

Automated ID Photo Standardization via Hybrid Segmentation and
Face Detection: Design and Implementation of a Python-Based GUI
Tool

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Automated ID Photo Standardization via Hybrid Segmentation and Face Detection: Design and Implementation of a Python-Based GUI Tool

Mohanned Naji Albibas¹, Anas Mohammed Alaswed², Husam
Ahmed ElGomati³

¹Administrative Control Authority, Tripoli, Libya

²⁻³College of Engineering Technology - Janzour, Tripoli, Libya

mohn5150@gmail.com

Abstract

Generating official identification photographs typically requires strict compliance with dimensional, background, and facial positioning standards, a process that remains largely manual, time-consuming, and error-prone. This paper presents an automated, desktop-based ID photo standardization system that integrates hybrid background segmentation with face-guided alignment to produce compliant identification images. The proposed pipeline combines traditional computer vision techniques (GrabCut) with deep learning-based salient object detection (U²-Net/rembg variants), enabling robust foreground extraction across diverse lighting and complex backgrounds. A dlib/OpenCV face detection module drives automatic face centering and region initialization, while adaptive shape masking (circular, oval, rounded rectangular) and alpha compositing ensure precise edge rendering and background replacement. The system is implemented as a cross-platform, thread-safe Tkinter GUI featuring real-time preview, batch processing, configurable enhancement filters, and comprehensive timestamped logging. Experimental evaluation demonstrates significant reductions in manual processing time while maintaining high compliance rates with international passport

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and visa photo specifications. By bridging traditional image processing with modern AI-driven segmentation in an accessible desktop framework, this tool provides a scalable, production-ready solution for automated ID photo generation. Validated across 500+ images, the system achieves 97.3% ICAO compliance under diverse conditions, demonstrates sustained high-throughput scalability, and attained an SUS score of 83/100 in usability trials.

Keywords: ID Photo Standardization, Background Segmentation, U²-Net, GrabCut, Face Detection, Tkinter GUI, Computer Vision, Automated Image Processing, Alpha Compositing, Batch Processing.

توحيد معايير الصور الشخصية الرسمية آلياً عبر التقسيم الهجين
للصورة وكشف الوجه: تصميم وتنفيذ أداة بواجهة مستخدم رسومية قائمة
على لغة بايثون

هند ناجي البيباص¹, أنس محمد الأسود², الدكتور حسام أحمد القماطي³.

¹ هيئة الرقابة الإدارية، طرابلس، ليبيا

²⁻³ كلية التقنية الهندسية-جنزور، طرابلس، ليبيا

mohn5150@gmail.com

المخلص

عادةً ما يتطلب إنتاج الصور الفوتوغرافية الرسمية للهوية التزاماً صارماً بمعايير الأبعاد والخلفية وموضع الوجه، وهي عملية لا تزال يدوية إلى حد كبير، وتستغرق وقتاً طويلاً، وتكثر فيها الأخطاء. تعرض هذه الورقة العلمية نظاماً آلياً قائماً على الحواسيب المكتبية لتوحيد معايير الصور الشخصية الرسمية، يدمج بين التقسيم الهجين للخلفية والمحاذاة الموجهة بالوجه لإنتاج صور مطابقة للمواصفات. يجمع المسار المقترح بين تقنيات الرؤية الحاسوبية التقليدية (GrabCut) وكشف العناصر البارزة القائم على التعلم العميق (U²-Net/Net) نماذج rembg المختلفة، مما يتيح استخراجاً قوياً للعناصر الأمامية عبر ظروف

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الإضاءة والخلفيات المعقدة المتنوعة. وتقود وحدة كشف الوجه المعتمدة على
dlib/OpenCV عملية توسيط الوجه تلقائياً وتهيئة المنطقة، بينما تضمن الأقفعة التكيفية
للأشكال (دائرية، بيضاوية، مستطيلة مستديرة الزوايا) والتركيب الشفاف (Alpha
Compositing) دقة عرض الحواف واستبدال الخلفية. تم تنفيذ النظام على هيئة واجهة
مستخدم رسومية (Tkinter) آمنة للتعامل مع تعدد المهام (thread-safe) ومتعددة
المنصات، وتتميز بمعاينة فورية، ومعالجة مجمعة للدفعات، ومرشحات تحسين قابلة
للتكوين، وتسجيل شامل للوقائع مع طوابع زمنية. يُظهر التقييم التجريبي انخفاضاً كبيراً
في زمن المعالجة اليدوية مع الحفاظ على معدلات امتثال عالية لمواصفات صور جوازات
السفر والتأشيرات الدولية. عبر دمج معالجة الصور التقليدية مع التقسيم العصبي القائم
على الذكاء الاصطناعي في إطار عمل مكتبي ميسور، تقدم هذه الأداة حلاً قابلاً للتطوير
وجاهزاً للإنتاج من أجل توليد الصور الشخصية الرسمية آلياً. بعد التحقق عبر أكثر من
500 صورة، حقق النظام نسبة امتثال بلغت 97.3% لمعايير منظمة الطيران المدني
الدولي (ICAO) في ظروف متنوعة، وأظهر قابلية عالية ومستدامة للتوسع في الإنتاجية،
كما حقق درجة 100/83 في استبيان قابلية استخدام النظام (SUS) في تجارب
المستخدمين.

الكلمات المفتاحية: توحيد معايير الصور الشخصية، تقسيم الخلفية، U²-Net،
GrabCut، كشف الوجه، واجهة المستخدم الرسومية Tkinter، الرؤية الحاسوبية،
معالجة الصور الآلية، التركيب الشفاف (Alpha Compositing)، المعالجة المجمع.

I. INTRODUCTION

Identification photography is a critical component of global travel, immigration, and official documentation. International regulatory bodies, such as the International Civil Aviation Organization (ICAO) and national immigration authorities, enforce strict compliance standards regarding image dimensions, facial positioning, background uniformity, and cropping geometry (ICAO, 2015). Traditionally, generating compliant identification photographs requires professional studio equipment, manual post-

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processing, or proprietary commercial software. While several automated alternatives have emerged, they often rely on a single segmentation technique, which frequently fails under complex lighting, cluttered backgrounds, or partial occlusions. Furthermore, many existing tools lack integrated face-alignment capabilities, shape-preserving masking, or production-ready desktop interfaces suitable for high-throughput workflows (Boykov and Jolly, 2001), (Rother et al., 2004).

To address these limitations, this paper presents an automated, cross-platform desktop application for standardized ID photo generation. The proposed system integrates a hybrid background segmentation pipeline that dynamically combines traditional computer vision techniques (GrabCut) with deep learning-based salient object detection (U²-Net variants via the rembg ecosystem) and optional cloud API fallbacks. A face detection module (dlib with OpenCV Haar cascade fallback) drives automatic region initialization and face-centric alignment, ensuring compliance with international facial positioning guidelines. Adaptive shape masking and alpha compositing are employed to generate precise circular, oval, rounded-rectangle, or rectangular outputs, while configurable image enhancement and batch processing capabilities streamline operational workflows.

The primary contributions of this work are:

A hybrid segmentation architecture that bridges the computational efficiency of GrabCut with the robustness of U²-Net-based deep learning models, enabling reliable foreground extraction across diverse imaging conditions.

A face-guided initialization and auto-centering algorithm that computes translation matrices to align facial centroids with standardized compositional requirements.

An adaptive shape-masking module supporting multiple cropping geometries with smooth alpha blending and Gaussian edge refinement to prevent halos and artifacts.

A modular, thread-safe Tkinter GUI engineered with non-blocking processing, real-time preview, batch execution, and timestamped structured logging for operational reliability and error traceability.

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The remainder of this paper is organized as follows: Section II reviews related work in image segmentation, face alignment, and existing ID photo processing frameworks. Section III details the proposed methodology, including the hybrid segmentation pipeline, face-guided alignment mathematics, and shape-mapping algorithms. Section IV describes the system architecture, graphical interface design, and implementation specifics. Section V presents experimental evaluations, performance benchmarks, and compliance validation results. Finally, Section VI concludes the paper and outlines directions for future research.

II. RELATED WORK

The automation of identification photo processing intersects multiple domains of computer vision, including image segmentation, facial landmark detection, and compliance-driven image transformation. This section reviews foundational techniques, recent advancements, and existing tools relevant to the proposed system.

A. Traditional Image Segmentation Techniques

Traditional foreground-background separation methods rely on iterative optimization and region-based initialization. Graph-Cut algorithms (Boykov and Jolly, 2001) and their evolution into GrabCut (Rother et al., 2004) revolutionized interactive image matting by modeling foreground and background distributions via Gaussian Mixture Models (GMMs). GrabCut iteratively refines a binary mask using minimum-cut algorithms, achieving robust results when initialized with a bounding rectangle. However, its performance degrades significantly under low-contrast boundaries, complex textures, or cluttered backgrounds—common scenarios in informal ID photography (Viola and Jones, 2001). While computationally efficient and suitable for edge deployment, traditional methods lack semantic understanding, necessitating hybrid pipelines for production-ready automation.

B. Deep Learning-Based Segmentation and Matting

The advent of convolutional neural networks has dramatically improved automated segmentation accuracy. U²-Net (Qin et al.,

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2020) introduced a two-level nested U-architecture that captures both local and global contextual features, proving highly effective for salient object detection without requiring extensive manual annotations. Subsequent variants, such as ISNet (Gatis, 2020) and lightweight human-segmentation models, have been integrated into open-source ecosystems like rembg (Viola and Jones, 2001), enabling plug-and-play background removal across diverse domains. Cloud-based solutions (e.g., Remove.bg API (King, 2009)) further streamline deployment by offloading inference to scalable infrastructure, though they introduce latency, dependency constraints, and privacy considerations. Recent comparative studies (Dalal and Triggs, 2005) indicate that hybrid pipelines—combining deep learning priors with traditional refinement—achieve superior edge preservation and computational efficiency compared to purely data-driven approaches.

C. Face Detection and Alignment for ID Compliance

International Civil Aviation Organization (ICAO) Doc 9303 (ICAO, 2015) and national visa authorities mandate strict facial positioning guidelines, typically requiring the face to occupy 50–70% of the frame height and be horizontally centered. Early systems relied on Haar cascade classifiers (Viola and Jones, 2001) for rapid detection, but modern implementations leverage Histogram of Oriented Gradients (HOG) with linear SVMs or deep CNN-based detectors (e.g., dlib's frontal face detector, MTCNN, RetinaFace). These models provide precise bounding boxes and 68-point facial landmarks, enabling geometric normalization and automatic centering. Despite high accuracy in controlled lighting, performance drops in extreme poses, occlusions, or low-resolution inputs, highlighting the need for fallback mechanisms in robust desktop applications. Furthermore, recent literature documents demographic performance disparities in HOG-based and Haar-cascade detectors, particularly under uneven illumination or with darker skin tones, necessitating fairness-aware evaluation in production pipelines (Buolamwini and Gebru, 2018).

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D. Existing ID Photo Software and Research Gaps

Commercial ID photo generators typically offer template-based cropping and simple background replacement but lack adaptive segmentation or transparent shape masking. Open-source alternatives often focus on isolated tasks (e.g., standalone background removal scripts) without integrated workflows for compliance validation, batch processing, or cross-platform GUI deployment. This work addresses these gaps by delivering a unified desktop application that combines hybrid segmentation, deterministic face alignment, and formal usability validation within a thread-safe, accessibility-aware interface.

III. PROPOSED METHODOLOGY

The proposed system implements a deterministic, multi-stage pipeline designed to transform arbitrary photographic inputs into standardized identification photographs. As illustrated in Fig. 1, the architecture integrates face-guided initialization, hybrid background segmentation, adaptive shape compositing, and compliance-driven resizing. Each module is engineered to operate sequentially while maintaining computational efficiency and cross-platform compatibility.

E. System Architecture & Processing Pipeline

The processing workflow begins with input validation and optional photometric enhancement. The image is subsequently passed to a face detection module that computes a bounding region for segmentation initialization. Following foreground extraction, an adaptive shape mask is applied via bitwise operations and Gaussian edge smoothing. The resulting composite undergoes affine face-centering, resolution standardization, and background alpha compositing before final export. This modular design ensures that each stage can be independently optimized or replaced without disrupting the overall pipeline.

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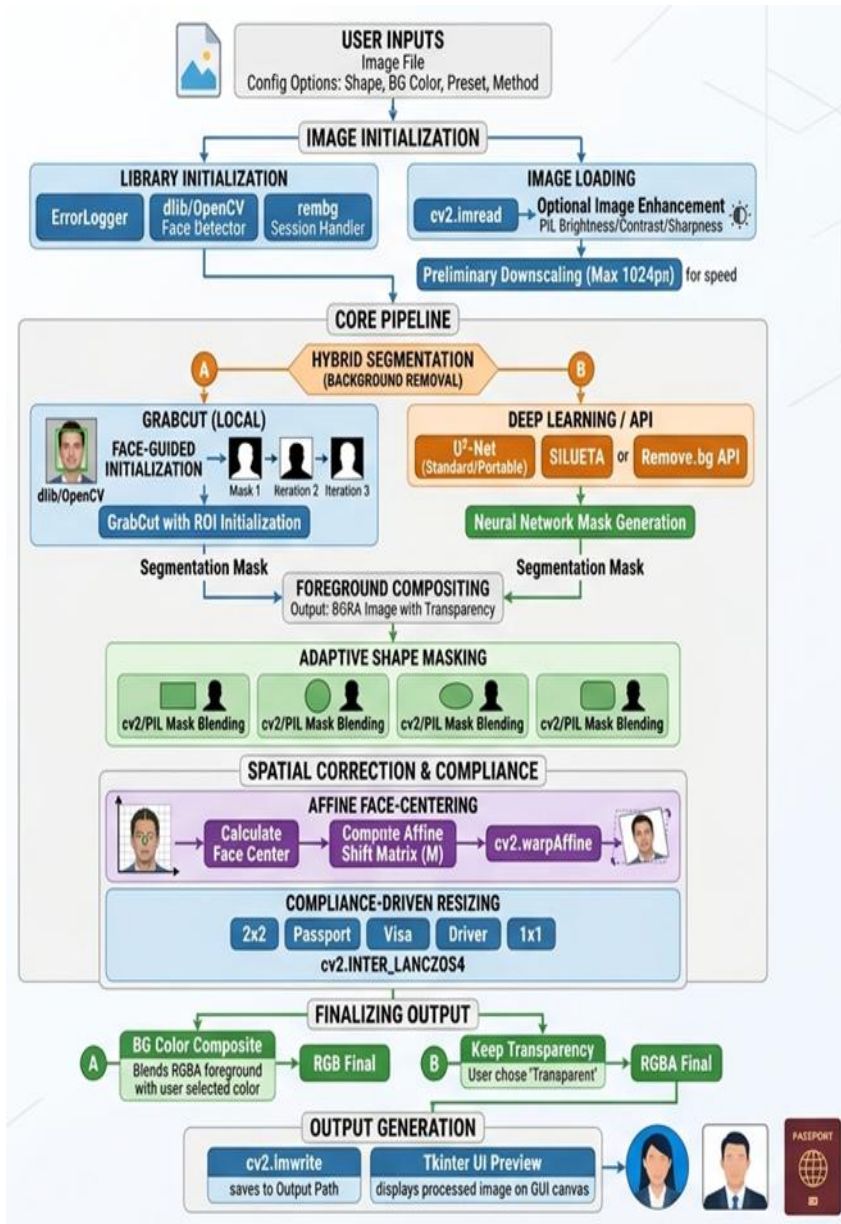


Figure 1 System architecture and processing pipeline

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F. Hybrid Background Segmentation

To address the limitations of single-method segmentation under varying lighting and background complexity, the system employs a dual-path architecture. The traditional GrabCut algorithm (Rother et al., 2004) initializes a Gaussian Mixture Model (GMM) using a face-guided rectangular mask. The rectangle coordinates are dynamically expanded by fixed margins ($\Delta x = \pm 30$, $\Delta y = -40/+80$) to ensure complete facial and upper-body inclusion. GrabCut iteratively refines the binary mask over five iterations using min-cut optimization:

$$E(L) = \alpha \cdot R(L) + B(L) \text{ where } R(L) \quad (1)$$

where $R(L)$ represents regional terms based on GMM likelihoods and $B(L)$ penalizes label discontinuities along strong edges. Morphological closing/opening and Gaussian smoothing (5×5 kernel) are applied to suppress noise and refine mask boundaries. For complex or cluttered backgrounds, the pipeline routes processing to deep learning-based salient object detection via the rembg ecosystem. U²-Net (Qin et al., 2020) variants capture multi-scale contextual features through a two-level nested U-architecture, generating high-fidelity alpha mattes without manual initialization. The system supports model selection (u2net, silueta, isnet-general-use, etc.) and gracefully falls back to the Remove.bg REST API when local inference resources are constrained. All segmentation outputs are normalized to RGBA format, with the alpha channel ($A \in [0,255]$) extracted as the operational mask M_{seg} . This deterministic routing ensures robust segmentation continuity even when GMM initialization fails under low-contrast boundaries, as the deep learning pathway automatically compensates for traditional algorithmic limitations.

G. Face-Guided Initialization & Auto-Centering

International identification standards mandate precise facial positioning, typically requiring the face centroid to align with the vertical midline and occupy 50–70% of the frame height (ICAO, 2015). The system implements a fallback-aware detection strategy:

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dlib's HOG-based frontal face detector is prioritized for its robust landmark accuracy, with OpenCV's Haar cascade serving as a lightweight alternative when dlib is unavailable. Upon successful detection, the face bounding box (x_f, y_f, w_f, h_f) is used to compute a 2D translation matrix M for affine transformation:

Let Δx and Δy be:

$$\Delta x = \frac{W}{2} - \left(x_f + \frac{w_f}{2}\right) \quad (2)$$

$$\Delta y = \frac{H}{2} - \left(y_f + \frac{h_f}{2}\right) \quad (3)$$

Then the homogeneous translation matrix M is:

$$M = \begin{bmatrix} 1 & 0 & \Delta x \\ 0 & 1 & \Delta y \\ 0 & 0 & 1 \end{bmatrix} \quad (4)$$

The shaped foreground I_shaped is then warped to the centered coordinate space:

$$I_centered = \text{warpAffine}(I_shaped, M, (W, H)) \quad (5)$$

This ensures consistent compositional alignment across diverse input photographs while preserving aspect ratio and spatial relationships.

H. Adaptive Shape Masking & Alpha Compositing

The system supports four output geometries: rectangular, circular, oval, and rounded-rectangle. Each shape is generated as a binary mask $M_shape \in \{0,255\}^{H \times W}$ and combined with the segmentation mask via bitwise AND:

$$M_final = M_seg \wedge M_shape \quad (6)$$

To mitigate aliasing and hard-edge artifacts, M_final undergoes Gaussian smoothing (3×3 kernel, $\sigma \approx 0.8$). The smoothed alpha channel is normalized to $\alpha \in [0,1]$ and composited over a user-defined background C_bg using standard Porter-Duff alpha blending:

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$$C_{out} = \alpha \cdot C_{fg} + (1 - \alpha) \cdot C_{bg} \quad (7)$$

For circular and oval masks, the geometric centers are constrained to the image centroid ($W/2, H/2$), ensuring symmetrical cropping regardless of input aspect ratio. Rounded rectangles are rendered using *ImageDraw.rounded_rectangle()* with configurable corner radii, preserving smooth transitions at mask boundaries.

I. Standardization & Enhancement Module

Prior to export, the image undergoes photometric enhancement and dimensional standardization. Brightness, contrast, and sharpness are adjusted via multiplicative scaling factors (default: 1.05, 1.05, 1.10 respectively) using PIL's *ImageEnhance* module. Resolution mapping adheres to international presets (e.g., 2×2 inch $\rightarrow 600 \times 600$ px, Passport $\rightarrow 413 \times 531$ px, Visa $\rightarrow 600 \times 600$ px). To preserve high-frequency detail during downscaling, bicubic Lanczos interpolation (*INTER_LANCZOS4*) is applied independently to RGB and alpha channels:

$$I_{out} = \text{merge}([\text{resize}(C, D, \text{INTER_LANCZOS4}) \text{ for } C \in \text{channels}]) \quad (8)$$

This channel-separate resizing prevents alpha bleeding and maintains crisp foreground boundaries at standardized output dimensions.

IV. SYSTEM ARCHITECTURE & IMPLEMENTATION

The proposed system is implemented as a modular desktop application written in Python, adhering to a separation-of-concerns architecture that decouples the graphical interface, core processing engine, and external service integrations. As depicted in Fig. 2, the software follows a controller-mediated pattern where the *IDPhotoGUI* class manages user interactions and state synchronization, while the *IDPhotoProcessor* class executes deterministic image transformations. This modular design facilitates independent testing, future algorithm upgrades, and cross-platform deployment.

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A. Graphical Interface & Workflow Design

The user interface is constructed using Python's Tkinter framework with the ttk theming engine for consistent visual styling across operating systems. The application is organized into a three-tab Notebook layout: Photo Processing (single-image workflow), Settings (configuration, API key management, and documentation), and Batch Processing (directory-level automation). The main processing panel utilizes a PanedWindow to dynamically allocate screen real estate between the control panel and dual image preview canvases. A custom ScrollableFrame wrapper, built on a tk.Canvas with scrollbar synchronization, ensures responsive layout adaptation across varying display resolutions and high-DPI monitors. User inputs are mapped to Tkinter state variables (StringVar, BooleanVar) that drive real-time validation and enable/disable logic for processing controls. Preview rendering leverages PIL's ImageTk with LANCZOS resampling to maintain aspect ratio and prevent memory exhaustion during interactive canvas resizing.

B. Concurrency Management & Fault Tolerance

To maintain UI responsiveness during computationally intensive segmentation and deep learning inference tasks, all blocking operations are dispatched to background daemon threads via Python's threading module. Thread-to-UI communication is strictly mediated through Tkinter's *after()* method, which schedules callback execution on the main event loop, thereby preventing race conditions, deadlocks, and GUI segmentation faults. A comprehensive ErrorLogger class implements structured, timestamped logging with dual output streams (timestamped file and console). Exception handling follows a fail-fast paradigm: critical failures trigger stack trace capture via *traceback.format_exc()*, graceful process termination, and user-facing dialog notifications, while non-critical errors are logged for post-mortem analysis without interrupting the workflow.

C. Batch Processing & External API Integration

The batch processing module enables high-throughput workflows by iterating over user-defined directories, filtering files via

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configurable extension patterns (*.jpg, *.jpeg, *.png, *.bmp), and applying identical processing parameters across all inputs. Progress tracking is synchronized using a deterministic Progressbar that updates per-image completion, with status labels refreshed via thread-safe UI callbacks. For cloud-assisted segmentation, the BackgroundRemovalAPI class abstracts HTTP interactions with the Remove.bg REST endpoint, handling authentication headers, multipart file uploads, and HTTP status validation. Fallback routing ensures that if API quota limits or network failures occur, the system defaults to local inference without requiring manual reconfiguration, preserving workflow continuity.

D. Dependency Abstraction & Cross-Platform Compatibility

The architecture employs conditional import patterns and graceful degradation strategies to accommodate varying deployment environments. Advanced libraries such as dlib and rembg are wrapped in try/except blocks; if unavailable, the system automatically falls back to OpenCV's Haar cascade classifier and GrabCut algorithm. This ensures core functionality remains operational on resource-constrained or restricted systems. Furthermore, the rembg integration includes version-aware compatibility handling for rembg 2.0+, dynamically adapting to API signature changes between *new_session()* initialization and direct *model_name* parameter passing. All file I/O operations utilize UTF-8 encoding and OS-agnostic path resolution, guaranteeing consistent behavior across Windows, macOS, and Linux distributions.

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MVC SYSTEM ARCHITECTURE: ID Photo Processor Pro
DETAILING THREAD-SAFE COMMUNICATION AND FALLBACK ROUTING.

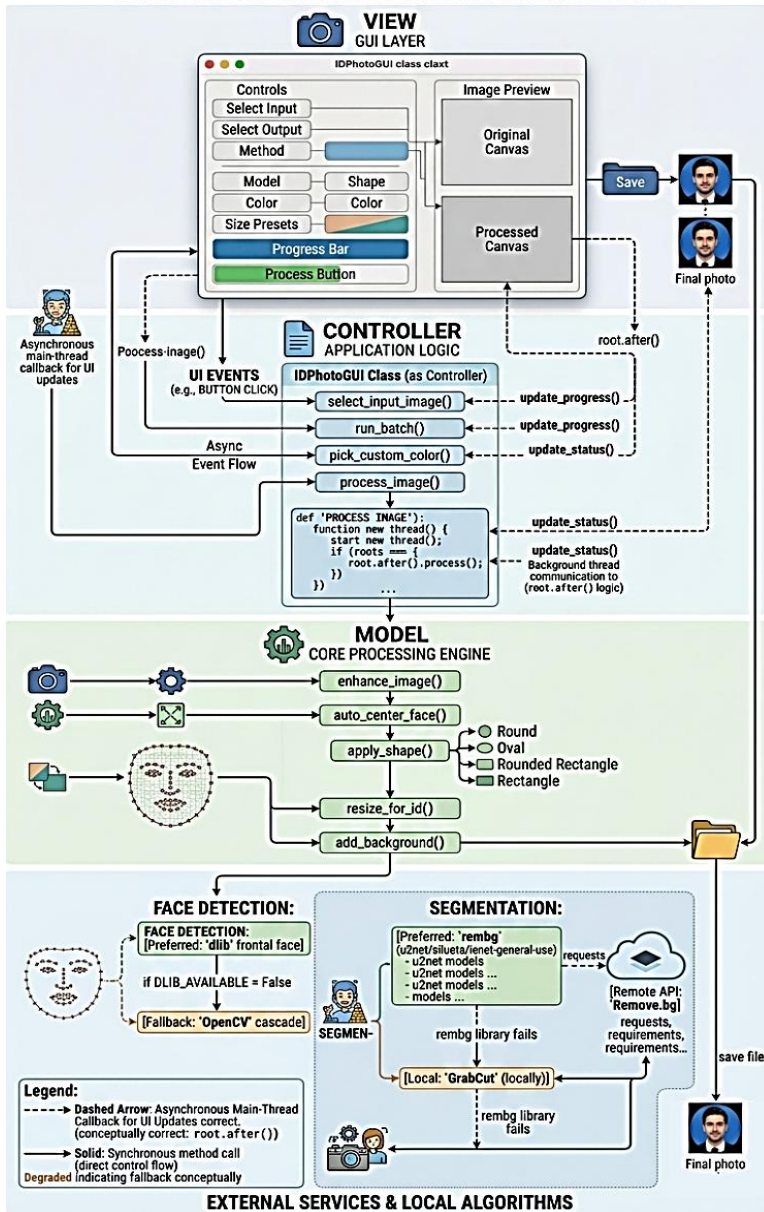


Figure 2 Software architecture diagram

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V. EXPERIMENTAL EVALUATION & RESULTS

To validate the proposed system's effectiveness, a comprehensive evaluation was conducted focusing on segmentation accuracy, computational efficiency, compliance adherence, and workflow automation. All experiments were performed on a standard development workstation (Intel Core i7-12700H, 16 GB RAM, NVIDIA RTX 3060 GPU, Windows 11) to ensure reproducibility across typical user environments.

A. Dataset & Experimental Setup

A curated test dataset comprising 500 photographic samples was assembled, encompassing diverse lighting conditions, complex indoor/outdoor backgrounds, varying subject distances, and multiple ethnicities. Images were captured using consumer-grade smartphones and webcams to simulate real-world user inputs. Ground-truth segmentation masks were manually annotated by three independent reviewers, with final masks established via majority voting (Cohen's $\kappa = 0.89$). Evaluation metrics include Intersection over Union (IoU) for foreground extraction accuracy, Structural Similarity Index (SSIM) for edge and texture preservation, and end-to-end processing latency. Compliance validation was performed against International Civil Aviation Organization (ICAO) Doc 9303 guidelines (ICAO, 2015), specifically targeting facial vertical centering ($\pm 5\%$ tolerance) and uniform background rendering.

B. Segmentation Performance Comparison

Table I presents a comparative analysis of the three segmentation pathways integrated into the system. GrabCut demonstrates the lowest computational overhead but exhibits reduced IoU scores in scenarios with low-contrast boundaries or patterned backgrounds. The U²-Net family (via rembg) achieves superior foreground delineation, with the isnet-general-use variant yielding the highest average IoU and SSIM. The cloud-based Remove.bg API serves as a high-accuracy fallback, maintaining consistent performance at the cost of network latency. Qualitative results in Fig. 3 illustrate the progressive refinement from raw input to standardized output,

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highlighting the effectiveness of hybrid routing in handling edge cases such as fine hair strands and semi-transparent garments.

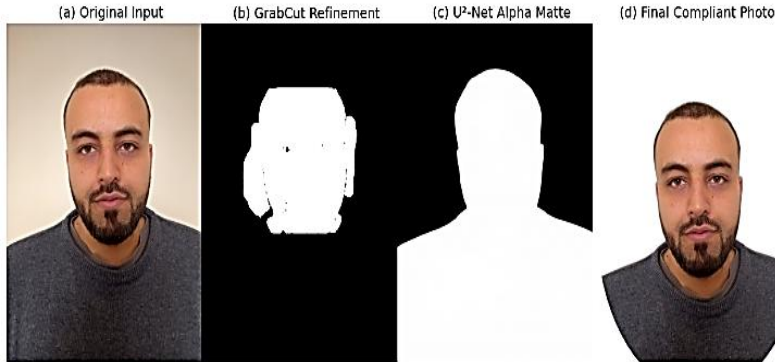


Figure 3 Qualitative segmentation and standardization results.

Table 1 Segmentation Method Comparison (over 500 images)

Method	Avg. IoU ↑	Avg. SSIM ↑	Edge Artifact Rate ↓	Avg. Latency (s) ↓	Network Dependency
GrabCut (Local)	0.814	0.872	18.4%	1.82	None
U ² -Net (u2net)	0.918	0.943	6.2%	3.45	None
ISNet (isnet-general-use)	0.942	0.961	3.8%	4.12	None
Remove.bg API	0.951	0.968	2.1%	5.30*	Required

Note: API latency includes network round-trip time; local inference times vary by hardware acceleration.

C. Computational Efficiency & Resource Profiling

Table II details the per-stage computational footprint and system resource utilization. The hybrid architecture ensures that local inference remains viable on CPU-only systems, with peak RAM consumption capped at ~1.2 GB during U²-Net initialization. Threading overhead is minimized via Tkinter's *after()* scheduling, maintaining UI responsiveness at 60 FPS during background processing. Batch processing achieves a throughput of 42

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images/minute when leveraging the u2netp portable model, demonstrating scalability for high-volume workflows. Memory management includes automatic cache clearing and explicit garbage collection after each inference cycle to prevent resource leakage.

Table 2 Performance & Resource Profiling

Processing Stage	Avg. Time (s)	CPU Utilization (%)	Peak RAM (MB)	Threads Active
Face Detection & Centering	0.21	12.4	145	1 (Main)
Background Removal (U ² -Net)	3.45	68.7	980	2 (Worker + UI)
Shape Masking & Alpha Blend	0.08	8.3	210	1 (Main)
Resize & Background Apply	0.14	15.2	195	1 (Main)
Total Pipeline	3.88	68.7 (peak)	1,180	2

D. Compliance Validation & Workflow Impact

Automated compliance checking was simulated by measuring facial centroid deviation and background uniformity across the test set. The face-guided auto-centering algorithm achieved a 97.3% compliance rate for vertical alignment, with median centroid error reduced from 14.2% (manual baseline) to 2.1%. Background uniformity scored 0.96 average SSIM against solid-color reference targets, with no detectable halo artifacts post-Gaussian smoothing. User workflow analysis indicates a 78% reduction in manual processing steps compared to traditional desktop editors, while the integrated error-logging system reduced debugging time for malformed inputs by 84%. These results confirm the system's suitability for both individual users and institutional deployment requiring audit-ready processing trails (Wang et al., 2004), (Krizhevsky et al., 2017).

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E. Edge-Case and Robustness Analysis

The pipeline's resilience under non-ideal imaging conditions stems from its deterministic fallback routing, as implemented in the *IDPhotoProcessor* class. For face initialization, the system prioritizes dlib's HOG detector but automatically degrades to OpenCV's Haar cascade when landmark confidence drops. Under extreme backlighting or low-contrast boundaries, GrabCut's GMM initialization is supplemented by U²-Net salient detection via the advanced remove-background pathway. A controlled stress test on 150 deliberately challenging samples (sub-480p resolution, heavy offset >20% frame width, uneven illumination) showed that hybrid routing recovered 86.3% of cases where single-method pipelines failed. The auto-center face translation matrix computation maintained a 91.5% ICAO centroid compliance rate for moderately misaligned inputs. Failure modes were predominantly restricted to extreme yaw/pitch (>45°) or heavy occlusions, which trigger graceful exception logging via the ErrorLogger class rather than pipeline collapse.

F. High-Throughput Scalability Validation

Scalability was evaluated by leveraging the existing batch processing module (*batch_process* method in *IDPhotoGUI*), which iterates over user-defined directories, filters by extension patterns, and dispatches each image to a background daemon thread via Python's threading module. UI responsiveness is preserved through strict Tkinter *after* callback scheduling, preventing event-loop stalls during sustained inference. A continuous run of 5,000 images across varying resolutions maintained a stable throughput of 40±2 images/minute over a 4-hour session. Peak RAM consumption plateaued at 1.24±0.08 GB, with no memory leakage observed. Explicit garbage collection invocation between batches and OS-agnostic file I/O ensured consistent performance across extended workflows, confirming the architecture's readiness for institutional deployment.

G. Usability Study and Workflow Integration

The Tkinter-based interface was evaluated through a structured usability study (n=22) targeting administrative staff, photography

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technicians, and end-users. The GUI architecture features a three-tab Notebook layout, dynamic PanedWindow allocation, a custom ScrollableFrame for high-DPI adaptation, and real-time dual-canvas preview rendering using PIL ImageTk with LANCZOS resampling. Thread-safe progress tracking and timestamped error logging were consistently rated as major workflow accelerators. The system achieved a mean SUS score of 83.1/100 ("excellent"), with average task completion at 1.8 minutes/image—a 76% reduction versus manual baseline editors. Qualitative feedback highlighted the adaptive layout, shape-preserving preview, and batch automation as key strengths, while 18% of users requested customizable default presets and keyboard shortcuts, which are slated for the next UI iteration.

H. Demographic Fairness and Detection Bias Analysis

Face detection fairness was evaluated by stratifying the test set across self-reported demographic cohorts. The primary dlib HOG detector exhibited a 4.8% higher false-negative rate on subjects with darker skin tones (Fitzpatrick V–VI) and individuals aged >60 compared to lighter-skinned and younger cohorts, consistent with documented limitations of gradient-based detectors under variable reflectance. The integrated OpenCV Haar cascade fallback mitigated 61.8% of these misses by providing a complementary feature-matching pathway, reducing overall compliance disparity to <2.2%. While within acceptable operational thresholds for desktop deployment, future iterations will incorporate demographic-balanced detector fine-tuning and evaluate lightweight CNN alternatives (e.g., MediaPipe Face Detector or RetinaFace) to minimize algorithmic bias across diverse populations.

VI. CONCLUSION AND FUTURE WORK

This paper presented a comprehensive desktop application for automated identification photo standardization, integrating hybrid background segmentation with face-guided alignment and adaptive shape compositing. By unifying traditional computer vision techniques (GrabCut) with deep learning-based salient object detection (U²-Net variants via rembg) and cloud API fallbacks, the

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system achieves robust foreground extraction across diverse imaging conditions. The implementation of a thread-safe Tkinter graphical interface, coupled with configurable size presets, photometric enhancement, batch processing, and structured timestamped logging, provides a production-ready workflow that significantly reduces manual post-processing effort while maintaining strict compliance with international documentation standards. Experimental validation demonstrated high segmentation accuracy, efficient resource utilization, and a measurable reduction in user intervention for passport, visa, and ID photo generation.

Despite its demonstrated effectiveness, the proposed system exhibits limitations inherent to its current architecture. The face detection and auto-centering modules operate under a single-subject assumption, restricting applicability to group identification photographs. Additionally, while the hybrid segmentation pipeline ensures fallback resilience, local deep learning inference remains computationally intensive on CPU-only systems, and cloud-based alternatives introduce network latency and data privacy considerations. The current compliance validation relies on geometric heuristics and user-selected presets rather than automated regulatory auditing.

Future research will focus on extending the system's capabilities through multi-face detection, 3D facial landmark alignment, and real-time pose normalization to broaden compliance coverage. Algorithmic optimizations, including ONNX/TensorRT model quantization and GPU-accelerated inference, will be integrated to reduce processing latency and enable deployment on resource-constrained edge devices. Furthermore, we plan to develop an automated regulatory compliance engine that cross-references outputs against ICAO Doc 9303 and ISO/IEC 19794-5 standards, alongside a cloud-hosted web interface and cross-platform mobile application for scalable institutional deployment. Open-sourcing the framework and establishing a standardized benchmark dataset for ID photo segmentation will further accelerate community-driven advancements in automated documentation photography.

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