INTRINSIC ERROR CORRECTION FOR HYPERSPECTRAL REMOTE SENSING IN LOW SNR SATELLITE LINKS

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PURPOSE

Hyperspectral remote sensing plays a crucial role in Earth observation and scientific missions, but its reliance on low signal-to-noise ratio (SNR) satellite links poses challenges for data integrity during transmission. To address this, we propose an intrinsic error correction method for hyperspectral image compression, enhancing the CCSDS 123B-2 standard without sacrificing its compatibility or compression efficiency.

OBJECTIVE

This research objective is to enhance the CCSDS 123B-2 standard by introducing an intrinsic error correction mechanism for hyperspectral image compression, addressing data integrity challenges in low signal-to-noise ratio (SNR) satellite links. Specific Aims:

- Leverage the spatial prediction calculations of the CCSDS 123B-2 standard to identify and correct transmission errors during decompression.
- Shift computational complexity to ground-based decompression to optimize resource use for limited-resource satellites.

BIBLIOGRAPHY

BOOK, BLUE. "LOW-COMPLEXITY LOSSLESS AND NEAR-LOSSLESS MULTISPECTRAL AND HYPERSPECTRAL IMAGE COMPRESSION." (2019).

Hernández-Cabronero, Miguel, et al. "The CCSDS 123.0-B-2 "Low-Complexity Lossless and Near-Lossless Multispectral and Hyperspectral Image Compression" Standard: A comprehensive review." IEEE Geoscience and Remote Sensing Magazine 9.4 (2021): 102-119.

METHOD

The proposed method leverages the geometric compression prediction mechanism by performing independent decompression along two orthogonal axes. This dual-axis approach enables precise localization of transmission errors by identifying discrepancies in reconstructed pixel values. Using the predictor algorithm formulation embedded in the standard, the method finds multiple potential correction options for identified errors, with each option assigned a probability based on statistical likelihood. This probabilistic approach allows for informed decision-making in the error correction process, enhancing the accuracy of the reconstructed data. An additional pixel is transmitted for each row to support this error correction mechanism, providing redundancy with minimal impact on overall performance and compression ratio.

RESULTS

Simulated experiments demonstrate a significant improvement in error correction, achieving over 80% recovery accuracy for corrupted pixels under various noise conditions. The method exhibits negligible degradation in compression ratio, maintaining consistency with the original CCSDS 123B-2 standard performance. Notably, the computational complexity associated with error correction is shifted to the ground segment during decompression, making it optimal for satellites with limited onboard processing resources. This approach is particularly beneficial for small satellites with limited storage and computational capabilities, as well as for missions with short orbital pass times where rapid reliable data downlink is critical.

CONCLUSION

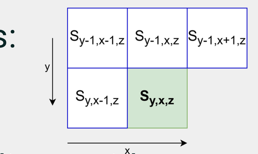
This work demonstrates a practical and effective enhancement to the CCSDS 123B-2 standard, providing robust error detection and correction for hyperspectral remote sensing in low SNR environments. The proposed solution ensures reliable data integrity while preserving the standard's applicability for real-world satellite operations.

ALGORITHM

Reconstructed pixel value (S) in the general form is the sum of the residual value (R) - as decoded from transmission, and the predicted value (P) based on neighboring pixels.

$$S(x,y,z) = P(x,y,z) + R(x,y,z) = W_N \cdot \left(4S'(x, y-1, z) - \sigma_{x,y,z}\right) + W_{NW} \cdot \left(4S'(x-1, y-1, z) - \sigma_{x,y,z}\right) + W_W \cdot \left(4S'(x-1, y, z) - \sigma_{x,y,z}\right) + R(x,y,z)$$

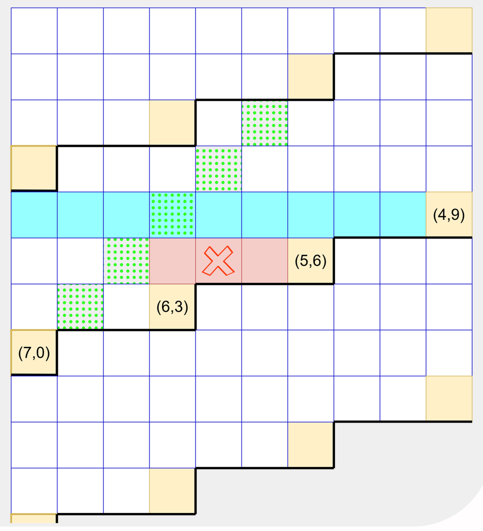
The visual structure of the neighboring pixels:
(Dependency on pixels above and to the left)



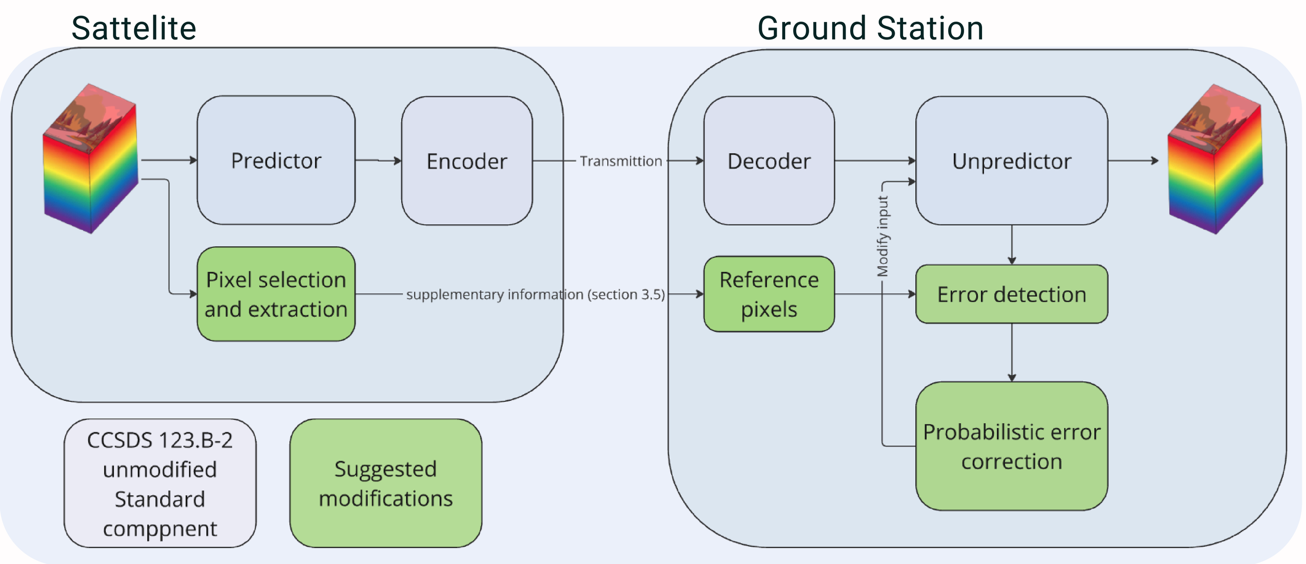
combining the geometric insights of the predictor with probabilistic correction, allows the system to identify and suggest multiple potential corrections.

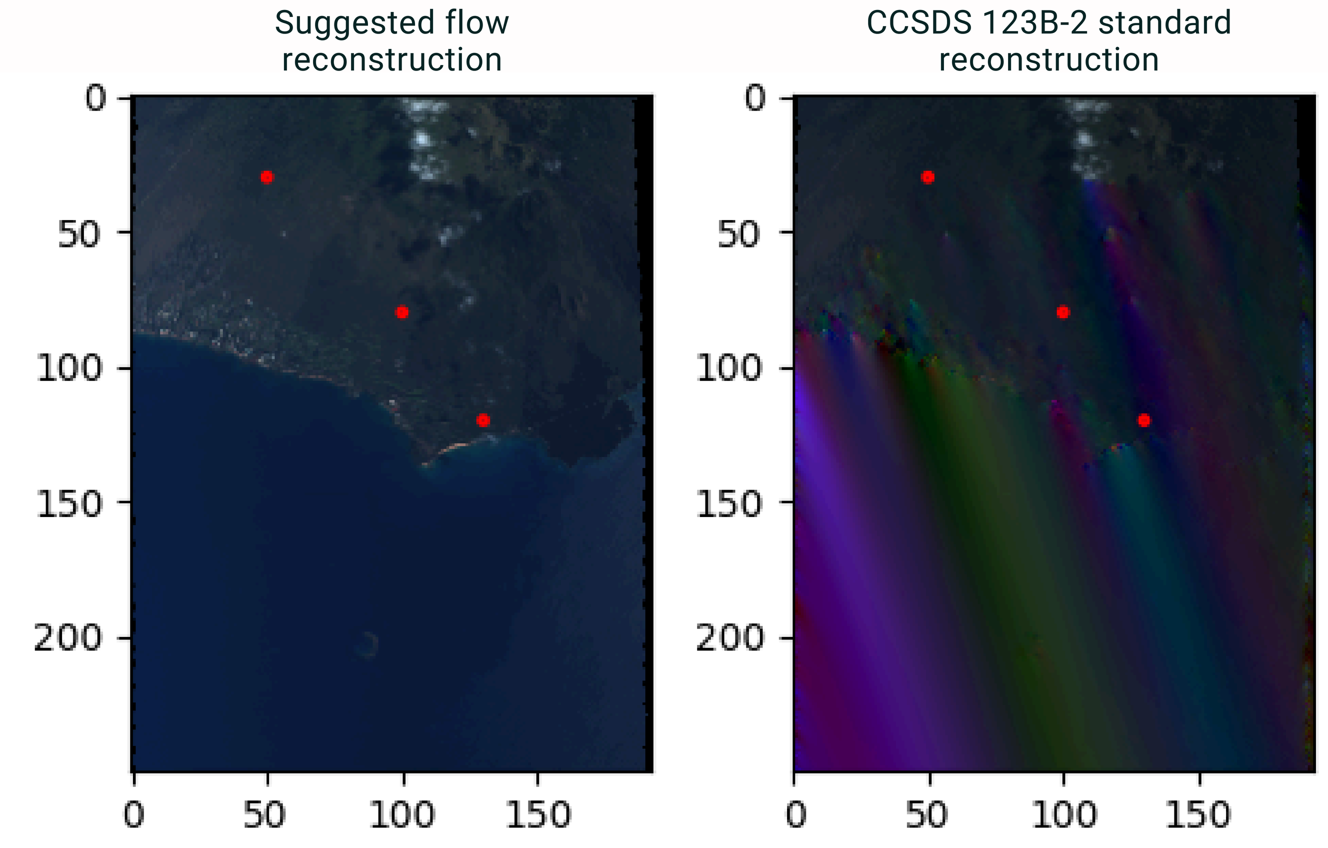
A simplified example:

- Assume that we have a single error at pixel (5,4) - red X
- During decompression, we compare the reconstructed pixels with the reference pixels (orange) on each row.
- On reference pixel (4,9) we get confirmation that no prior error occurred - blue is validated.
- We get a discrepancy on ref pixel (5,6) - hence, the error is on line 5.
- According to the geometric structure of the predictor, we can reconstruct in a diagonal direction (SW)-> reference pixel (7,0) validates diagonal pixels (green dots).
- Bounded by validated pixels we identified the error in the red area - columns 3-5.
- Using reference pixels at (5,6) and (6,3) we can develop the equation above as a function of R at each location in order to find potential corrections for both equations.
- Probabilities and constraints will lead us to the most likely solution.



VISUALS





Aviris-3 hyperspectral image with errors in 3 pixels (marked in red).
Full reconstruction using suggested flow