DISERTASI
(TEK 010317)

SEGMENTASI INSTANCE MULTICLASS UNTUK INTERPRETASI OBJEK CITRA JANTUNG JANIN

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PROGRAM STUDI DOKTOR ILMU TEKNIK
FAKULTAS TEKNIK
UNIVERSITAS SRIWIJAYA

2025

HALAMAN PENGESAHAN

DISERTASI

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Telah disetujui
Pada Tanggal, 18 Juli 2025

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Disertasi berjudul " Segmentasi Instance Multiclass Untuk Interpretasi Objek Citra Jantung Janin " telah dipresentasikan dihadapan Tim Penguji Disertasi pada Program Studi Doktor Ilmu Teknik Fakultas Teknik Universitas Sriwijaya pada *Jumat, 18 Juli 2025.*

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Dengan ini menyatakan bahwa disertasi saya dengan judul "Segmentasi Instance Multiclass Untuk Interpretasi Objek Citra Jantung Janin Normal", bebas dari fabrikasi, falsifikasi, plagiat, kepengarangan yang tidak sah dan konflik kepentingan dan pengajuan jamak, seperti yang tercantum dalam Peraturan Menteri Pendidikan, Kebudayaan, Riset, dan Teknologi Republik Indonesia No 39 Tahun 2021.

Bilamana ditemukan ketidak sesuaian dengan hal-hal di atas, maka saya bersedia menerima sanksi akademik dari Universitas Sriwijaya sesuai dengan aturan yang berlaku.

Demikian pernyataan ini dibuat dengan sesungguhnya dan dengan sebenar-benarnya.

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KATA PENGANTAR

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Palembang,   Juli 2025

Penulis

Hadi Syaputra

RINGKASAN

Segmentasi Instance Multiclass Untuk Interpretasi Objek Citra Jantung Janin Normal

Penelitian ini bertujuan untuk mengembangkan model segmentasi instance multiclass berbasis Mask R-CNN guna mengidentifikasi struktur anatomi jantung janin normal pada citra ultrasonografi tampilan empat ruang (*four-chamber view*). Latar belakang penelitian ini didasarkan pada urgensi deteksi dini kelainan jantung bawaan (*congenital heart disease*/CHD), yang merupakan salah satu penyebab utama kematian neonatal, serta keterbatasan jumlah dokter subspesialis fetomaternal dan variabilitas kualitas citra ultrasonografi yang dihasilkan di layanan klinis. Model yang dikembangkan dirancang sebagai sistem pendukung keputusan klinis berbasis kecerdasan buatan (AI) untuk membantu dokter obstetrik dalam interpretasi awal citra ultrasonografi, terutama di fasilitas dengan keterbatasan sumber daya spesialis. Dataset yang digunakan terdiri dari 176 citra hasil ekstraksi video ekokardiografi janin, yang dianotasi ke dalam 10 kelas anatomi, termasuk struktur mayor (LV, LA, RV, RA, AO) dan minor (PV, MV, TV, AV), serta kelas tambahan Spine sebagai penanda orientasi anatomis janin. Penelitian ini juga mengevaluasi pengaruh beberapa teknik peningkatan kualitas citra (*Histogram Equalization*, AHE, CLAHE, Blind Deblurring, dan kombinasi metode) terhadap performa segmentasi. Evaluasi dilakukan menggunakan metrik mean *Average Precision* (mAP), *Intersection over Union* (IoU), *Dice Similarity Coefficient* (DCS), dan *Confusion Matrix*. Hasil eksperimen menunjukkan bahwa model R50_sgd_20 dengan konfigurasi tertentu memberikan hasil terbaik pada sebagian besar kelas mayor. Namun, performa segmentasi terhadap objek kecil seperti PV dan AV masih menunjukkan keterbatasan. Selain itu, meskipun teknik peningkatan citra berhasil meningkatkan kualitas visual, efeknya terhadap akurasi segmentasi tidak seragam di seluruh kelas. Temuan ini menunjukkan bahwa performa segmentasi dipengaruhi tidak hanya oleh kualitas visual citra, tetapi juga oleh arsitektur model, distribusi kelas, dan karakteristik spasial objek dalam citra.

Kata Kunci : Segmentasi *Instance*, Mask R-CNN, Jantung Janin, Ultrasonografi, *Deep Learning*, Peningkatan Citra (CLAHE, HE, BD), mAP, IoU, DCS, Confusion Matrix

SUMMARY

Multiclass Instance Segmentation for the Interpretation of Normal Fetal Heart Ultrasound Images

This study aims to develop a multiclass instance segmentation model based on Mask R-CNN to identify anatomical structures of the normal fetal heart in four-chamber view (4CV) ultrasound images. The background of this research stems from the urgent need for early detection of congenital heart disease (CHD), one of the leading causes of neonatal mortality, combined with the limited availability of fetomaternal subspecialists and the variability in ultrasound image quality encountered in clinical practice. The proposed model is designed as a clinical decision support system powered by artificial intelligence (AI) to assist obstetricians in the initial interpretation of fetal cardiac ultrasound images, particularly in healthcare facilities with limited specialist resources. The dataset used in this study comprises 176 images, extracted from fetal echocardiography videos and annotated into 10 anatomical classes, including major structures (LV, LA, RV, RA, AO), minor structures (PV, MV, TV, AV), and an additional class for the spine, which serves as a reference for fetal anatomical orientation. The study also investigates the impact of various image enhancement techniques, including Histogram Equalization (HE), Adaptive Histogram Equalization (AHE), Contrast Limited AHE (CLAHE), Blind Deblurring (BD), and their combinations, on the segmentation performance. Evaluation was conducted using standard performance metrics, namely mean Average Precision (mAP), Intersection over Union (IoU), Dice Similarity Coefficient (DCS), and Confusion Matrix. Experimental results show that the R50_sgd_20 model configuration achieved the best segmentation performance across most major anatomical classes. However, challenges remain in segmenting small anatomical structures such as Pulmonary Valve (PV) and Aortic Valve (AV). Although enhancement techniques improved image clarity, their effect on segmentation accuracy varied across classes. These findings suggest that segmentation performance is influenced not only by image quality, but also by the underlying model architecture, class distribution, and spatial characteristics of the anatomical structures within the image.

Keywords: Instance Segmentation, Mask R-CNN, Fetal Heart, Ultrasound, Deep Learning, Image Enhancement (CLAHE, HE, BD), mAP, IoU, DCS, Confusion Matrix

BAB I

PENDAHULUAN

1.1. Latar Belakang

Artificial Intelligence (AI) berkembang dengan pesat dan menjadi bagian yang tidak dapat dipisahkan dalam kehidupan masyarakat. Hal ini disebabkan karena karakteristik dari teknologi ini memiliki kemampuan dalam merasionalkan dan mengambil tindakan atau solusi yang memiliki peluang terbaik dalam mencapai tujuan [1]. Dalam beberapa tahun terakhir, AI telah diaplikasikan secara luas di berbagai sektor, seperti dalam pemerintahan [2], infrastruktur [3], peternakan [4], dan kesehatan [5]. Dalam sektor kesehatan, pendekatan *Machine Learning* (ML) dan *Deep Learning* (DL) semakin menunjukkan potensi besar, terutama dalam pengolahan citra medis yang kompleks. Teknologi DL secara signifikan telah meningkatkan akurasi dalam klasifikasi, deteksi, dan segmentasi berbagai jenis data medis [6], [7]. Salah satu tantangan besar dalam dunia kesehatan adalah deteksi dini penyakit jantung bawaan atau *Congenital Heart Disease* (CHD) pada janin.

CHD merupakan salah satu kelainan struktural yang paling umum terjadi dan menyumbang angka kematian neonatal yang cukup tinggi. Prevalensi CHD secara global diperkirakan mencapai sekitar 8–10 kasus per 1.000 kelahiran hidup [8], [9]. Di Indonesia, keterbatasan jumlah dokter subspesialis fetomaternal serta kurangnya akses terhadap pelatihan Ekokardiografi janin turut menjadi hambatan signifikan dalam deteksi dini kelainan ini [10]. Dari lebih dari 6.000 dokter obstetri dan ginekologi (SpOG) di Indonesia, hanya sebagian kecil yang memiliki kompetensi dalam bidang fetomaternal [11]. Ekokardiografi janin merupakan metode pencitraan non-invasif yang penting dalam mendeteksi kelainan jantung sejak masa kehamilan, namun interpretasinya sangat bergantung pada keterampilan operator dan kualitas citra yang diperoleh. Citra ultrasonografi sering kali terganggu oleh *noise*, *blur*, dan rendahnya kontras, yang menyulitkan proses identifikasi struktur jantung janin secara akurat. Untuk mengatasi keterbatasan tersebut, pendekatan berbasis *Deep Learning* (DL), khususnya *Convolutional Neural Network* (CNN), telah banyak digunakan dalam pengolahan citra medis, termasuk klasifikasi, deteksi objek, dan segmentasi [12], [13], [14]. Dalam konteks ekokardiografi janin, CNN terbukti mampu mengenali berbagai struktur dan anomali dengan akurasi tinggi, sehingga meningkatkan kecepatan dan ketepatan diagnosis klinis [15], [16]. Deteksi dini terhadap kelainan struktural dan fungsional jantung janin memungkinkan intervensi medis yang lebih cepat, sehingga dapat menurunkan risiko komplikasi dan kematian akibat CHD [17]. Agar deteksi dapat dilakukan secara optimal, pengenalan menyeluruh terhadap seluruh struktur jantung janin normal menjadi sangat penting [18]. Berbagai studi telah mengembangkan metode segmentasi untuk membedakan sembilan kelas utama anatomi jantung, yaitu *Left Atrium* (LA), *Right Atrium* (RA), *Left Ventricle* (LV), *Right Ventricle* (RV), *Tricuspid Valve* (TV), *Pulmonary Valve* (PV), *Mitral Valve* (MV), *Aortic Valve* (AV), dan *Aorta* (AO) [18]. Namun, sebagian besar pendekatan segmentasi sebelumnya masih terbatas pada segmentasi semantik, yang hanya mampu mengelompokkan piksel berdasarkan kelas tanpa membedakan antar objek dalam kelas yang sama [19]. Padahal, dalam praktik klinis, diperlukan interpretasi citra yang mampu mengenali setiap struktur anatomi secara individual dalam satu tampilan citra, terutama untuk mendeteksi kelainan secara menyeluruh. Oleh karena itu, pendekatan segmentasi instance *multiclass* menjadi lebih relevan, karena mampu membedakan objek-objek serupa dalam satu kelas serta memungkinkan pengukuran spesifik terhadap struktur penting, seperti bilik jantung dan katup. Kemampuan ini sangat penting untuk memastikan akurasi diagnostik dalam kondisi citra yang kompleks, sebagaimana sering dijumpai dalam pencitraan ultrasonografi janin. Segmentasi *instance multiclass* juga mendukung analisis yang lebih komprehensif dan objektif, sehingga sangat bermanfaat dalam menunjang pengambilan keputusan klinis secara efisien.

Proses segmentasi merupakan teknik penting dalam analisis citra medis yang bertujuan untuk membagi suatu citra menjadi beberapa segmen yang bermakna, sehingga representasi citra menjadi lebih sederhana dan informatif. Segmentasi memungkinkan identifikasi dan pengelompokan setiap piksel ke dalam area atau objek yang memiliki makna serupa, serta mampu membedakan berbagai instance dari objek yang sama dalam satu citra. Setiap instance diberi label unik, sehingga memungkinkan analisis yang lebih mendetail terhadap struktur yang diamati [20]. Untuk mencapai hasil segmentasi yang akurat, khususnya pada citra medis seperti ultrasonografi jantung janin, diperlukan metode yang andal dan telah terbukti efektif. Berbagai arsitektur segmentasi instance telah dikembangkan, antara lain Mask R-CNN [21], YOLO [22], YOLACT [23], SOLOv2 [24], dan DETR [25]**.** Pemilihan Mask R-CNN pada penelitian ini didasarkan pada kemampuannya memadukan deteksi objek dan segmentasi piksel dalam satu arsitektur, sehingga dapat memberikan label unik untuk setiap *instance* yang terdeteksi [21], [26]. Pendekatan ini sangat relevan untuk mengidentifikasi struktur anatomi jantung janin secara individual pada berbagai pandangan (misalnya *four-*

chamber, 3VT, LVOT/RVOT), di mana penelitian sebelumnya menunjukkan nilai *Dice* mencapai ±0,90 dan mAP sekitar ±0,96 [27]. Mask R-CNN bekerja dalam dua tahap, yaitu pelokalan dan klasifikasi objek menggunakan *Region Proposal Network* (RPN), kemudian segmentasi piksel di dalam setiap *Region of Interest* (RoI) melalui cabang *Fully Convolutional Network* (FCN) [21]. Selain keunggulan Mask R-CNN sebagai metode *instance segmentation*, pemilihan *backbone* yang tepat sangat berpengaruh terhadap kualitas hasil segmentasi. Pada penelitian ini digunakan ResNet-50 karena memiliki kemampuan mengatasi masalah *vanishing gradient* melalui *residual connection*, sehingga jaringan dapat dilatih lebih dalam tanpa kehilangan akurasi [28], [29]. ResNet-50 secara efektif mengekstraksi fitur multi-skala berkat desain residual-nya (dengan FPN atau arsitektur serupa), sehingga mampu mendeteksi objek kecil, bertekstur halus, dan berkontras rendah seperti struktur jantung pada citra USG janin [30]. Selain itu, arsitektur ini menunjukkan generalisasi yang baik pada dataset medis berukuran terbatas karena desain yang efisien dan stabil, termasuk dalam skema *transfer learning*, yang dibuktikan melalui akurasi tinggi pada klasifikasi organ janin menggunakan citra USG [31]. Pilihan *backbone* ini diperkuat oleh hasil empiris bahwa Mask R-CNN dengan backbone ResNet-50 mencapai performa deteksi dan segmentasi sangat tinggi (mAP > 0,95) pada segmentasi anatomi jantung janin [32]. Sebaliknya, penggunaan *backbone* lebih dangkal atau tanpa *residual connection* berpotensi menurunkan akurasi deteksi dan segmentasi karena keterbatasan ekstraksi fitur, kesulitan mendeteksi struktur kecil atau berkontras rendah, serta risiko kesulitan konvergensi akibat degradasi performa pada jaringan dalam. Meskipun demikian, segmentasi pada citra ultrasonografi tetap menghadapi tantangan besar, terutama yang berkaitan dengan variabilitas interpersonal dan kualitas citra. Faktor-faktor seperti kabur, pencahayaan tidak merata, ketidakterfokusan, serta kontras yang rendah menyebabkan kesulitan dalam mengekstraksi fitur anatomi secara tepat [32], [33], [34]. Oleh sebab itu, citra dengan kualitas rendah perlu melalui tahap peningkatan kualitas sebelum dilakukan segmentasi. Beberapa penelitian telah menunjukkan bahwa peningkatan kualitas citra dapat meningkatkan akurasi segmentasi [35]. Metode seperti *Histogram Equalization* digunakan untuk meningkatkan kontras dengan memperbesar perbedaan antara area terang dan gelap [36], [37], [38], sedangkan *Blind Deblurring* diterapkan untuk mengurangi efek *blur* akibat pergerakan atau gangguan pencitraan [39], [40].

Berdasarkan tinjauan tersebut, dapat disimpulkan bahwa permasalahan utama dalam segmentasi citra jantung janin adalah keterbatasan metode segmentasi semantik dalam mengenali seluruh struktur secara individu, ditambah dengan kualitas citra yang tidak konsisten dan keterbatasan sumber daya manusia dalam praktik klinis. Oleh karena itu, diperlukan pendekatan komprehensif yang menggabungkan teknik peningkatan citra dan segmentasi *instance multiclass* berbasis Mask R-CNN untuk menghasilkan hasil segmentasi yang akurat dan dapat diandalkan. Penelitian ini bertujuan untuk mengembangkan pendekatan segmentasi *instance multiclass* yang mampu mengenali dan menginterpretasikan berbagai kelas anatomi jantung janin normal dalam satu citra ultrasonografi. Inovasi utama dalam penelitian ini adalah penambahan satu kelas objek baru, yaitu tulang belakang (*spine*), yang memiliki nilai penting dalam membantu identifikasi tampilan empat ruang jantung janin pada citra ultrasonografi [41]. Pada tahap awal, akan dikembangkan model segmentasi *instance* *multiclass* menggunakan arsitektur Mask R-CNN, yang selanjutnya akan dioptimalkan melalui penyesuaian hiperparameter seperti *learning rate, momentum*, dan ukuran citra. Hasil konfigurasi terbaik ini akan digunakan untuk membangun ulang model dengan menggunakan data citra yang telah ditingkatkan kualitasnya melalui kombinasi metode *Histogram Equalization* dan *Blind Deblurring*. Evaluasi kinerja model akan dilakukan menggunakan metrik performa yang mencakup *Mean Average Precision* (mAP), *Intersection over Union* (IoU), *Dice Similarity Coefficient* (DICE), dan *Confusion Matrix* guna mengukur tingkat akurasi segmentasi, tumpang tindih area prediksi terhadap ground truth, serta kesesuaian spasial antar area segmentasi.

1.2. Perumusan Masalah

Berdasarkan penelitian terdahulu yang telah dianalisis, diperlukan suatu pengembangan metode untuk mencari model segmentasi yang akurat pada citra jantung janin normal. Dengan demikian pertanyaan riset utama pada penelitian ini adalah "Bagaimana Membangun Model Segmentasi Otomatis yang Akurat dalam Menginterpretasi Objek Citra Jantung Janin Normal ?". Adapun perumusan masalah yang akan diangkat sebagai bagian dari pertanyaan riset utama adalah sebagai berikut:

1. Bagaimana membangun model segmentasi *instance multiclass* yang mampu mengenali dan membedakan berbagai struktur anatomi jantung janin normal secara individual dalam satu citra ultrasonografi ?
2. Bagaimana meningkatkan kualitas citra ultrasonografi jantung janin untuk mendukung akurasi segmentasi struktur anatomi jantung janin ?

3. Bagaimana mengoptimalkan arsitektur Mask R-CNN melalui penyesuaian hiperparameter untuk memperoleh konfigurasi model segmentasi yang optimal ?
4. Bagaimana kinerja model segmentasi *instance multiclass* berbasis Mask R-CNN terhadap citra yang telah ditingkatkan kualitasnya, ditinjau dari metrik performa seperti mAP, IoU, DICE, dan Confusion Matrix?

1.3. Tujuan Penelitian

Sesuai dengan perumusan masalah diatas, maka tujuan penelitian ini adalah sebagai berikut:

1. Mengembangkan model segmentasi instance multiclass berbasis Mask R-CNN yang mampu mengenali berbagai kelas struktur anatomi jantung janin normal secara individual dan simultan dalam satu citra ultrasonografi.
2. Meningkatkan kualitas citra ultrasonografi jantung janin menggunakan metode *Histogram Equalization* dan *Blind Deblurring* sebagai tahap pra-pemrosesan.
3. Mengoptimalkan model segmentasi dengan melakukan tuning hiperparameter Mask R-CNN, seperti *learning rate*, *momentum*, dan ukuran citra.
4. Mengevaluasi performa model segmentasi berdasarkan metrik mAP, IoU, Dice, dan Confusion Matrix terhadap citra yang telah ditingkatkan kualitasnya.

1.4. Ruang Lingkup Penelitian

Adapun ruang lingkup penelitian ini adalah:

1. Penelitian ini berfokus pada pengembangan dan evaluasi model segmentasi berbasis DL, khususnya dengan menggunakan *Mask R-CNN*, untuk mendeteksi anatomi pada citra ultrasonografi jantung janin.

2. Penelitian mencakup penggunaan teknik *Histogram Equalization* dan *Blind Deblurring* untuk meningkatkan kualitas citra ultrasonografi jantung janin yang memiliki kontras rendah dan *blur*.
3. Penggunaan dan modifikasi *Mask R-CNN* akan dieksplorasi dengan tujuan meningkatkan akurasi segmentasi citra dalam mengidentifikasi anatomi jantung janin normal. Performa model akan diuji menggunakan metrik evaluasi standar seperti mAP, IoU, DCS, dan *Confusion Matix*.
4. Penelitian ini akan menggunakan *dataset* citra ultrasonografi jantung janin yang bersumber dari *video online* yang telah diberikan izin untuk menggunakannya. Fokus pada citra dengan kualitas rendah akan diperhatikan untuk memperlihatkan dampak metode *preprocessing*.
5. Penelitian ini hanya sampai pada model segmentasi *instance* untuk objek citra jantung janin normal dari *video* ultrasonografi jantung janin. Implementasi model dalam praktik medis yang sesungguhnya memerlukan pengujian tambahan yang tidak dibahas dalam penelitian ini.

1.5. Sistematika Penulisan

Adapun sistematika penulisan terhadap proposal disertasi ini yaitu:

BAB I PENDAHULUAN

Dalam bab terdiri dari latar belakang penelitian, perumusan masalah, tujuan penelitian, ruang lingkup penelitian dan sistematika penulisan.

BAB II TINJAUAN PUSTAKA

Bab ini berisikan teori mendasar tentang AI, AI dalam bidang kesehatan, pendekatan AI dengan menerapkan ML dan DL, segmentasi pada objek medis, segmentasi citra, dan evaluasi kinerja segmentasi.

BAB III METODOLOGI PENELITIAN

Dalam bab ini berisi tentang langkah kerja penelitian mulai dari pengumpulan data, metode pra-pemrosesan data, anotasi data, kerangka kerja penelitian, metode segmentasi yang digunakan dan metode evaluasi

BAB IV HASIL

Pada bab ini dipaparkan tentang hasil, kemudian beberapa perkiraan hasil yang diharapkan.

BAB V KESIMPULAN

Pada bab ini dipaparkan tentang kesimpulan.

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