

**PENGEMBANGAN MODEL *HYBRID CONVOLUTIONAL
CAPSULE NETWORK* UNTUK DETEKSI MULTI-OBJEK
PADA CITRA TERMAL**



SKRIPSI

diajukan untuk memenuhi sebagian syarat untuk memperoleh gelar Sarjana
Teknik (S.T.) pada Program Studi Sistem Telekomunikasi

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Pengembangan Model *Hybrid Convolutional Capsule Network* Untuk Deteksi Multi-Objek Pada Citra Termal

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Sebuah skripsi yang diajukan untuk memenuhi salah satu syarat memperoleh gelar
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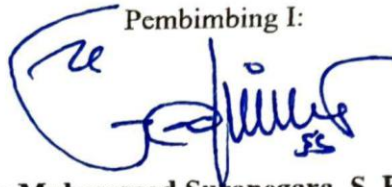
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ABSTRAK

Pencitraan termal memainkan peran penting dalam berbagai aplikasi, termasuk pengawasan, navigasi otonom, dan pemantauan keselamatan pejalan kaki. Studi ini menyajikan implementasi *Hybrid Convolutional Capsule Network* (HCCN) untuk deteksi multi-objek dalam citra termal, dengan fokus pada klasifikasi objek *human* dan *cyclist*. Model dievaluasi menggunakan metode *6-Fold Cross-Validation*, yang memastikan distribusi kelas objek yang seimbang di seluruh *subset* validasi. Pendekatan *Stratified K-Fold* digunakan untuk menjaga distribusi ini, sehingga penilaian model tetap adil dan tidak bias. Temuan ini menegaskan bahwa HCCN mampu melakukan generalisasi dengan baik dalam berbagai skenario pencitraan termal, menjadikannya solusi yang andal untuk tugas deteksi multi-objek di dunia nyata. Penelitian di masa depan dapat berfokus pada penanganan ketidakseimbangan kelas melalui teknik augmentasi data atau *class weighting*, guna lebih meningkatkan kinerja deteksi, terutama untuk kelas dengan jumlah data yang lebih sedikit.

Kata Kunci— Citra Thermal, Deteksi Objek, Deteksi Multi-Objek, *Machine Learning*, *Deep Learning*

ABSTRACT

Thermal imaging plays a crucial role in various applications, including surveillance, autonomous navigation, and pedestrian safety monitoring. This study presents the implementation of a Hybrid Convolutional Capsule Network (HCCN) for multi-object detection in thermal images, focusing on the classification of human and cyclist objects. The model was evaluated using 6-Fold Cross-Validation, ensuring a balanced distribution of object classes across all validation subsets. A Stratified K-Fold approach preserved this distribution, ensuring fair and unbiased model assessment. These findings highlight HCCN's capability to generalize well across different thermal imaging scenarios, making it a robust solution for real-world multi-object detection tasks. Future research could focus on addressing class imbalance through data augmentation or class weighting strategies to further enhance detection performance, particularly for minority classes.

Keywords— *Thermal Imaging, Object Detection, Multi-Object Detection, Machine Learning, Deep Learning*

DAFTAR ISI

LEMBAR HAK CIPTA.....	i
LEMBAR PENGESAHAN	ii
SURAT PERNYATAAN KEASLIAN SKRIPSI DAN BEBAS PLAGIARISME	iii
KATA PENGANTAR	iv
ABSTRAK.....	vi
<i>ABSTRACT</i>	vii
DAFTAR ISI.....	viii
DAFTAR GAMBAR	xi
DAFTAR TABEL.....	xii
BAB I PENDAHULUAN.....	1
1.1 Latar Belakang	1
1.2 Rumusan Masalah	2
1.3 Tujuan Penelitian	2
1.4 Batasan Masalah	2
1.5 Manfaat Penelitian	2
BAB II KAJIAN PUSTAKA.....	4
2.1 Citra Termal	4
2.2 <i>Deep Learning</i> Dalam Klasifikasi Objek.....	5
2.3 <i>Convolutional Neural Network</i> (CNN).....	6
2.4 <i>Capsule Network</i> (Capsnet)	8
2.5 Evaluasi <i>Hybrid Convolutional Capsule Network</i> (HCCN)	9
BAB III METODE PENELITIAN	11
3.1 Desain Penelitian	11

3.2	Lokus Penelitian.....	11
3.3	Alur Penelitian	12
3.3.1	Akuisisi dan Praproses <i>Dataset</i> Citra Termal	12
3.3.2	Perancangan dan Implementasi Modifikasi <i>Capsule Network</i>	13
3.3.3	Pelatihan Model Dengan <i>Dataset</i> Termal.....	14
3.4	<i>Dataset</i>	14
3.5	Arsitektur Model.....	15
3.5.1	<i>Hybrid Convolutional Capsule Network</i> (HCCN).....	15
3.5.2	Modifikasi <i>Capsule Network</i> (CapsNet).....	18
3.6	Distribusi Data	20
3.7	Lingkungan Pengujian	22
3.8	Metrik Evaluasi.....	22
3.9	Validasi dan Eksperimen	23
3.10	Teknik Analisis Data.....	23
3.11	Diagram Proses Alur Model HCCN	23
3.11.1	<i>Load Thermal Image Datasets</i>	24
3.11.2	<i>Capsule Network Model Development</i>	25
3.11.3	<i>Training Model</i>	26
3.11.4	<i>Testing dan Evalutaion Test Model</i>	27
3.12	Integrasi Diagram Alur dengan Proses Penelitian	30
3.13	Arsitektur Model <i>Capsule Network</i>	31
3.13.1	<i>Input Layer</i> (Citra Termal).....	31
3.13.2	<i>Convolutional Layers</i> (5 Lapisan Konvolusi Bertingkat).....	31
3.13.3	<i>Primary Capsule Layer</i>	31
3.13.4	<i>Digit Capsule Layer</i> (Class Capsule Layer).....	32

3.13.5	<i>Output Layer (Prediction Vector)</i>	32
3.14	Integrasi Arsitektur dalam Penelitian.....	33
BAB IV HASIL DAN PEMBAHASAN		34
4.1	Hasil Implementaasi Pelatihan dan Visualisasi Pelatihan Model	34
4.2	Hasil Pengujian Model.....	35
4.2.1	<i>Confusion Matrix</i>	36
4.2.2	<i>Precision, Recall, dan F1-Score</i>	37
4.2.3	<i>Mean Average Precision (mAP)</i>	39
4.3	Interpretasi dan Analisis Hasil	40
BAB V SIMPULAN DAN SARAN.....		43
5.1	Simpulan	43
5.2	Saran	44
DAFTAR PUSTAKA		46
LAMPIRAN.....		49
DAFTAR RIWAYAT PENULIS		53

DAFTAR GAMBAR

Gambar 3. 1 Alur Proses Penelitian	12
Gambar 3. 2 Pengambilan <i>Dataset</i> Citra Termal	13
Gambar 3. 3 Konfigurasi Sistem Model	24
Gambar 3. 4 Lapisan Arsitektur <i>Model Hybrid Convolutional Capsule</i>	31
Gambar 4. 1 Grafik <i>Training</i> dan Validasi <i>Epoch-1</i>	35
Gambar 4. 2 Grafik <i>Training</i> dan Validasi <i>Epoch-25</i>	35
Gambar 4. 3 Visualisasi <i>Confusion Matrix human</i> dan <i>cyclist</i>	36
Gambar 4. 4 Visualisasi Grafik <i>Average Precision (AP)</i> Setiap Kelas	40
Gambar 4. 5 Visual kelas <i>human</i> (1)	41
Gambar 4. 6 Visual Kelas <i>human</i> (2)	41
Gambar 4. 7 Visual Kelas <i>cyclist</i> (1)	41
Gambar 4. 8 Visual Kelas <i>cyclist</i> (2)	41

DAFTAR TABEL

Tabel 3. 1 Arsitektur Model <i>Hybrid Convolutional Capsule Network</i> (HCCN)...	15
Tabel 4. 1 Hasil Nilai <i>Training</i> dan Validasi <i>Dataset</i>	34
Tabel 4. 2 Hasil Nilai Evaluasi Metrik Model HCCN	38
Tabel 4. 3 Visualisasi Tabel Nilai <i>Average Precision</i> (AP) Tiap Kelas.....	40

DAFTAR PUSTAKA

- Agaian, S., Ayunts, H., Trongtirakul, T., & Hovhannisyan, S. (2025). *A new method for judging thermal image quality with applications*. *Signal Processing*, 229. <https://doi.org/10.1016/j.sigpro.2024.109769>
- Ben, L., & Junkai, F. (2025). *Real time thermal imaging monitoring based on object detection in the design of physical education auxiliary system: Computational thermal modeling*. *Thermal Science and Engineering Progress*, 58. <https://doi.org/10.1016/j.tsep.2024.103209>
- Bin, J., Zhang, H., Bahrami, Z., Zhang, R., Liu, H., Blasch, E., & Liu, Z. (2023). *The registration of visible and thermal images through multi-objective optimization*. *Information Fusion*, 95, 186–198. <https://doi.org/10.1016/j.inffus.2023.02.020>
- Chen, M., Yi, S., Wu, L., Yin, H., & Chen, L. (2024). *Highly robust thermal infrared and visible image registration with canny and phase congruence detection*. *Optics and Lasers in Engineering*, 183. <https://doi.org/10.1016/j.optlaseng.2024.108526>
- Dahiya, R., G, M., Jawale, S. S., Das, S., Choudhary, S., Rathod, V. M., & Rajput, B. J. (2025). *Deep learning-based multi-brain capsule network for Next-Gen Clinical Emotion recognition using EEG signals*. *Neuroscience Informatics*, 5(2). <https://doi.org/10.1016/j.neuri.2025.100203>
- Dai, G., Wang, C., Tang, Q., He, L., Chen, H., Sunil, C. K., & Dewi, C. (2025). *Aerial infrared thermal imaging transmission line defect detection methods incorporating explicit visual center structures*. *Measurement: Journal of the International Measurement Confederation*, 245. <https://doi.org/10.1016/j.measurement.2024.116605>
- Feng, H., Zhang, L., Zhang, S., Wang, D., Yang, X., & Liu, Z. (2023). *RTDOD: A large-scale RGB-thermal domain-incremental object detection dataset for UAVs*. *Image and Vision Computing*, 140. <https://doi.org/10.1016/j.imavis.2023.104856>
- Gogulamudi, N., Golla, M., G, A. N., Kautish, S., Almazyad, A. S., Xiong, G., & Mohamed, A. W. (2024). *Evaluating the performance of a non-uniform squash function in Capsule networks for early diabetic retinopathy detection using fundus image analysis*. *Results in Engineering*, 23. <https://doi.org/10.1016/j.rineng.2024.102820>
- Gürsoy, E., & Kaya, Y. (2025). *Multi-source deep feature fusion for medical image analysis*. *Multidimensional Systems and Signal Processing*, 36(1). <https://doi.org/10.1007/s11045-024-00897-z>

- Hespeler, S. C., Nemati, H., & Dehghan-Niri, E. (2021). *Non-destructive thermal imaging for object detection via advanced deep learning for robotic inspection and harvesting of chili peppers. Artificial Intelligence in Agriculture*, 5, 102–117. <https://doi.org/10.1016/j.aiia.2021.05.003>
- Huang, L., & Gong, A. (2025). *Trigonometric feature learning for RGBD and RGBT image salient object detection. Knowledge-Based Systems*, 310. <https://doi.org/10.1016/j.knosys.2024.112935>
- Ishii, A., & Horikawa, K. (2025). *Quantitative analysis of hydrogen absorption in pure aluminum: Theoretical and experimental approaches. Materialia*, 42. <https://doi.org/10.1016/j.mtla.2025.102449>
- Jaddoa, M. A., Zaidan, A. A., Gonzalez, L. A., Deveci, M., Cuthbertson, H., Al-Jumaily, A., & Kadry, S. (2024). *An approach-based machine learning and automated thermal images to predict the dark-cutting incidence in cattle management of healthcare supply chain. Engineering Applications of Artificial Intelligence*, 135. <https://doi.org/10.1016/j.engappai.2024.108804>
- Sun, F., Zhou, W., Yan, W., & Zhang, Y. (2024). HFENet: *Hybrid feature encoder network for detecting salient objects in RGB-thermal images. Digital Signal Processing: A Review Journal*, 148. <https://doi.org/10.1016/j.dsp.2024.104439>
- Ünalán, S., Günay, O., Akkurt, I., Gunoglu, K., & Tekin, H. O. (2024). *A comparative study on breast cancer classification with stratified shuffle split and K-fold cross validation via ensembled machine learning. Journal of Radiation Research and Applied Sciences*, 17(4), 101080. <https://doi.org/10.1016/j.jrras.2024.101080>
- Wan, D., Lu, R., Hu, B., Yin, J., Shen, S., xu, T., & Lang, X. (2024a). YOLO-MIF: *Improved YOLOv8 with Multi-Information fusion for object detection in Gray-Scale images. Advanced Engineering Informatics*, 62. <https://doi.org/10.1016/j.aei.2024.102709>
- Wan, D., Lu, R., Hu, B., Yin, J., Shen, S., xu, T., & Lang, X. (2024b). YOLO-MIF: *Improved YOLOv8 with Multi-Information fusion for object detection in Gray-Scale images. Advanced Engineering Informatics*, 62. <https://doi.org/10.1016/j.aei.2024.102709>
- Wang, Y., Khodadadzadeh, M., & Zurita-Milla, R. (2025). *A dissimilarity-adaptive cross-validation method for evaluating geospatial machine learning predictions with clustered samples. Ecological Informatics*, 90. <https://doi.org/10.1016/j.ecoinf.2025.103287>
- Yu, Y., Wang, J., Qiang, H., Jiang, M., Tang, E., Yu, C., Zhang, Y., & Li, J. (2021). *Sparse anchoring guided high-resolution capsule network for geospatial*

object detection from remote sensing imagery. International Journal of Applied Earth Observation and Geoinformation, 104.
<https://doi.org/10.1016/j.jag.2021.102548>

Zhang, Y., Liu, G., & Wang, J. (2025). *Automated detection of sheep eye temperature using thermal images and improved YOLOv7. Computers and Electronics in Agriculture, 230.*
<https://doi.org/10.1016/j.compag.2025.109925>