356, Springer-Verlag, 2012. 8, 10, 15, 16, 17, 18, 19
- [2] Y. Chen, K. Biddell, A. Sun, P. Relue, and J. Johnson, “An automatic cell counting method for optical images,” in *[Engineering in Medicine and Biology, 1999. 21st Annual Conference and the 1999 Annual Fall Meeting of the Biomedical Engineering Society] BMES/EMBS Conference, 1999. Proceedings of the First Joint*, vol. 2, pp. 819 vol.2–, Oct 1999. 9
- [3] X. Chen, X. Zhou, and S.-C. Wong, “Automated segmentation, classification, and tracking of cancer cell nuclei in time-lapse microscopy,” *Biomedical Engineering, IEEE Transactions on*, vol. 53, pp. 762–766, April 2006. 9, 12
- [4] L. Vincent, “Morphological grayscale reconstruction in image analysis: applications and efficient algorithms,” *Image Processing, IEEE Transactions on*, vol. 2, pp. 176–201, Apr 1993. 9
- [5] J. Serra, *Image Analysis and Mathematical Morphology*. Orlando, FL, USA: Academic Press, Inc., 1983. 9
- [6] D. Mukherjee, N. Ray, and S. Acton, “Level set analysis for leukocyte detection and tracking,” *Image Processing, IEEE Transactions on*, vol. 13, pp. 562–572, April 2004. 9, 11
- [7] C. Tang, Y. Wang, and Y. Cui, “Tracking of active cells based on kalman filter in time lapse of image sequences of neuron stem cells.” 10, 12
- [8] D. Xu and L. Ma., “Segmentation of image sequences of neuron stem cells based on level-set algorithm combined with local gray threshold.” Master’s thesis, Harbin Engineering University, 2010. 10
- [9] C. Arteta, V. S. Lempitsky, J. A. Noble, and A. Zisserman, “Learning to detect partially overlapping instances.” in *CVPR*, pp. 3230–3237, IEEE, 2013. 10, 17
- [10] J. Matas, O. Chum, M. Urban, and T. Pajdla, “Robust wide baseline stereo from maximally stable extremal regions,” in *Proceedings of the British Machine Vision Conference*, pp. 36.1–36.10, BMVA Press, 2002. doi:10.5244/C.16.36. 10
- [11] T. Joachims, T. Finley, and C.-N. J. Yu, “Cutting-plane training of structural svms,” *Mach. Learn.*, vol. 77, pp. 27–59, Oct. 2009. 10
- [12] R. Bise, T. Kanade, Z. Yin, and S. il Huh, “Automatic cell tracking applied to analysis of cell migration in wound healing assay,” in *Engineering in Medicine and Biology Society, EMBC, 2011 Annual International Conference of the IEEE*, pp. 6174–6179, Aug 2011. 10, 22

- [13] S. Huh, *Toward an Automated System for the Analysis of Cell Behavior: Cellular Event Detection and Cell Tracking in Time-lapse Live Cell Microscopy*. PhD thesis, Robotics Institute, Carnegie Mellon University, Pittsburgh, PA, March 2013. 10, 12
- [14] D. House, M. Walker, Z. Wu, J. Wong, and M. Betke, “Tracking of cell populations to understand their spatio-temporal behavior in response to physical stimuli,” in *Computer Vision and Pattern Recognition Workshops, 2009. CVPR Workshops 2009. IEEE Computer Society Conference on*, pp. 186–193, June 2009. 12
- [15] B. Xu, M. Lu, P. Zhu, Q. Chen, and X. Wang, “Multiple cell tracking using ant estimator,” in *Control, Automation and Information Sciences (ICCAIS), 2012 International Conference on*, pp. 13–17, Nov 2012. 12
- [16] K. Li and T. Kanade, “Cell population tracking and lineage construction using multiple-model dynamics filters and spatiotemporal optimization,” in *Proceedings of the 2nd International Workshop on Microscopic Image Analysis with Applications in Biology (MIAAB)*, September 2007. 12
- [17] A. Massoudi, D. Semenovich, and A. Sowmya, “Cell tracking and mitosis detection using splitting flow networks in phase-contrast imaging,” in *Engineering in Medicine and Biology Society (EMBC), 2012 Annual International Conference of the IEEE*, pp. 5310–5313, Aug 2012. 13
- [18] L. Zhang, Y. Li, and R. Nevatia, “Global data association for multi-object tracking using network flows,” in *Computer Vision and Pattern Recognition, 2008. CVPR 2008. IEEE Conference on*, pp. 1–8, June 2008. 13, 23
- [19] C. Huang, B. Wu, and R. Nevatia, “Robust object tracking by hierarchical association of detection responses,” in *Computer Vision - ECCV 2008* (D. Forsyth, P. Torr, and A. Zisserman, eds.), vol. 5303 of *Lecture Notes in Computer Science*, pp. 788–801, Springer Berlin Heidelberg, 2008. 13, 23
- [20] R. Bise, Z. Yin, and T. Kanade, “Reliable cell tracking by global data association.,” in *ISBI*, pp. 1004–1010, IEEE, 2011. 13, 14, 23, 26
- [21] H. Kuhn, “The hungarian method for the assignment problem,” *Naval Research Logistics Quarterly*, vol. 2, pp. 83–97, 1955. 13
- [22] J. Matas, O. Chum, M. Urban, and T. Pajdla, “Robust wide-baseline stereo from maximally stable extremal regions,” *Image and Vision Computing*, vol. 22, no. 10, pp. 761 – 767, 2004. British Machine Vision Computing 2002. 15, 16
- [23] I. Tsochantaridis, T. Hofmann, T. Joachims, and Y. Altun, “Support vector machine learning for interdependent and structured output spaces,” in *Proceedings of the Twenty-first International Conference on Machine Learning, ICML ’04*, (New York, NY, USA), pp. 104–, ACM, 2004. 17
- [24] J. Schindelin, I. Arganda-Carreras, E. Frise, V. Kaynig, M. Longair, T. Pietzsch, S. Preibisch, C. Rueden, S. Saalfeld, B. Schmid, J.-Y. Tinevez, D. J. White, V. Hartenstein, K. Eliceiri, P. Tomancak, and A. Cardona, “Fiji: an open-source platform for biological-image analysis,” *Nature Methods*, vol. 9(7), pp. 676–682, 2012.

- [25] S. F. I. o. T. L. Philippe Thévenaz, Biomedical Imaging Group, “Point picker: An interactive imagej plugin that allows storage and retrieval of a collection of landmarks,” May 2014.