

ABSTRACT

The use of digital images in data storage and transmission requires a security mechanism capable of preserving information confidentiality without neglecting decrypted image quality and computational efficiency. This study compares the performance of image encryption algorithms based on 4D hyperchaotic systems, namely Chen 4D, Lorenz 4D, Lü 4D, and Rössler 4D, after the ciphertext undergoes lossy compression using JPEG, JPEG 2000, WebP, HEIC, and AVIF formats at High, Medium, and Low quality levels, with 12 RGB images of 512×512 pixels from the USC-SIPI Image Database. The encryption process employs a pixel permutation and XOR-based diffusion scheme, evaluated using entropy, pixel correlation, NPCR, UACI, PSNR, MSSIM, and runtime metrics. Lorenz 4D demonstrates the most dominant security performance with the lowest average pixel correlation of 0.03046, average NPCR of 99.5161%, and average UACI of 28.3418%, while Rössler 4D achieves the lowest average total pipeline runtime of 13.4147 seconds. Lossy compression degrades decrypted image quality, with JPEG 2000 achieving the highest PSNR of 21.69 dB and MSSIM of 0.5098 at High quality, and WebP remaining more stable at Low quality with PSNR of 13.17 dB and MSSIM of 0.2033. Based on the weighted combined evaluation, Lorenz 4D obtains the highest final score of 3.15 and is recommended as the most balanced algorithm, whereas Rössler 4D is more suitable for time-efficiency requirements.

Keywords: 4D hyperchaotic, decryption quality, image encryption, lossy compression, security evaluation.

ABSTRAK

Penggunaan citra digital dalam penyimpanan dan transmisi data memerlukan mekanisme pengamanan yang mampu menjaga kerahasiaan informasi tanpa mengabaikan kualitas hasil dekripsi dan efisiensi komputasi. Penelitian ini membandingkan performa algoritma enkripsi citra berbasis sistem *hyperchaotic* 4D, yaitu Chen 4D, Lorenz 4D, Lü 4D, dan Rössler 4D, setelah *ciphertext* mengalami kompresi *lossy* menggunakan format JPEG, JPEG 2000, WebP, HEIC, dan AVIF pada kualitas High, Medium, dan Low, dengan 12 citra RGB berukuran 512×512 piksel dari USC-SIPI Image Database. Proses enkripsi menggunakan skema permutasi piksel dan difusi berbasis XOR, dievaluasi menggunakan metrik entropi, korelasi piksel, NPCR, UACI, PSNR, MSSIM, dan *runtime*. Lorenz 4D menunjukkan performa paling dominan pada aspek keamanan dengan korelasi piksel rata-rata terendah sebesar 0,03046, NPCR rata-rata 99,5161%, dan UACI rata-rata 28,3418%, sedangkan Rössler 4D menghasilkan *runtime* total *pipeline* paling rendah sebesar 13,4147 detik. Kompresi *lossy* menurunkan kualitas hasil dekripsi, dengan JPEG 2000 menghasilkan PSNR tertinggi sebesar 21,69 dB dan MSSIM 0,5098 pada kualitas High, serta WebP lebih stabil pada kualitas Low dengan PSNR 13,17 dB dan MSSIM 0,2033. Berdasarkan penilaian gabungan berbobot, Lorenz 4D memperoleh skor akhir tertinggi sebesar 3,15 dan direkomendasikan sebagai algoritma paling seimbang, sedangkan Rössler 4D lebih sesuai untuk kebutuhan efisiensi waktu.

Kata kunci: enkripsi citra, evaluasi keamanan, hyperchaotic 4D, kompresi *lossy*, kualitas dekripsi.